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Risk assessment of phosphorus (P) loss and guidelines for P use in lower Herbert soils[a]

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CSR™ Sugar

Sugar Research and Development Corporation

[a]To be read as an addendum to Bramley *et al.* (1998) Environmentally sound phosphorus management for sugarcane soils. Final report on SRDC Project No CSS3S.

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Summary

In project CSS3S (Bramley *et al.*, 1998), a field and laboratory-based survey of the behaviour of phosphorus (P) was carried out on the soils of the lower Herbert River catchment, and sediments derived from them. The aim was to explore the factors governing P sorption or desorption in Herbert soils, and in suspended sediments in associated riverine and estuarine waters, so that the extent of any problem associated with sugarcane and soil-derived inputs to streamwaters could be defined and advice on the development of best management practices for P fertilizer could be provided. Accordingly, an assessment of the risk of P loss from selected lower Herbert soils was made based on their P sorption characteristics and an assessment of the susceptibility of the lower Herbert soils to runoff following rainfall events. One of the recommendations made at the conclusion of CSS3S was that "spatial analysis of the assessment of P desorption risk based on digital maps of the CSR soil survey would enable more precise guidelines for better P management to be derived.". Following the recent availability of the CSR 1:5,000 soil survey in geo-referenced digital form, this report details the results of the suggested spatial analysis.

Nine hundred and thirty four soils for which detailed soil property data are available in the database accompanying the 1:5,000 CSR survey of lower Herbert sugarcane soils were classified according to a range of indices of P sorption and the results mapped using either a geostatistical interpolation routine (kriging) or the mean values for each soil type identified in field survey. The results were coupled with an analysis of the susceptibility of these soils to runoff to produce maps of the potential for P loss.

Significant areas within the lower Herbert canegrowing district have a high potential for P loss when the soils are bare, that is, in the period between pre-planting tillage operations and the establishment of a crop. Thus, improved fertilizer management aimed at making more efficient use of the expensive fertilizer input has the potential to also realise significant environmental benefits through a reduction of the risk of P export offsite. Through the use of the maps of P sorption indices, and especially those highlighted in the extension report for this project (provided in the Appendix), growers and their advisors have a basis for refining their P management. In general, we conclude that since the sugarcane soils of the Herbert have a significant P fertilizer history, further P additions should be made at reduced rates compared to current recommendations:

- Soils with higher P sorption indices will tend to contain relatively large amounts of residual fertilizer P. These soils can therefore have the frequency of further P additions reduced.
- Soils with lower P sorption indices need less P than those with a higher sorption index to achieve the same concentration of P in the soil solution, However, the frequency of application should not be reduced to the same extent due to them having lower contents of residual P.
- Irrespective of the sorption index, on previously fertilized soils, the current recommendation should be regarded as an absolute maximum rate of P application.
- On previously unfertilized soils, those with a high sorption index will need more P than those with a lower sorption index.

Details are provided in the Extension report in Appendix 1.

Contents

1.0 Background

A field and laboratory-based survey of the behaviour of phosphorus (P) was carried out on the soils of the lower Herbert River catchment, and sediments derived from them, as part of SRDC project CSS3S (Bramley *et al.*, 1998). The aim of this survey was to explore the factors governing P sorption or desorption in Herbert soils, and in suspended sediments in associated riverine and estuarine waters, so that the extent of any problem associated with sugarcane and soil-derived inputs to streamwaters could be defined and advice on the development of best management practices for P fertilizer could be provided.

The results of this study of P behaviour in Herbert soils led the CSS3S project team to suggest that scope existed for refinement of the management of P fertilizer in the sugar industry based on a knowledge of particular soil properties and the behaviour of P in specific soils. In particular, it was concluded that clustering soils of similar physico-chemical properties was a useful basis for identifying soils of similar potential P reaction so that, when coupled with a knowledge of existing P status, they may also form a basis for delivery of improved fertilizer advice. Since a large database already exists as a consequence of the CSR 1:5,000 survey of Herbert sugarcane soils (eg Wood and Bramley, 1996), it was felt that this could be used to identify areas requiring similar management.

In the laboratory study, it was found that a good correlation exists between the equilibrium phosphate concentration (EPC) - the P concentration at which neither sorption nor desorption occurs - when measured in soils, and the EPC when determined for suspended sediment in simulated river waters. This correlation, together with the close relationship between P sorption in soils and selected soil properties, enabled estimation of P desorption from suspended sediments on the basis of the properties of the soils from which the sediments were derived. Thus, classes of "P desorption risk" were derived and the soils assigned to a desorption risk class. Using the same criteria, and data available from the 1:5,000 CSR survey of Herbert sugarcane soils (data from over 400 soil profiles), it was possible to assign the mapped soils of the lower Herbert to a P desorption risk class. However, the absence, at the time that CSS3S was carried out, of Herbert soils data in digital geo-referenced format, meant that it was not possible to produce definitive maps of P desorption risk for the lower Herbert, nor to overlay this with a spatial representation of key soil properties. Furthermore, whilst the clustering of similar soil types was useful, it suffered from the limitation that, in the case of soil P behaviour, the location of boundaries between map units were determined by the boundaries between the soil types making up the clusters, rather than the actual P data for individual samples of the same soil type or types making up the clusters. It was partly for this reason that CSS3S did not attempt to produce maps showing anything other than point data for the samples analysed as part of that project. Nevertheless, there was a clear opportunity, assuming the availability of geo-referenced data, to produce a set of maps that extension staff could use in assisting growers to refine their P management - from both a crop production and environmental sustainability perspective, using the results obtained in CSS3S.

Since the completion of CSS3S, the CSR soil survey data have become available in digital georeferenced format and the database expanded to include information for over 900 soil profiles in the lower Herbert. This project therefore sought to use the output from CSS3S as a basis for the production of maps that could make a real contribution to the improved management of phosphorus fertilizer in the lower Herbert sugar industry.

2.0 Objectives

Against the background outlined above, and as stated in the project proposal, this project "seeks to add value to the recently completed project (CSS3S) by overlaying records of the P sorption characteristics of Herbert River soils, and sediments derived from them with [...] digital maps (1:5,000) of Herbert soils. This will enable production of maps depicting:

- risk assessment of P loss;
- relative P fertilizer requirement;

and will thereby promote improved delivery of fertilizer advice."

3.0 Mapping of P behaviour in soils

Readers are referred to the CSS3S report (Bramley *et al.*, 1998) for details of the field and laboratory based survey of P behaviour in Herbert soils and the means by which soils exhibiting similar P behaviour were identified and classified. For the purposes of this study, analytical data from the CSR soil survey for topsoils (0-20 cm) were used (ie. we did not use data for subsoils). Data for 934 soil profiles were available for the present study. Their distribution amongst the mapped soil types (Map 1), and the membership of these in clusters determined on the basis of soil chemical properties is detailed in Table 1; the location of the sampled profiles is shown in Map 2 whilst Map 3 shows the clustered soils.

3.1 Methodology

3.1.1 Indices of P behaviour in soil - K_{soil} and phosphate buffer capacity (PBC)

CSS3S dealt with the behaviour of P in 73 lower Herbert soil samples; a subset of 11 samples was used for the analysis of P behaviour in simulated sediments derived from these soils. For both sets of samples, the parameters of the Freundlich equation (eg. Barrow, 1978)

$$\Delta P = KC^{b} - Q \qquad 1$$

were determined. Here, ΔP denotes the amount of P sorbed following a period of equilibration with a solution whose P concentration at the end of the equilibration period was C, and Q is the amount of P already present in the soil which Bramley *et al.* (1998) determined using an ion-exchange resin (Saggar *et al.*, 1990); K and b are constants describing the slope and curvature of the sorption curve. One objective of using equation 1 was to enable calculation of the equilibrium phosphate concentration (EPC), that is, the concentration at which $\Delta P = 0$, so that it could be used as a means of classifying the soils in terms of the likelihood of them releasing P when in riverine suspension. In the case of the 934 soil profiles in the CSR database, neither the EPC, nor the parameters of equation 1 were included in the available data. In this work, we decided to focus on K as an index of P sorption. This approach is consistent with our initial survey of P behaviour in soil, as carried out as part of CSS3S, and also that currently being explored by the Australasian Soil and Plant Analysis Council in its attempts to improve the delivery of P fertilizer advice Australia-wide (P.W. Moody – pers. comm.). It as also similar to the approach taken previously by a number of authors (eg. Ozanne and Shaw, 1967; Rayment and Higginson, 1992; Allen and Jeffrey, 1990; and Blakemore *et al.*, 1987) as summarised by Moody and Bolland (1999).

Table 1. **Distribution and cluster membership of the 934 soil profiles for which analytical data were available from the CSR soil survey**

Soil Type[A]	No. Samples	Cluster[B]
Heavy Clay	9	1
Clay	115	1
Clay Loam	55	1
Black Organic Clay	7	1
River Overflow	73	2
Silty Clay	130	2
Terrace Silt	103	2
Clay Ridge	8	3
Red Loam	81	3
Ripple Alluvium	6	3
River Bank	94	3
Coarse Sandy Clay	4	4
Coarse Sandy Loam	51	4
Fine Black Sand	5	4
Fine Grey Sand	8	4
Fine Sandy Loam	66	4
Grey Brown Loam	5	4
Grey Sand	16	4
Pale Brown Sandy Loam	6	4
Red Sand	16	4
River Sand	25	4
Sandy Clay	27	4
Sand Ridge	24	4

[A]These are the soil type names as given in the CSR survey (Map 1) and do not necessarily describe soil texture.
[B]Cluster membership was based on a suite of statistical techniques (Bramley and Wood, unpublished) as applied to a smaller database comprising top- and subsoil property data for about 400 lower Herbert profiles. Further details are given by Bramley *et al.* (1998).

Based on the properties of the 73 soils studied in CSS3S, it was found that a useful index of P sorption by soil, K_{soil}, could be closely modelled using (Bramley *et al.*, 1998)

$$K_{soil} = 943\ Al_{ox} + 1.1\ clay + 1.16\ silt - 33.5 \qquad r^2\ (adj) = 0.82 \qquad 2$$

where Al_{ox} denotes oxalate extractable aluminium and K_{soil} is calculated from equation 1 with the value of b set to 0.34. Whilst a wide range of soil property data are available from the CSR survey, Al_{ox} is not one of them. Thus, to calculate K_{soil} for the 934 soil profiles for which data are available, we had to use the simpler descriptor for the 73 soils studied in CSS3S (Bramley *et al.*, 1998):

$$K_{soil} = 4.98\ clay + 45.5\ OC + 6 \qquad r^2\ (adj) = 0.62 \qquad 3$$

where OC denotes the soil organic carbon content.

K_{soil} is not commonly used as an index of P sorption, partly because the assumption of a common value of b (equation 1) as we have used here, only holds for soils sampled from restricted geographical regions (Barrow and Shaw, 1975; Barrow, 1980), and also because the data necessary for equation 1 to be fitted are not routinely collected by commercial soil testing laboratories. Moody and Bolland (1999) have recently reviewed the testing and interpretation of soil P status and P sorption. Given the infrequent use of K_{soil} as a P sorption index, we thought it useful to compare the results of our analysis of K_{soil} with the results of a similar analysis based on the more commonly used phosphate buffer capacity (PBC) of Ozanne and Shaw (1967). PBC is determined on the basis of the P sorbed between solution P concentrations of 0.25 and 0.35 mg P L^{-1} and is given by:

$$PBC\ (L\ Kg^{-1}) = 10 \times K \times (0.35^b - 0.25^b) \qquad 4$$

where K and b are the same as in equation 1. Since the parameters of equation 1 have not been defined for all 934 soils in the CSR database, we estimated PBC assuming the common value of b of 0.34 (Bramley *et al.*, 1998), and used equation 3 to estimate K. Note however, that when values of K_{soil} and PBC were compared for the soils for which we did have values of K and b (equation 1), they were seen to be closely related (Figure 1.). Note also that, this analysis was confined to the 61 soils sampled as part of CSS3S that could be assigned with certainty to the soil types identified in the CSR survey.

3.1.2 P sorption in river water - K_{river}

In CSS3S, an index of P behaviour analogous to K_{soil} was developed to describe P reaction in suspended riverine sediments derived from the soils for which we had estimates of K_{soil}. This is useful because, whilst K_{soil} provides information of value in improving P fertilizer management from the point of view of crop production, it does not necessarily infer the risk of any downstream environmental impact. K_{river} was developed to assist in the assessment of P behaviour instream; note that the experiments used to estimate K_{river} were conducted using a different background matrix to that used for K_{soil}.

As with K_{soil}, K_{river} was closely correlated with a range of soil properties (Bramley *et al.*, 1998):

$$K_{river} = 5.4\ clay + 1.3\ silt - 122\ pH + 116\ OC - 845\ Al_{ox} + 601 \qquad r^2\ (adj) = 0.99 \qquad 5$$

Good predictions of K_{river} were also obtained when Al_{ox} was omitted which was fortunate in view of the absence of Al_{ox} data from the CSR soil database:

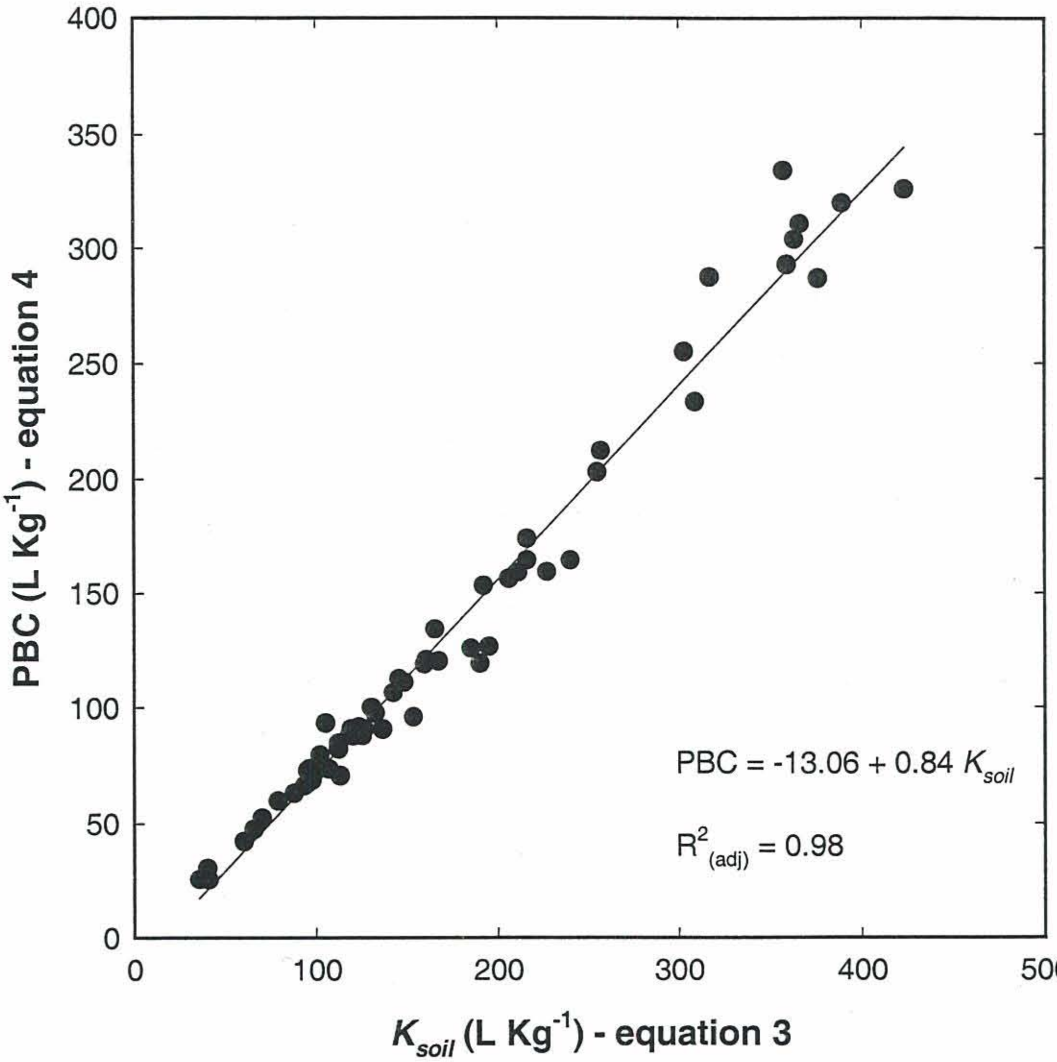

Figure 1. The relationship between K_{soil} and P buffering capacity (PBC; Ozanne and Shaw, 1967).

$$K_{river} = 2.6\ \text{clay} + 0.2\ \text{silt} - 122\ \text{pH} + 68.4\ \text{OC} + 609 \qquad r^2\ (\text{adj}) = 0.95 \qquad 6$$

Equation 6 was used in the present study to estimate values of K_{river} for all 934 soil profiles in the CSR database. We did not attempt to calculate PBC for suspended sediments (cf. Equation 4) in view of the different background matrix used to estimate the parameters of equation 1 for simulated sediments (Bramley *et al.* 1998), and also in view of the fact that water quality monitoring in the lower Herbert has demonstrated riverine P concentrations to typically be substantially lower than 0.25 mg L^{-1} (Bramley and Muller, 1999).

3.1.3 *Map production and spatial analysis*

All map production and spatial analysis was conducted using ArcView software (ESRI, 1996). The maps were produced on the basis of either mean values of the indices of P behaviour for each soil type (Table 1), or on the basis of the location of the 934 profiles in the CSR soil database. In the latter case, the surfaces were created by block kriging using VESPER (Minasny *et al.*, 1999). Knowing the location of the 934 soil profiles (Map 2), map surfaces were interpolated for the various properties of interest using a global variogram model and blocks of 500 m with the results projected onto a 200 m grid. Note that, kriging involves interpolation of unsampled values on the basis of the sampled values and a knowledge of the relationship between the variance associated with pairs of sample values and the distance between them (ie. the variogram). Thus, the boundaries between classes of values is determined solely by the data and their location. In contrast, where soil types (ie field survey) were used as the basis for mapping, the boundaries between mapped classes are determined by the location of the boundaries between the soil types as determined by field survey.

3.2 *Results and Discussion*

3.2.1 *Indices of P sorption*

Values of K_{soil}, K_{river} and PBC ranged widely amongst the 934 soils for which they were estimated reflecting the similar range in textures and organic matter contents amongst these soils sampled from an area of approximately 50,000 ha (Table 2; Maps 1 and 2). Note however, that the standard error of the mean for both measured and estimated values is low (Table 2). This suggests that on the one hand, there are gross similarities amongst a large proportion of the soils in the lower Herbert, whilst on the other, significant differences exist between a few selected soil types and the *typical* lower Herbert soil. The Black Organic Clays (6 profiles) and River Sands (25 profiles; Table 1) provide good examples of these markedly different soil types (see below).

For the P sorption indices to be mapped in a readily interpretable way, it was necessary for them to be classified. Since the Australasian Soil and Plant Analysis Council has determined that 5 categories of P sorption behaviour is an appropriate number to aim for in its initial attempts at improving the interpretation of soil P tests Australia-wide (P.W. Moody – pers. comm.), it was decided that a similar approach should be adopted here. Thus, values obtained by applying equations 3 and 6 to the 934 soil profiles from the CSR database were used to calculate 20^{th} percentiles for K_{soil} and K_{river} and the resultant categories assigned as in Table 3. In the case of PBC, the classification of Moody and Bolland (1999) was followed (Table 3).

Table 2. Summary statistics for selected lower Herbert soil properties – clustered topsoils[A]

	pH	OC (%)	Silt (%)	Clay (%)	K_{soil}	PBC	K_{river}
Cluster 1							
Mean	4.93	1.26	31.67	34.34	234.55	177.32	189.95
SE	0.03	0.04	0.69	0.78	4.51	3.41	5.33
Range	3.62-6.04	0.18-3.18	8.80-71.86	4.34-56.30	76.70-401.28	57.99-303.37	0.02-385.36
CV (%)	8.1	39.7	29.7	31.0	26.2	26.2	38.3
Cluster 2							
Mean	4.92	0.81	25.86	24.31	163.92	123.93	137.47
SE	0.02	0.02	0.57	0.49	2.80	2.12	4.00
Range	4.17-6.65	0.31-1.39	7.76-51.40	8.10.47.68	88.11-294.13	66.61-222.36	-88.93-278.62
CV (%)	8.0	28.4	30.2	27.8	23.3	23.3	39.7
Cluster 3							
Mean	4.80	0.79	16.34	19.46	139.03	105.11	130.31
SE	0.03	0.02	0.45	0.37	2.09	1.58	3.69
Range	4.00-6.21	0.33-2.00	5.63-40.51	4.72-43.50	77.85-253.48	58.85-191.63	-39.77-228.02
CV (%)	8.3	35.4	37.6	25.7	20.5	20.5	38.7
Cluster 4							
Mean	5.00	0.77	12.28	15.46	117.84	89.09	94.19
SE	0.03	0.03	0.33	0.30	1.87	1.41	3.87
Range	4.05-6.45	0.15-2.56	0-35.60	0-29.70	39.80-231.94	30.09-175.34	-101.64-244.99
CV (%)	8.4	55.8	43.3	30.4	25.2	25.2	65.4

[A]Refer to Table 1 for details of the cluster groupings.

Table 3. A classification of P sorption indices

Sorption category	PBC[A]	K_{soil}[B]	K_{river}[B]
Very very low	< 10		
Very low	10-50	< 60	< 54
Low	50-100	60-120	54-108
Moderate	100-200	120-180	108-162
High	200-300	180-240	162-215
Very high	> 300	> 240	> 215

[A]Classification of Moody and Bolland (1999) using the index of Ozanne and Shaw (1967).
[B]Categories delineated on the basis of 20th percentiles calculated from 934 lower Herbert soils.

The mean values of the various P sorption indices for each of the soil types (Map 1; Table 1) are presented in Table 4 together with details of the sorption category that each soil type falls under. As Table 4 indicates, the *moderate* category predominates for both K_{soil} and PBC – the indices of sorption in soil. In terms of K_{river} – the index of sorption by suspended riverine sediments derived from the soils - the *moderate* category again predominates, although there is a greater separation amongst the soil types with more falling into the *low*, *high*, and, *very high* categories, and one (River Sand) falling into the *very low* category. This is consistent with our findings from CSS3S (Bramley *et al.*, 1998) when EPC was used as the P sorption index (cf. equation 1) for a restricted subset of soils. It also supports the contention that some soils (those in the high and very high category) will tend to have high residual P values following a history of fertilization and therefore require infrequent P by way of additional fertilizer application in the short term. In contrast, those in the low and very low categories have the potential to act as significant sources of riverine and estuarine P, should sediments derived from them end up in creeks and streams; these soils can be expected to require more frequent, but smaller, additions of P fertilizer for optimal crop growth.

Table 4 also points to the potential utility of the clustering approach. Note that these clusters were determined from a discriminant analysis of the soil types based on 24 physico-chemical soil properties (Bramley and Wood, unpublished) in both top- and subsoils. As Table 4 indicates, the soils in Cluster 1, which is dominated by clays tend to have the highest indices of P sorption, as one would expect. Conversely, Cluster 4 is dominated by sandy soils which tend to have the lowest indices of P sorption. Clusters 2 and 3, the silty and well mixed loam soils, are intermediate between clusters 1 and 4 and, with respect to their P sorption properties, are little different from each other. Analysis of differences between the soil types for each of the sorption indices using paired *t*-tests (data not presented) gives a very similar result, which again, is consistent with the findings of CSS3S using EPC (Bramley *et al.*, 1998) and a restricted subset of soils. Map 3 shows the distribution of the clusters.

3.2.2 Mapping P sorption behaviour

The various P sorption indices are shown in Maps 4-10; whether these have been produced on the basis of mean values of the indices for each soil type (Table 4) or by interpolation from the 934 georeferenced profiles as described in section 3.1.3, the classification detailed in Table 3 has been used, with the exception of Map 8 (see below). It is important that readers recognise that, whilst we consider the classification to have a sound basis, it should be regarded as specific to lower Herbert canelands at this stage, given that the classification is driven by the distribution of the estimates of the P sorption indices amongst the 934 sampled topsoils for which data were available from the CSR soil database.

As can be seen from Maps 4-7, the lower Herbert is dominated by soils with moderate P sorption as defined in Table 3. The Heavy Clays of Lannercost extension have the highest P sorption whilst the sandy soils on the footslopes of hills in Abergowrie and Upper Stone tend to have the lowest (eg Map 4); these results are similar to those of Wood (1988). It is axiomatic that when the P sorption indices are mapped as means for each soil type, the boundaries between mapping units are the same as those between soil types. In contrast, when the location of the data points is used as the basis for map production, as in the interpolated (ie kriged) surfaces, the result is a map which at first glance appears to be less detailed (eg Map 5 compared to Map 4), but one which has a much stronger regional definition. Thus, Map 5 (K_{soil} – kriged) picks up a zone of very high P sorption in the Ripple Creek area and more extensive areas of low P sorption in Upper Stone and near Long Pocket than does Map 4 (K_{soil} – means) which emphasises, for example, the generally high P sorbing nature of the Heavy Clays. When PBC is used as the index of P sorption, there is relatively little

Table 4. Mean values of P sorption indices for soil types identified in the 1:5,000 CSR survey of lower Herbert soils.

Soil type	K_{soil}	K_{river}	PBC	n[A]	Cluster[B]
Heavy Clay	288.15	233.03	217.84	9	1
Clay	231.80	178.74	175.24	115	1
Clay Loam	223.01	195.53	168.59	55	1
Black Organic Clay	301.51	274.85	227.94	7	1
River Overflow	189.70	145.75	143.42	73	2
Silty Clay	169.05	136.52	127.80	130	2
Terrace Silt	156.08	135.45	117.99	103	2
Clay Ridge	159.75	186.02	120.77	8	3
Red Loam	147.59	129.63	111.58	81	3
Ripple Alluvium	191.20	151.57	144.55	6	3
River Bank	127.25	126.91	96.20	94	3
Coarse Sandy Clay	155.26	123.33	117.38	4	4
Coarse Sandy Loam	112.78	81.85	85.26	51	4
Fine Black Sand	160.84	172.96	121.60	5	4
Fine Grey Sand	114.06	93.11	86.23	10	4
Fine Sandy Loam	125.65	114.63	94.99	66	4
Grey Brown Loam	123.27	82.82	93.19	5	4
Grey Sand	108.85	90.72	82.29	16	4
Pale Brown Sandy Loam	132.38	141.49	100.08	6	4
Red Sand	122.86	82.58	92.88	16	4
River Sand	87.53	42.93	66.17	25	4
Sandy Clay	128.44	90.90	97.10	27	4
Sand Ridge	113.06	107.63	85.48	24	4

The colour coding in this table refers to the classification of P sorption indices detailed in Table 3 as follows:

Magenta	Very high
Yellow	High
Blue	Moderate
Green	Low
Grey	Very low

[A]Denotes the number of profiles of this soil type in the CSR soil database
[B]Refer Table 1 and Bramley *et al.* (1998).

discrimination between soil types (Map 6) and whilst Map 7 indicates a strongly regional separation in terms of PBC, only the low and moderate categories are picked up when kriging is used (note that a significant amount of data smoothing is implicit in the kriging procedure).

One reason for the apparently poor ability of PBC to discriminate amongst the Herbert soils (Maps 6 and 7) in comparison to K_{soil} is that the classification of Moody and Bolland (1999) is based on analysis of P sorption behaviour in soils from all over Australia – which clearly represents a significant contrast with approximately 50,000 ha in the lower Herbert. Further, we had to use a common value of b (equation 1) to calculate PBC. Whilst this was also the case for K_{soil} (and also K_{river}), since PBC represents sorption at much high values of C (equation 1) than were used in our own sorption studies (Bramley *et al.*, 1998), it is likely that the estimates of PBC were more sensitive to errors in b (ie the difference between the actual value and the assumed value of 0.34) than was K_{soil} or K_{river}. As a check of the potential utility of PBC, 20th percentiles were calculated for the 934 profiles in the CSR database as a means of classifying mean values of PBC calculated for each soil type. As shown in Map 8, when this classification is used for PBC, its ability to discriminate between Herbert soils is similar to that for K_{soil} which is the expected result, given the correlation between these sorption indices as shown in Figure 1. We consider maps 4 and 5 to provide the most appropriate basis for revised P fertilizer recommendations (see section 4.1 and the extension report in Appendix 1).

In terms of the fate of P lost from land under cane, K_{river} is arguably of more interest than K_{soil}. Comparison of Maps 9 and 4 illustrates the point made in section 3.2.1 that K_{river} is a more sensitive discriminator of P sorption behaviour amongst lower Herbert soils than K_{soil}. For example, the very low P sorbing River Sands on the north bank of the Herbert near Ingham are identified by K_{river} as are the very high sorbing Black Organic Clays of the Seymour district and southern part of Hamleigh. Like Map 5 (K_{soil} kriged), Map 10 shows the value of the kriging procedure for identification of soils of particular characteristics on a more regional basis than is provided by the mean values for soil types. Clearly, the area around the point at which Lannercost Creek flows into the Stone River is one which warrants particular care with respect to P fertilizer management and good environmental stewardship. It is noteworthy in this regard that streamwaters sampled from Lannercost and Crissafuli Creeks tended to be the dirtiest collected on any given sampling occasion during the fieldwork stage of the CSIRO Coastal Zone Program activities in the lower Herbert (Bramley – pers. comm.) and also tended to have higher than average P concentrations in streamwaters (Bramley and Muller, 1999).

3.2.3 Mapping the risk of P impact in streamwaters

In CSS3S, a classification of runoff susceptibility (C.H. Roth – pers. comm) was used as a means of integrating the likelihood of P being desorbed by suspended riverine sediment with the likelihood of that sediment being derived from the lower Herbert soils studied. Ideally, construction of a P risk assessment should be done using measures of soil erosion as opposed to susceptibility to runoff. However, on the basis that soil erosion from bare land surfaces and runoff susceptibility are likely to be reasonably well correlated, and in the absence of any available indices of soil erosion, we continue to use the classification of runoff susceptibility for this study. A description of how this was developed is given in Bramley *et al.* (1998). For the present study, we restrict this approach to the bare ground scenario which corresponds to a period of a few weeks following the tillage operations that normally precede the planting of a plant crop – assuming that planting follows immediately after tillage. Thus, we have not considered runoff susceptibility under a covered ground scenario, as it is unlikely that there is a close relationship between runoff susceptibility and soil loss in conditions of high soil cover (ie ratooned paddocks). Note also, that the estimation of runoff susecptibility for any particular point did not take account of the distance between that point and the stream into which runoff from that point would drain. This is one of the important limitations of the use of runoff susceptibility as opposed to soil erosion potential, although it is also true that there are relatively few points in the lower Herbert cane growing area that are more than about 200m from a stream or drain.

Map 11 shows the runoff susceptibility for the bare ground scenario; note that we have *masked* the otherwise similar map used by Bramley *et al.* (1998) so that only the area covered by the CSR soil survey is shown. In order to integrate the information in Map 11 with our P sorption indices, a further classification exercise was necessary. Note that since K_{river} is of greatest interest with respect to the potential environmental impact of P, this analysis was confined to K_{river}; that is, the other indices of P sorption (Maps 4-8) were not used.

The classification of K_{river} detailed in Table 3, was modified (Table 5) to reflect the risk of desorption – ie. P release. Note that K_{river} is an index of P sorption or retention, yet we are interested here in P release or desorption. Since soils with high values of K_{river} hold P more tightly than those with low values, a low value for desorption risk was assigned to these soils, and those with low values of K_{river}, and which release P readily were assigned high values of desorption risk. Values for runoff risk were similarly assigned on a scale of 1 (*Minimal runoff*; Map 11) to 5 (*Very frequent runoff*). These values were combined with those for desorption potential in a matrix describing the potential for P loss (Table 6). It should be noted that, whilst we consider this classification scheme and the methodology used to construct it useful for the purposes of identifying the relative potential for P loss from different areas within the lower Herbert canegrowing area, we nevertheless recognise that the classification is qualitative rather than quantitative, and should therefore be used only as a guide to the identification of the potential for P loss.

Table 5. Classification of potential P desorption

P sorption category	K_{river}	Desorption potential
Very low	< 54	5
Low	54-108	4
Moderate	108-162	3
High	162-215	2
Very high	> 215	1

The classification of runoff susceptibility was developed on the basis of the 1:100,000 soil survey of Wilson and Baker (1990). Because of the mismatch in scale between this and the CSR soil survey (1:5,000), it was considered inappropriate to use the soil type-based mean values of K_{river} (Map 9) for the construction of a potential P loss map. Since we also saw some value, from an extension viewpoint, in the regionalised nature of the kriged maps of P sorption (eg Map 10), the map of potential P loss was constructed using the kriged surface of K_{river}. Thus, Map 10 was re-classified using Table 5 and the result overlain with Map 11 using the classification matrix for potential P loss (Table 6) to produce Map 12.

As can be seen from Map 12, there are extensive areas of the lower Herbert canegrowing region which have a significant potential for P loss when the soil is uncovered following tillage, and during and immediately after planting; we would not recommend the use of bare fallows in these areas. There are relatively few areas for which the potential for P loss is *Low* and no areas with a *Very low* classification. Note that the region that was identified in CSS3S as being worthy of future water quality monitoring targeted at possible environmental consequences of P fertilizer use – downstream of the mouth of the Stone River and in the Ripple Creek / Hawkins Creek region – shows up in Map 12 as being a region with a significant potential for P loss.

Table 6. **Matrix for estimation of the potential for P loss[A]**

P desorption risk	Runoff risk 1	2	3	4	5
1	1	2	2	2	3
2	2	2	3	3	4
3	2	3	4	4	4
4	2	3	4	5	5
5	3	4	4	5	5

[A]The values in the matrix indicate the potential for P loss where 1-5 denote a *Very low*, *Low*, *Moderate*, *Significant*, or *High* potential for P loss, respectively.

4.0 Recommendations and further directions

This project has used a simple GIS analysis and the availability of detailed georeferenced soil information to convert the outputs from the previous SRDC project No. CSS3S (Bramley *et al.*, 1998) to a useable map format that should enable the sugar industry in the Herbert to better target its management of phosphorus fertilizer with the dual goals of better management of P nutrition and improved environmental stewardship. An extension report is provided in Appendix 1 in which we suggest specific guidelines for growers and extension officers as to how these goals might be achieved. We also discuss them below.

4.1 A basis for modification to the P fertilizer recommendations

Maps 4-8 illustrate that even within a fairly small region like the lower Herbert canegrowing area, significant variation exists in the ability of canegrowing soils to retain P, and thus, to supply it to crops. Ideally, further work (ie field trials, laboratory analysis of soil tests) would be desirable for the establishment of exactly what rates of P fertilizer are appropriate for growing sugarcane on the different soils that exist within the district. However, the knowledge embodied in this report, that for CSS3S and the work reported by Bramley and Wood (1996) should enable some modification of existing practice to be carried out with confidence. We suggest that Maps 4 and 5 be used as the basis for this. Given that growers are often conservative and prefer incremental rather than rapid change, Map 5 may be a useful starting point – it reflects regional variation in P sorption. However, as growers become more comfortable with the notion that different P fertilizer management strategies are appropriate for blocks that may not be all that far apart, Map 4, which reflects soil type based variation in P sorption should be used as the basis for providing improved P management guidelines.

Bramley and Wood (1996) demonstrated that the existing P recommendation (Calcino, 1994) was about right for cane grown on the organic clay and silty clay soils of the Hamleigh region, but significantly higher than what the crop required on the sandy soils of Upper Stone. Note however, that the land used in this work had not been previously fertilised. Thus, the existing recommendation should be considered to be an absolute maximum rate of application. For soils with a history of P fertilization, this should certainly be reduced.

In general, when there is a limited history of P use, crops grown on high P sorbing soils require more P than those grown on low sorbing soils, because high sorbing soils have a greater capacity to retain P, and thus, a reduced tendency to release P for crop growth. However, where a history of P application exists, higher sorbing soils will have a greater capacity to supply P to crops over a long period than lower sorbing soils, on account of the relatively high residual value of P in higher sorbing soils. These soils can therefore have their P application reduced or even stopped for a period, without a detrimental impact on crop production occurring. Given their lower ability to retain P, low sorbing sandy soils will need more frequent additions of P fertilizer than higher sorbing soils, but the rates of addition can be considerably reduced relative to the existing recommendation, in view of the much higher plant-availability of this P.

It is important that readers understand that we are not simply advocating a general reduction in the rates of P fertilizer recommended by Calcino (1994); what is also needed is a new basis for interpretation of the soil test on which these recommendations are based. Working with soils that would fall into the *low* and *high* categories as used in Maps 4 and 5, Bramley and Wood (1996) demonstrated the effects of the differing P sorption properties of contrasting soils on P soil test values. They did this by adding the same amount of P to both soils, and then following a period of incubation, conducting soil P tests using both the BSES P test (Kerr and Von Steiglitz, 1938) and a more sensitive test (Menon *et al.*, 1989; Bramley and Roe, 1993) similar to the resin test used in the present study. They demonstrated that the BSES test, which involves extraction in dilute acid (nevertheless a strong extractant), is relatively insensitive to differences in sorption characteristics compared to tests which induce desorption of sorbed P from the soil (which is what a plant root does by taking up P from the soil solution). One implication of this is that a BSES soil test value of say, 40 ppm, on a sandy (Cluster 4) soil indicates that more P is readily plant-available than would be the case for a clayey soil (Cluster 1) with the same soil test value. Similarly, the critical soil test values for optimal crop production on sandy soils can be expected to be lower than on higher sorbing soils. Further research which aims to establish the precise basis for soil test interpretation criteria for Australian sugarcane soils would be highly worthwhile; what is needed is something similar to Table 12.3 of Moody and Bolland (1999). At this stage it might be reasonable to assume that an upper critical soil test value of 40 ppm is correct (as at present) for the high sorbing (Cluster 1) soils, but that a value of say, 32 ppm be adopted for Cluster 2 and 3 soils and 25ppm for Cluster 4 since the CSR soil chemical database shows an average BSES P for topsoil samples with a high P sorption index of 53 ppm, whereas soils with a low P sorption index have an even higher average BSES P of 84 ppm. Note that this general recommendation is based on expert opinion rather than laboratory experimentation and as such, is qualitative. Whatever, the analysis of the CSR database suggests that over-fertilization with P is currently a more significant problem than under-fertilization. Guidelines for improved management of fertilizer P are provided in Appendix 1.

4.2 Recommendations for the mitigation of P release to receiving waters in the lower Herbert

Of course, aside from making more efficient use of an expensive input to sugarcane production, and thereby improving the profitability of the sugarcane production system, there are strong environmental imperatives for modifying existing management. As we have demonstrated in this report, just as the phosphorus chemistry varies substantially amongst lower Herbert soils, so too does the risk for potential P loss offsite. Thus, whilst we encourage the industry to make use of Maps 4 and 5 for the purposes of increasing the efficiency of P fertilizer use in the lower Herbert, we also encourage it to make use of Map 12 in identifying a route to improved environmental stewardship. Clearly, the margin for error in getting P fertilizer rates right for crop production in those areas for which the potential for P loss is high, is much less than in those areas with a low potential for P loss. In our view, there is no excuse for over-fertilizing with P, especially given the long history of P fertilizer use which applies to most lower Herbert sugarcane soils. Nevertheless, recent surveys of fertilizer use by the Herbert Cane Protection and Productivity Board (Ron Kerkwyk – pers. comm.) suggest that growers typically apply more P than is recommended by BSES (Calcino, 1994). Here, we recommend simply, that extension personal use Map 12 in addition to Maps 4 and 5 as a basis for persuading growers to reduce their use of fertilizer P. Again, Appendix 1 provides more specific guidelines.

4.3 Further work

In CSS3S, we identified a number of opportunities for further work *viz*.

- Evaluation of the utility of oxalate-extractable aluminium (Al_{ox}) as a predictor of P fertilizer requirement;
- Establishing that the environmental impact of inappropriate P fertilizer use was likely to be greatest in the freshwater, as opposed to the estuarine or marine zone;
- Further investigating the role of redox on P retention and release by sediments in the streams of canegrowing regions; and
- Targeting any subsequent environmental and/or water quality monitoring work in the lower Herbert downstream of the mouth of the Stone River and in creeks and drains which drain clayey soils under cane, especially those in the Ripple Creek/Hawkins Creek.

The results of this project suggest that the merits of undertaking such work remain high. In addition, we recommend that a laboratory study aimed at providing a basis for re-interpretation of the BSES soil test on the basis of soil type be conducted.

5.0 Acknowledgments

We are most grateful to Anne Kinsey-Henderson (CSIRO Land and Water, Townsville) who carried out much of the GIS analysis for this project, to Dr Christian Roth (CSIRO Land and Water, Townsville) for allowing us to use his assessment of runoff susceptibility and making useful comments on an earlier draft of this report, and to Greg Shannon (BSES, Ingham) for agreeing to facilitate the extension of the results of this work. The team of field and lab workers in the CSR Technical Field Office (Macknade and Victoria Mills) also deserve particular thanks for their dedication to the production of the 1:5,000 survey of lower Herbert sugarcane soils and acquisition of the accompanying soil property data - a unique resource, the value of which should not be underestimated. Finally, we are grateful to the Sugar Research and Development Corporation for contributing to the costs of this research.

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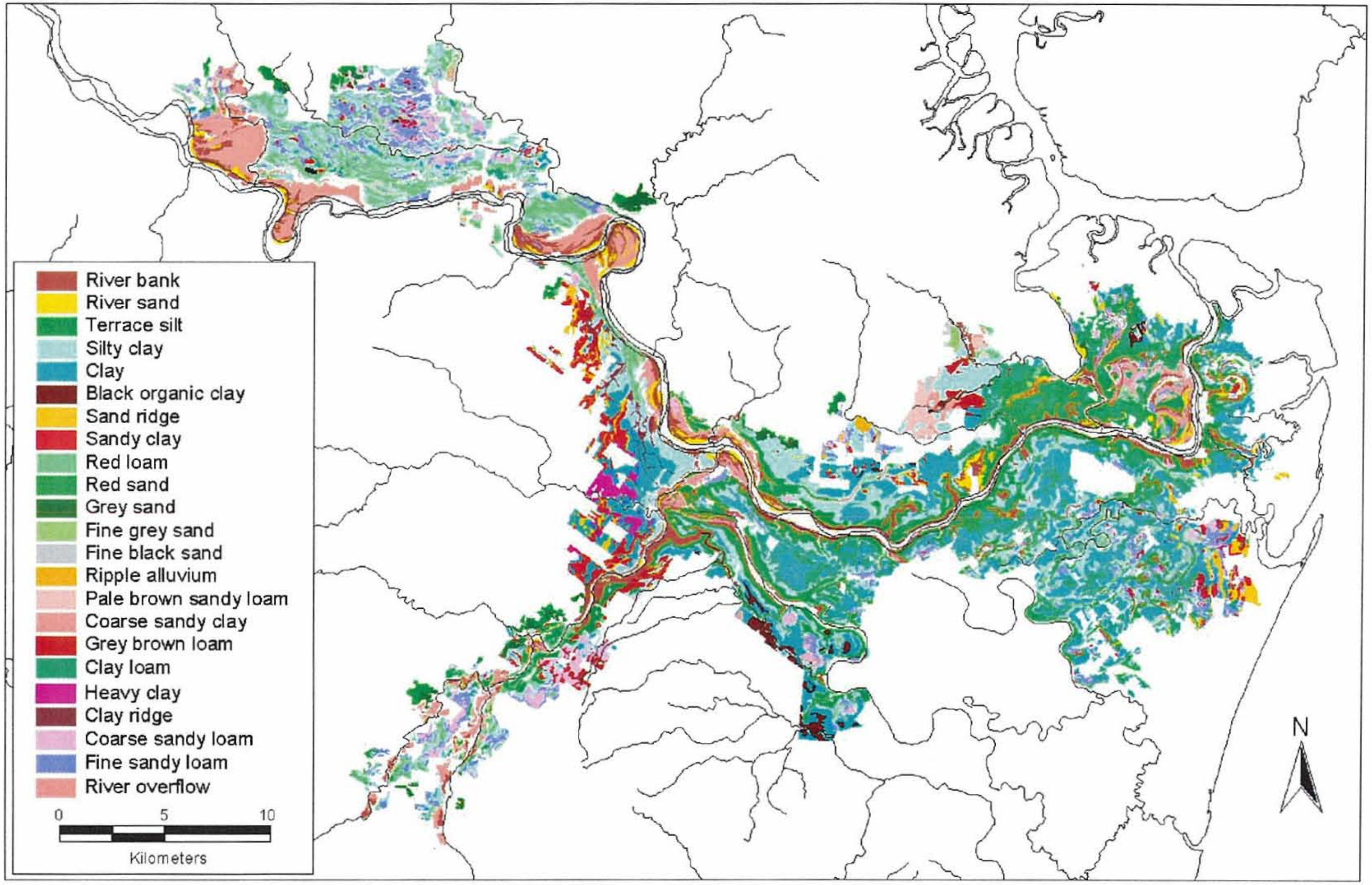
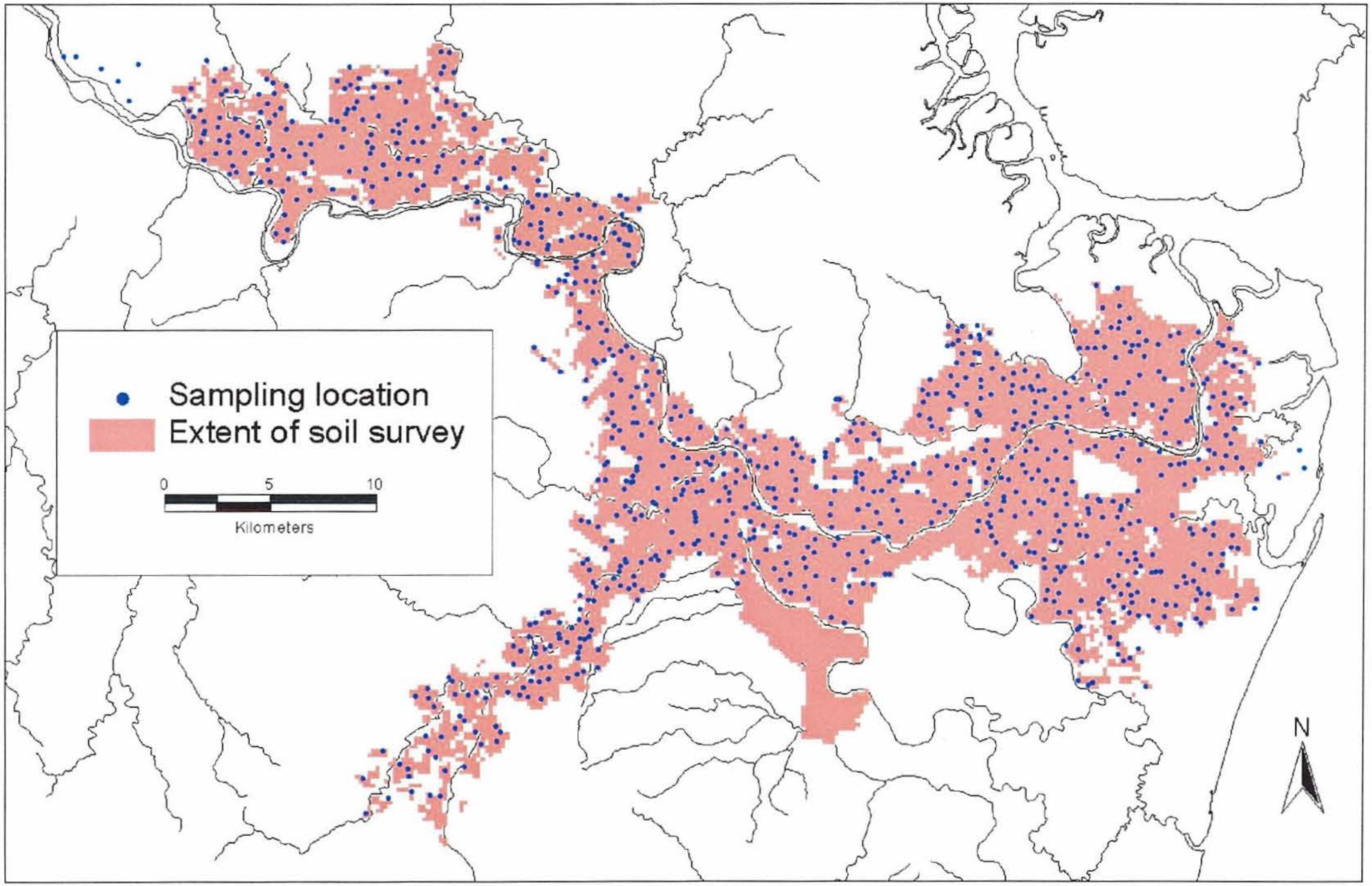
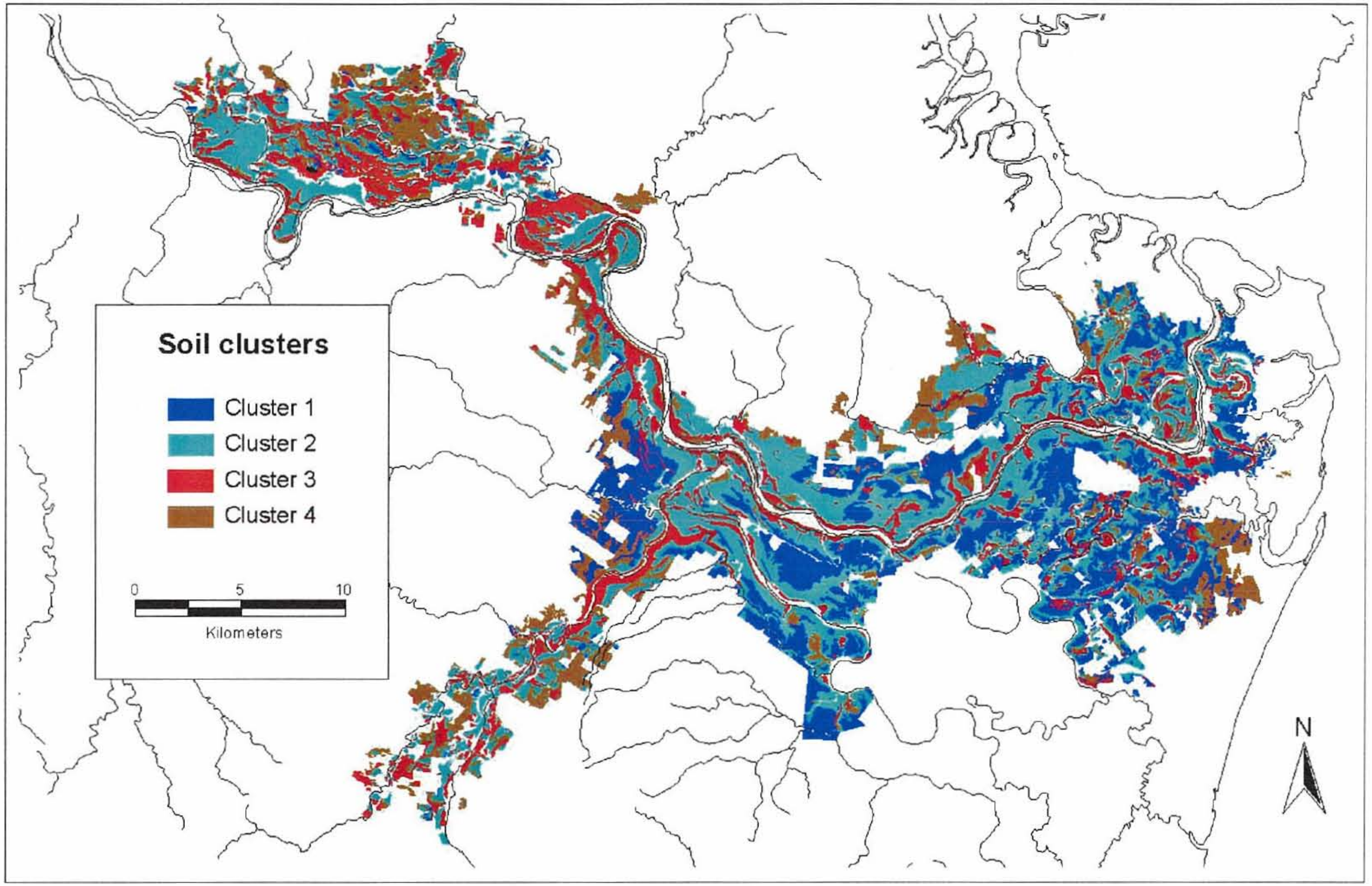
The maps



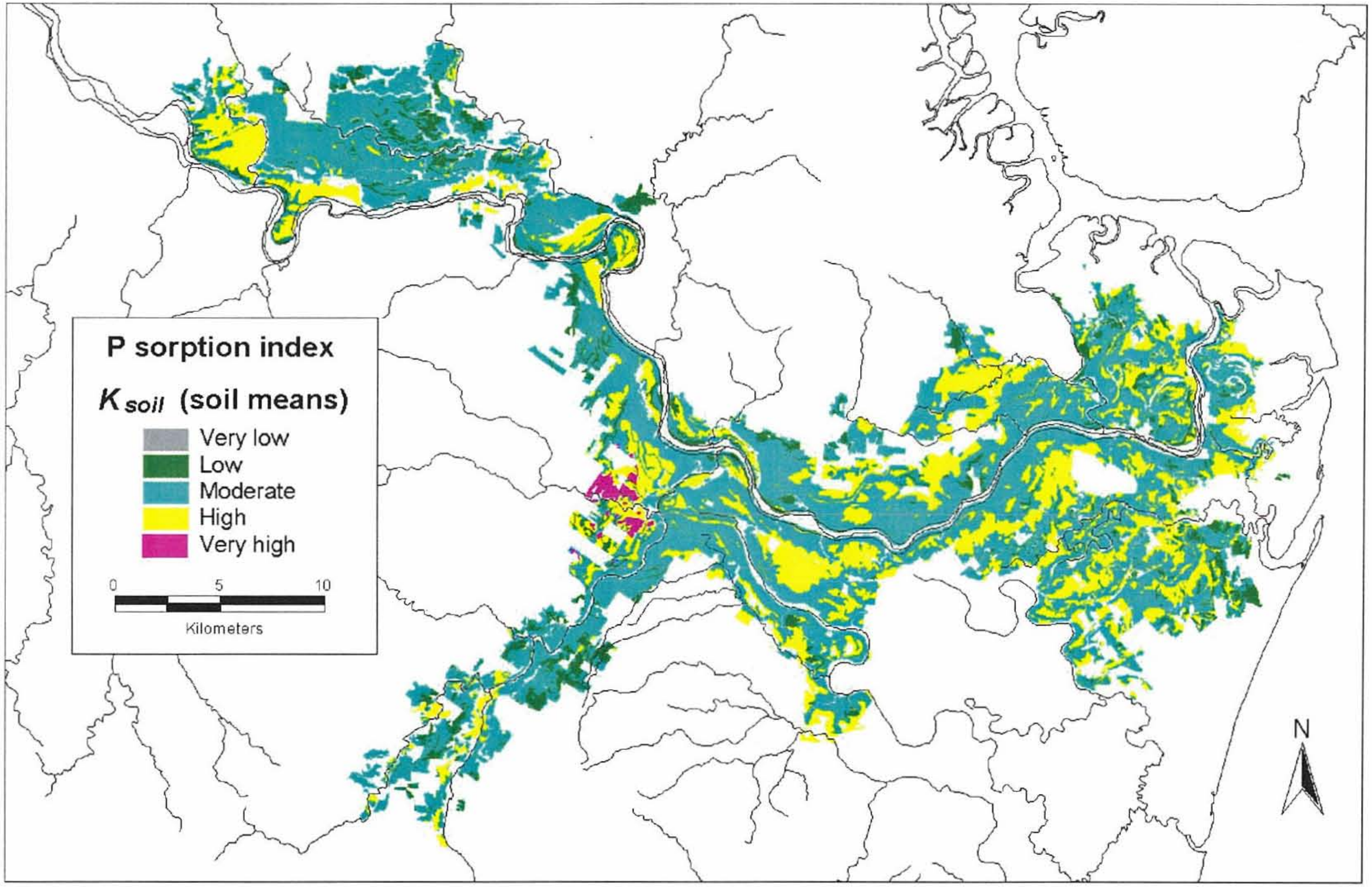
Map 1 **The 1:5,000 CSR survey of lower Herbert sugarcane soils**



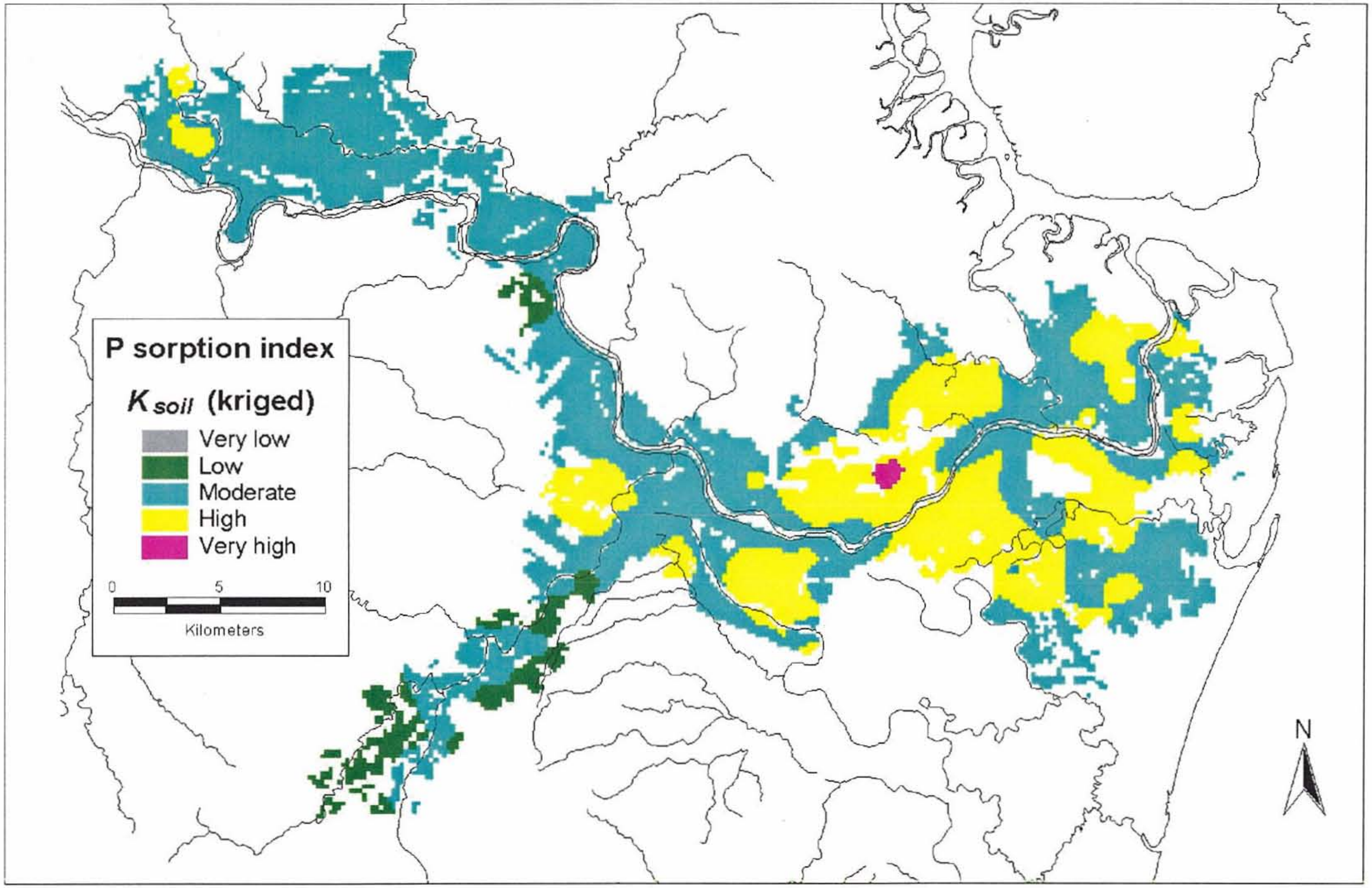
Map 2 **Location of the 934 profiles for which soil property data were available**



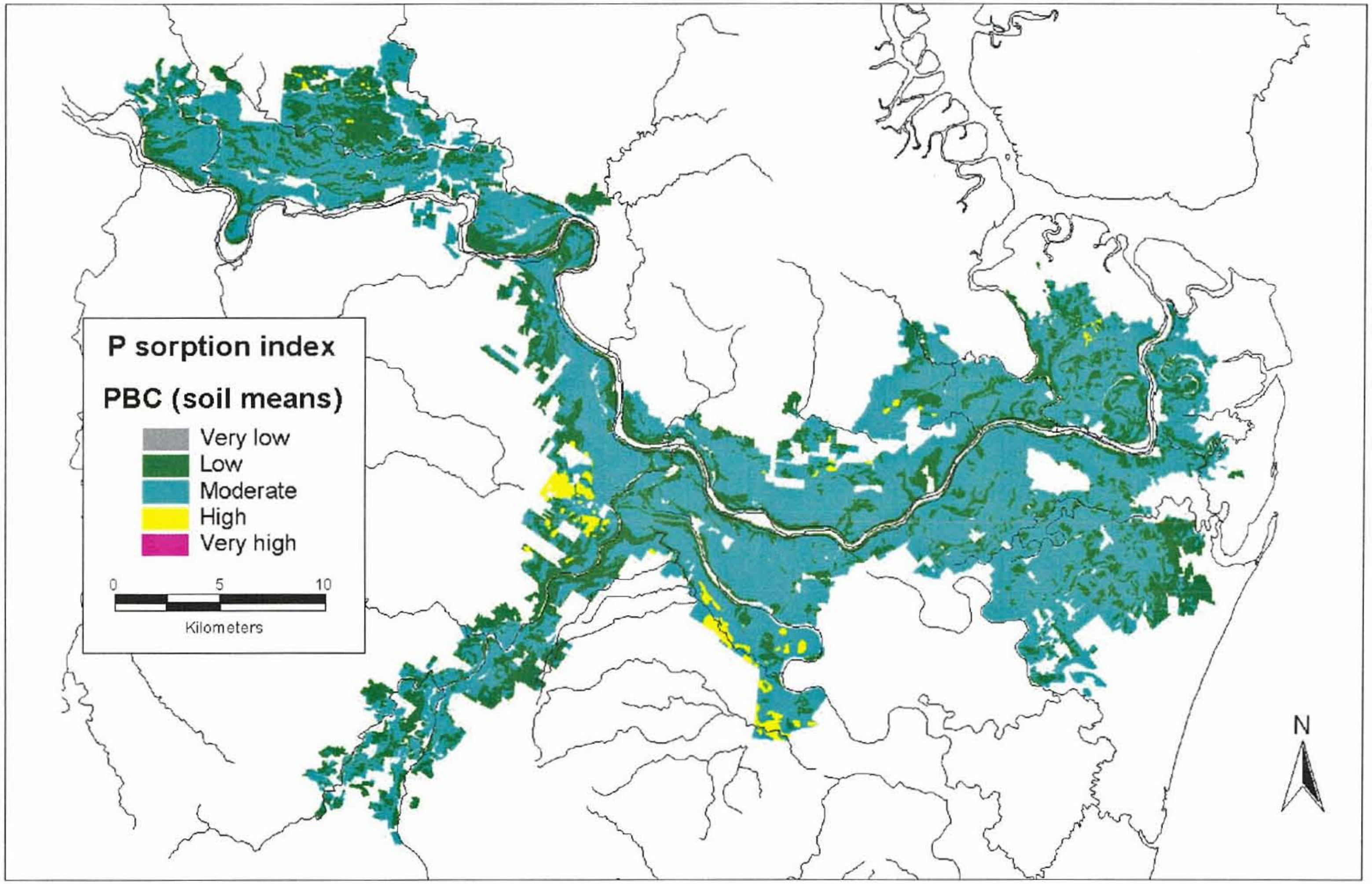
Map 3. **Clusters of lower Herbert soils of similar chemical properties (see Table 1)**



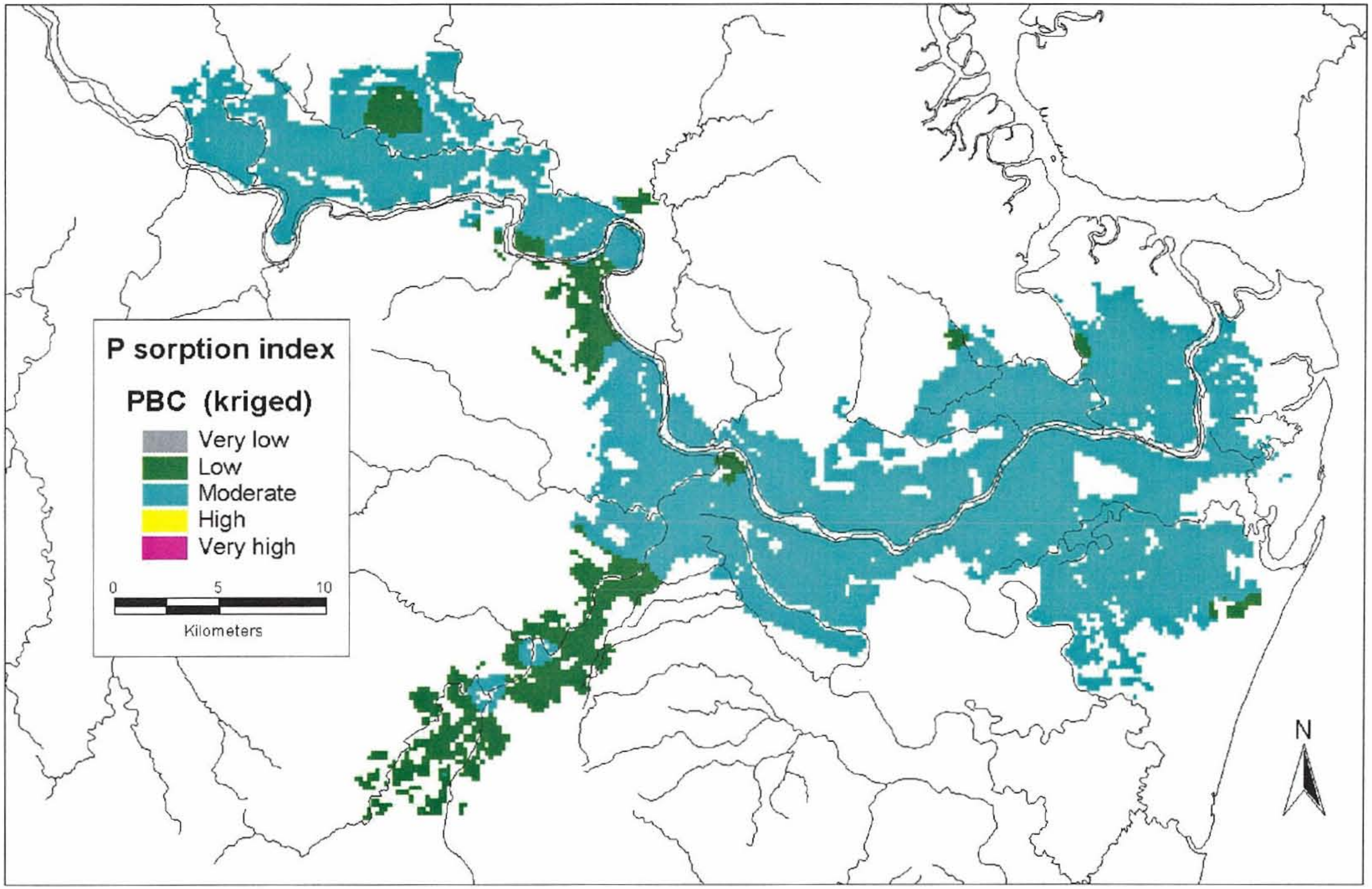
Map 4. Map of P sorption based on mean values of K_{soil} for each soil type (Map 1) and a classification based on 20th percentiles



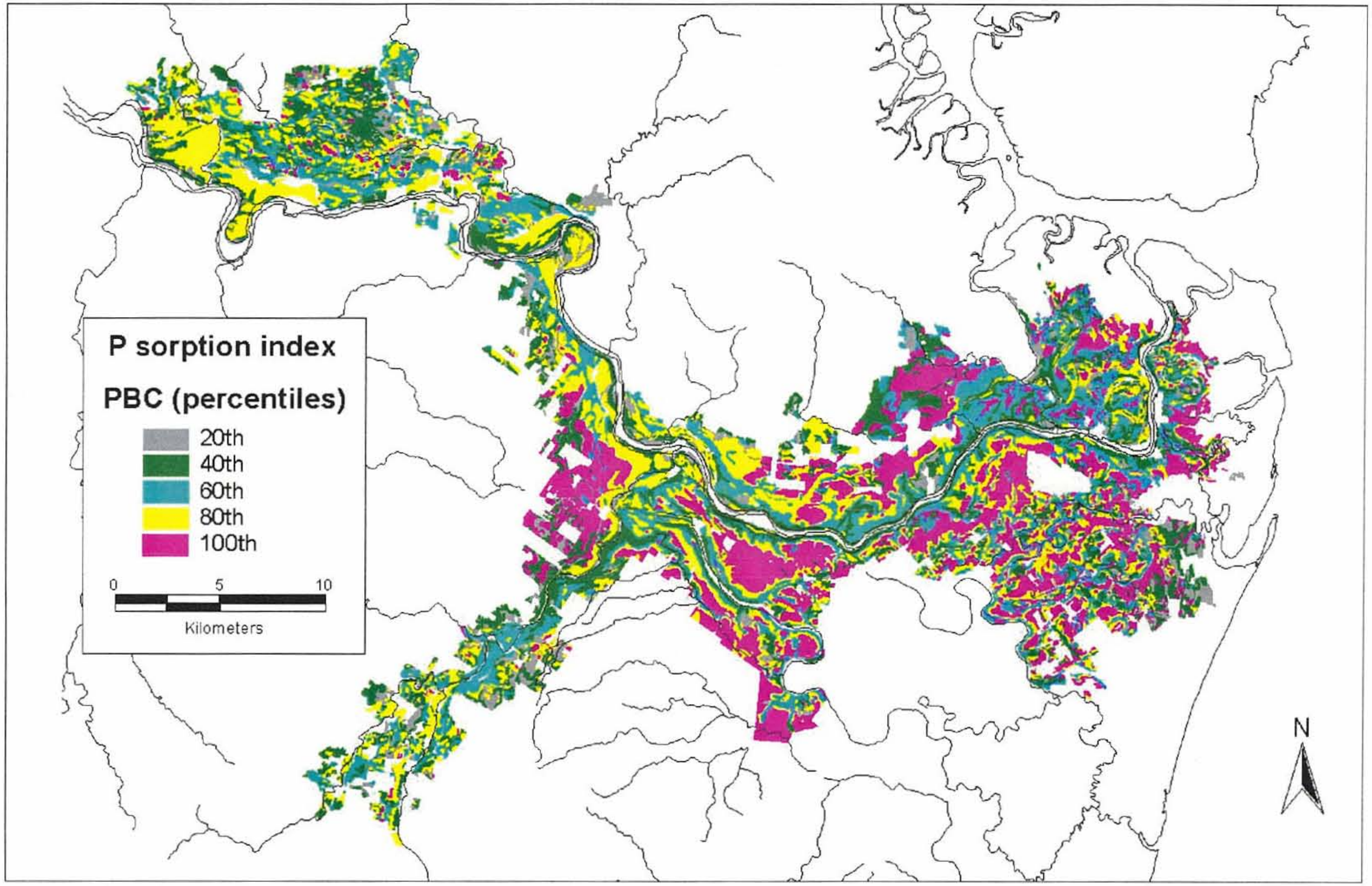
Map 5. Map of P sorption interpolated from calculated values of K_{soil} for each profile location (Map 2)



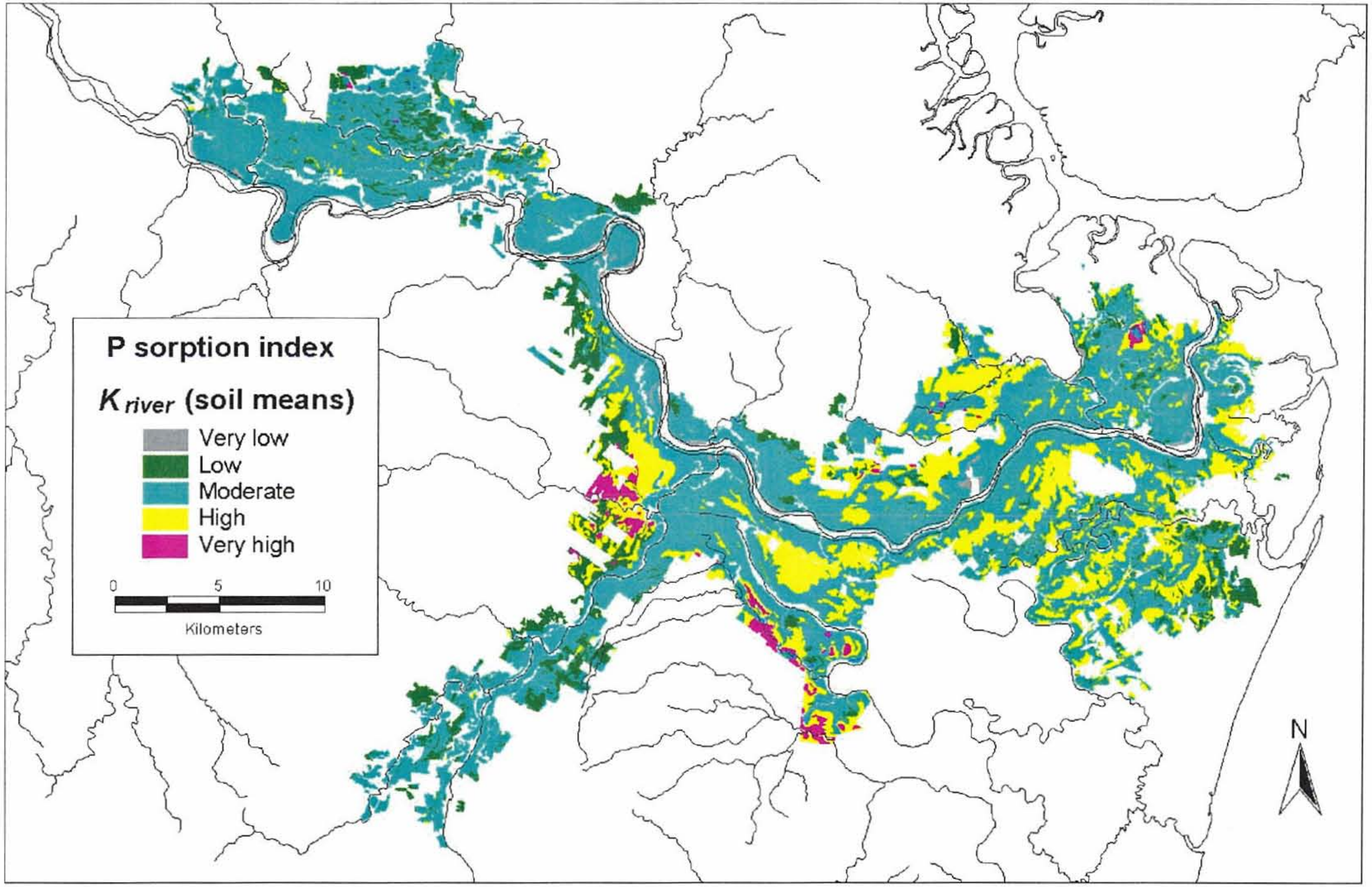
Map 6. **Map of P sorption based on mean values of PBC for each soil type (Map 1) and the classification of Moody and Bolland (1999)**



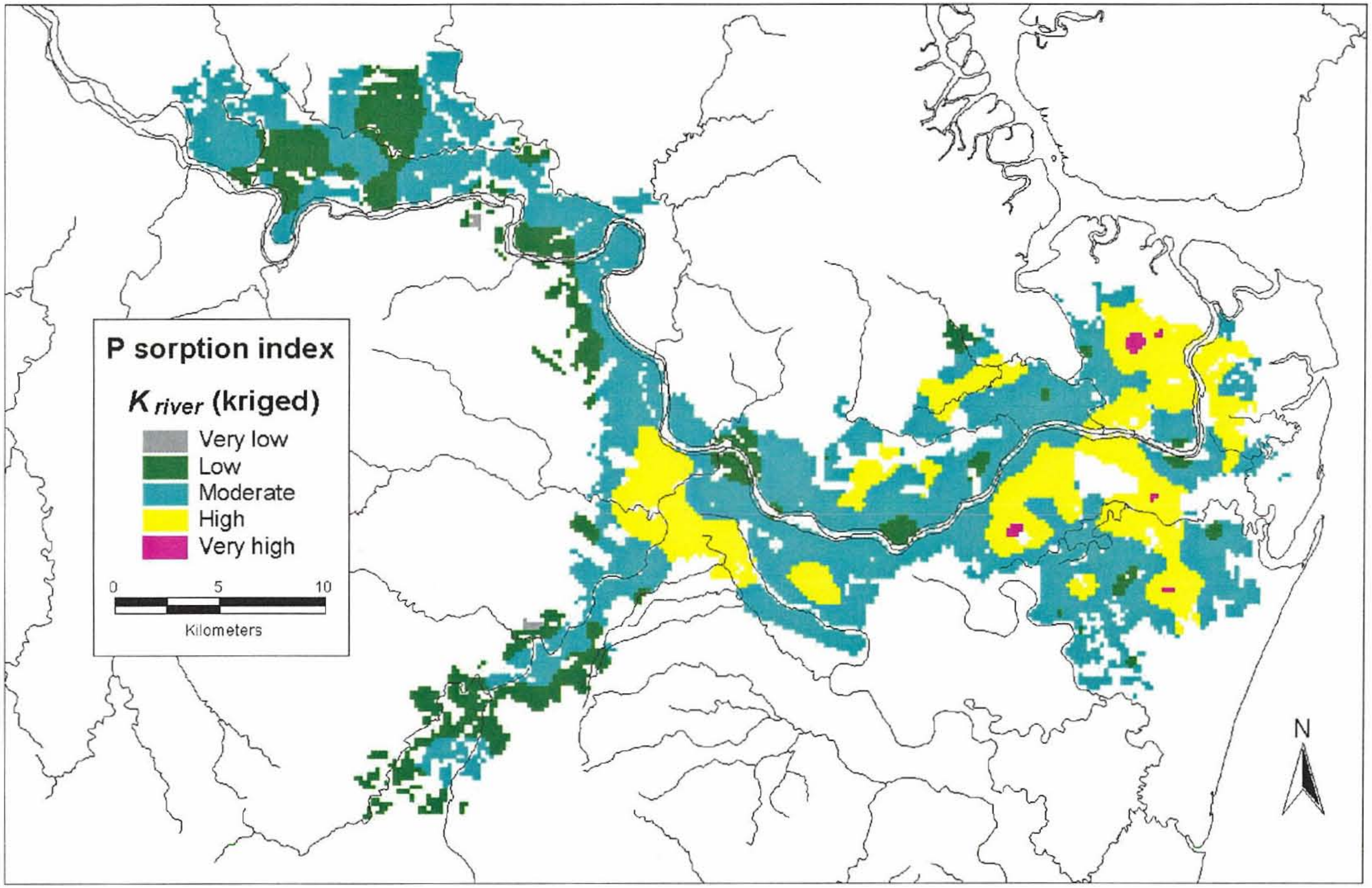
Map 7. **Map of P sorption interpolated from calculated values of PBC for each profile location (Map 2)**



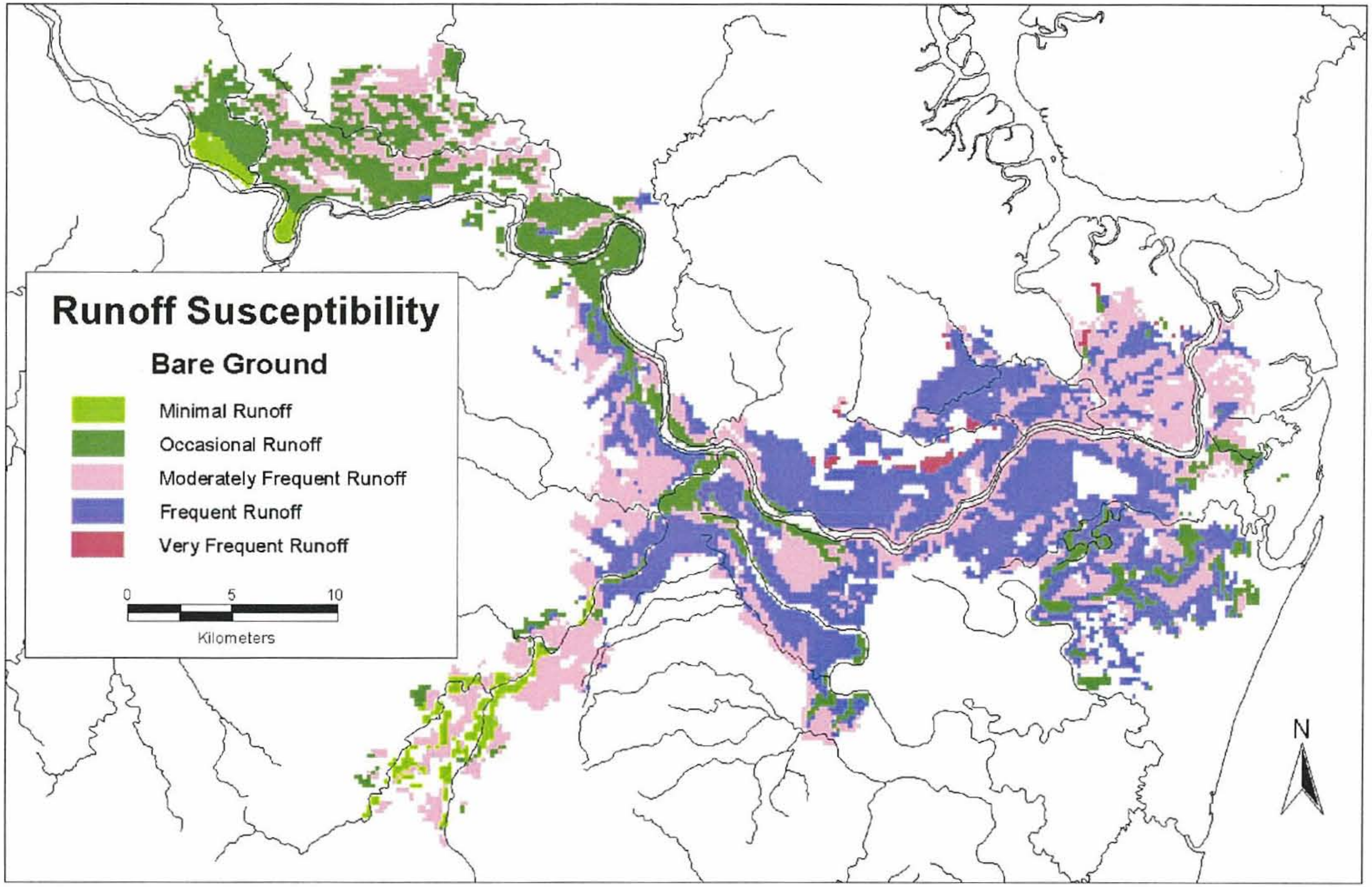
Map 8. **Map of P sorption based on mean values of PBC for each soil type (Map 1) and a classification based on 20th percentiles**



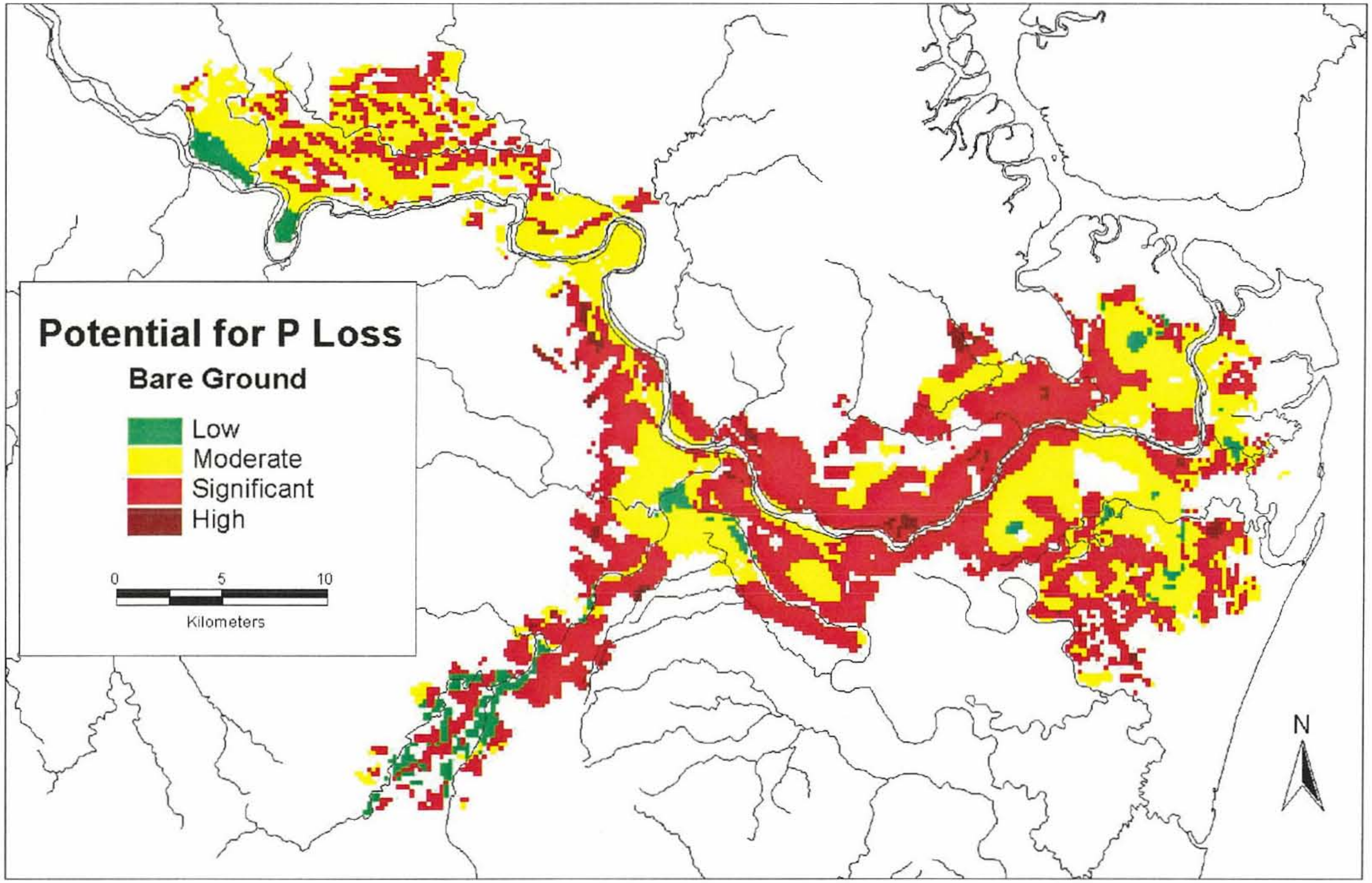
Map 9. Map of P sorption based on mean values of K_{river} for each soil type (Map 1) and a classifcation based on 20th percentiles



Map 10. **Map of P sorption interpolated from calculated values of K_{river} for each profile location (Map 2)**



Map 11. **Runoff susceptibility in the lower Herbert – bare ground (C.H. Roth – pers. comm)**



Map 12. **Potential for P loss from lower Herbert sugarcane soils under bare ground**

Appendix 1. Extension Report

CSIRO

CSIRO LAND and WATER

Guidelines for improved P management in lower Herbert soils

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CSR™ Sugar

Sugar Research and Development Corporation

Summary

This guide is intended for use by extension advisers in the sugar industry who interact with and advise cane farmers and other land users. It will be accompanied by a series of informative posters which are intended for display at field days and grower meetings and will be largely self explanatory.

A summary of the main findings of SRDC project CLW010 is provided and this is translated into a set of management recommendations for different soils which should ensure that cane yields are not limited by insufficient P fertilizer being applied and should also minimise any effects of phosphorus fertilizing practices on the environment. Note that these recommendations are qualitative in that they rely on the use of expert opinion in the interpretation of P sorption behaviour in soils and sediments, and on local soils and agronomic knowledge of Herbert cane production systems. They are not based on extensive fertilizer trials and soil testing.

Introduction

SRDC project CLW010 sought to add value to a previous phosphorus project (CSS3S) conducted in the Herbert River District by producing maps of part of the Herbert River cane area which show the phosphorus fertilizer requirement of different soil types, and the risks of this phosphorus being lost from the land by soil erosion. The maps cover that part of the cane area for which detailed soil mapping information is available through the CSR soil survey.

The original project (CSS3S) arose out of concern that river sediments derived from some sugarcane areas had the potential to contribute phosphorus to water leaving river catchments which could ultimately have an adverse effect on the Great Barrier Reef. The project focused on the Herbert catchment and aimed to increase our understanding of how phosphorus is held in different soils, how it becomes available to sugarcane crops and how it is released from sediments should soil particles from fertilized cane fields be washed into drains, creeks and rivers. The project also attempted to characterise the chemical properties of different soils with respect to the way they react with phosphorus fertilizer, and aimed to group together soils with similar properties. This opens the way to developing soil-based recommendations for phosphorus management that apply to particular soils based on their particular chemical properties. However, since the CSR soil survey has recognised 24 different soil types, these have been grouped into 4 soil clusters with each cluster containing soils with broadly similar properties.

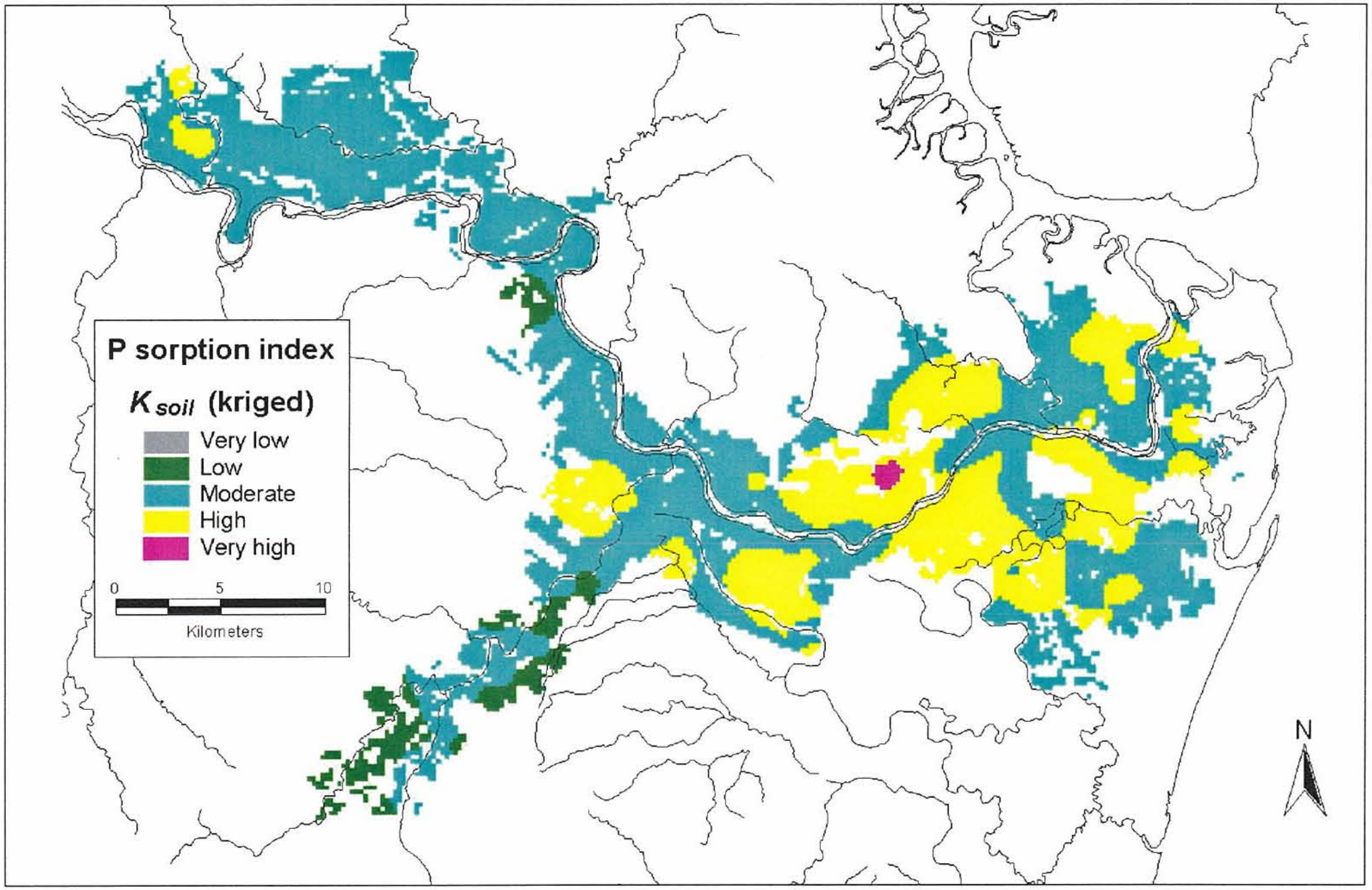
This guide is intended for use by extension advisers in the sugar industry who interact with and advise cane farmers and other land users. It will be accompanied by a series of informative posters which are intended for display at field days and grower meetings and will be largely self explanatory.

Phosphorus fertilizer and soils

When phosphorus fertilizer is applied to a soil, it dissolves. Some of the phosphorus released by this dissolution process becomes tightly held or *sorbed* onto soil particle surfaces. The amount of fertilizer P that is sorbed varies between soils and appears to depend on the amount of clay, the amount of organic matter in the soil and on various other soil chemical properties that are not routinely measured (Nelson *et al.*, 1999). Clay soils that are high in organic matter sorb phosphorus fertilizer most strongly and sandy soils that are low in organic matter sorb phosphorus very weakly. The phosphorus that is sorbed is stored in the soil and is not immediately available for crop uptake. Growing crops use the phosphorus that is present in the soil solution (water in the soil) and there is an equilibrium between sorbed P and soil solution P with sorbed P being progressively released as P in the soil solution is depleted by crop uptake. The rate at which sorbed P is released into the soil solution also varies between soil types. Organic clay soils will release this P more slowly than less organic, sandier soils.

Map 1 shows the P sorption index for the areas of the Herbert catchment where the soils have been mapped, sampled and characterised. Soils with a low P sorbing index are generally sandy and low in organic matter and are restricted mainly to the middle and upper Stone River areas and to the northern part of the Lannercost area. Most of the area has soils with a moderate P sorption index. Areas of high P sorption occur mainly in the lower catchment and there is a zone of very high P sorption in the Ripple Creek area.

The general principles of P fertilization for these categories are therefore as follows:



Map 1. **Map of P sorption in lower Herbert sugarcane soils. (See discussion of Map 5 in Bramley and Wood (2000) for further explanation).**

- Soils with a high P sorption index and a long history of P fertilization will have built up large reserves of stored P which are tightly held onto soil particle surfaces and which are gradually being released for crop uptake. Provided sufficient P is being released, they will not require any additions of P fertilizer until the reserves have been depleted. This could take more than 10 years.
- Soils with a high P sorption index, which have been recently brought into production, will require comparatively large applications of P fertilizer in order to achieve the desired level of P in the soil solution as much of the added P will be sorbed (fixed) and will not be immediately available for crop use.
- Soils with a low P sorption index and a long history of P fertilization will have larger amounts of P that can be readily released to the soil solution and so are available for crop uptake. These will therefore not require any immediate additions of P fertilizer. However, the stored reserves will not be high and so the available P will be depleted more rapidly. They will therefore require more frequent additions of P fertilizer than the strongly P sorbing soils.
- Soils with a low P sorption index, which have been recently brought into production, will require more frequent but smaller amounts of P fertilizer than the soils which sorb P strongly.

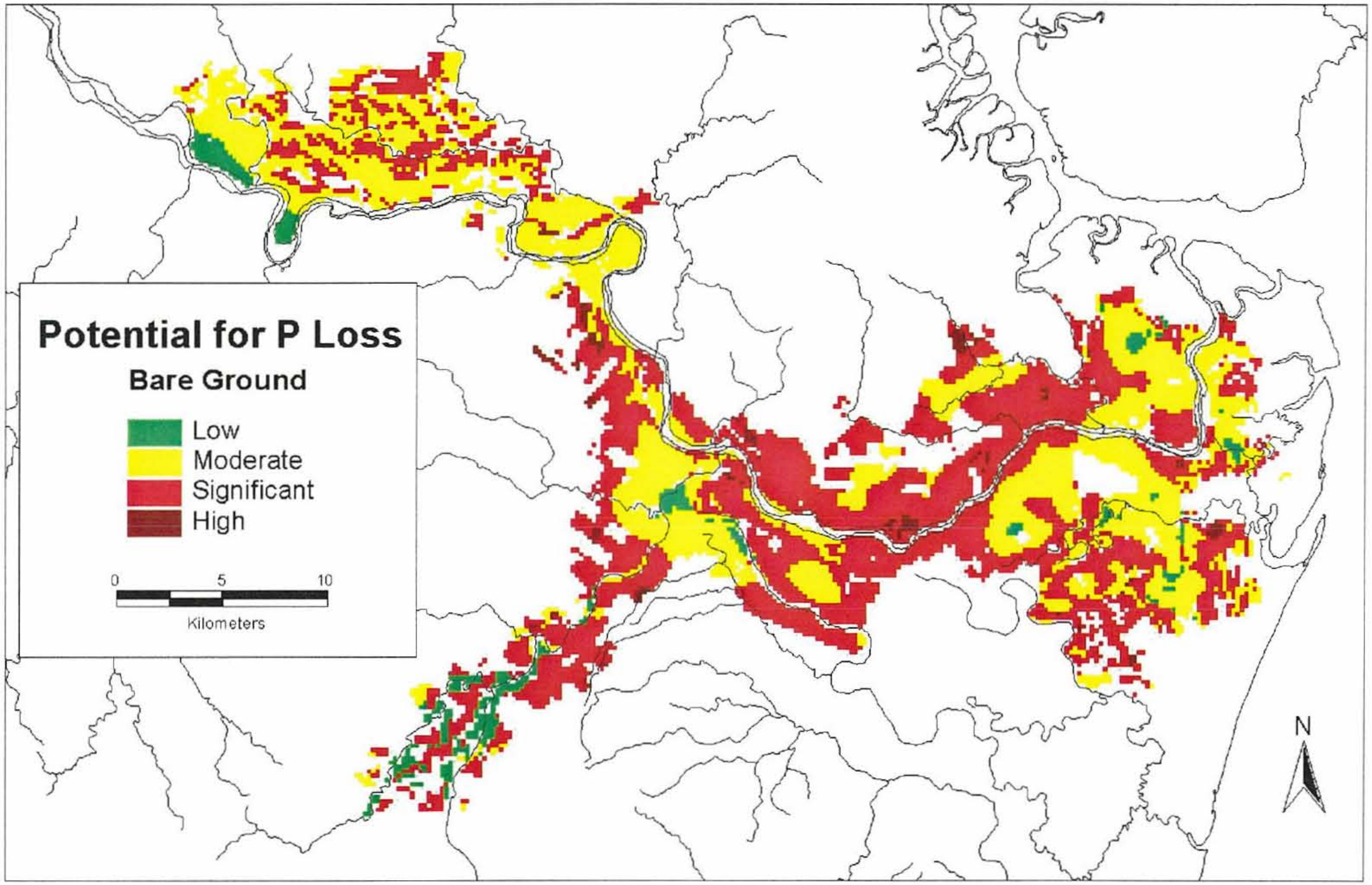
Losses of phosphorus from sugarcane soils

The main way in which phosphorus is lost from sugarcane soils is principally through soil erosion, whereby soil particles with sorbed P attached are washed into drains, streams and rivers and are transported downstream as river sediment. In order to quantify the risk of phosphorus fertilizer polluting the rivers and streams of the Herbert River catchment we need to know firstly the risk of soil erosion occurring on different soils and secondly the likelihood of the soil phosphorus becoming dissolved in both fresh water and sea water.

We have assumed in this study that soil erosion risk is closely related to runoff susceptibility (see Bramley *et al.* (1998) for further information) and that bare ground immediately before and after planting is going to be at greatest risk.

The ease with which soil phosphorus is removed from the soil and dissolved in river water will depend on the soil P sorption properties discussed above. Strong P sorbing soils may not release their P very easily and, depending on the amount of P already in solution in the river water, may in fact act as a sink for phosphorus rather than a source (ie they will absorb dissolved phosphorus from stream water rather than providing it). Weakly sorbing soils will pose the greatest risk of releasing their phosphorus into stream water, although again, this will depend on the P concentration in the water (Bramley *et al.*, 1998).

Map 2 shows the potential for P loss in the areas of the Herbert catchment where the soils have been mapped. The categories were developed by combining runoff risk and the ease with which P is desorbed from different soils when in river water. There are relatively few areas where the potential for P loss is low and none where it is very low. There are extensive areas having a significant potential for P loss when the soil is uncovered following tillage and during/after planting. The recommendation in these areas is therefore to ensure where possible that soils are protected by some form of cover particularly during the wet season. Furthermore, it is important that additions of P fertilizer are only made when and where they are needed.



Map 2. **Potential for P loss from lower Herbert sugarcane soils under bare ground (See discussion of Map 12 in Bramley and Wood (2000) for further explanation.**

Current phosphorus fertilizer recommendations

Current phosphorus recommendations for sugarcane soils, provided by BSES (Calcino, 1994), take no account of different soil properties except in the case of soils being fertilized for the first time. Phosphorus recommendations are based on the amount of P which can be extracted from soils using a dilute sulphuric acid extractant.

However, because this is a strong extractant, it may remove more P than the plant-available fraction. Thus it is much more difficult to distinguish between soils that sorb P strongly and those that do not using this method than would be the case with a much more sensitive test. This is probably the reason why the industry has only one P fertilizer recommendation for all soils.

Under the existing recommendations, soils with an extractable soil P level of >40 ppm P are considered not to require any phosphorus. Soils with an extractable soil P level of 20-40 ppm P and a high yield expectation are recommended an application of 20 kg P ha^{-1} on both plant and ratoon cane. Soils with an extractable soil P level of 10-20 ppm P are recommended an application of 40 kg P ha^{-1} on both plant and ratoon cane. Soils with <10 ppm extractable P are recommended an application of 80 kg P ha^{-1} on plant cane and 40 kg P ha^{-1} on ratoon cane.

This approach, which fails to take into account the ways in which fertilizer P reacts with different soils, is unfortunately at odds with the philosophy of sustainable and environmentally friendly agricultural production. It is likely to result in over fertilization with P and wastage of fertilizer on soils with a low P sorption index. However, there is no evidence to suggest that under fertilization has occurred on soils with a high P sorption index. The CSR soil chemical database shows an average BSES P for topsoil samples with a high P sorption index of 53 ppm, whereas soils with a low P sorption index have an even higher average BSES P of 84 ppm. Over fertilization with P is clearly a more significant problem than under fertilization, and is likely to be more prevalent on the very soils with the greatest desorption potential.

A more sophisticated approach is needed which takes into account the ways in which phosphorus reacts with different soils and the susceptibility of those soils to losses of fertilizer P.

A more agronomically and environmentally sound basis for phosphorus fertilizer management

The key criteria which need to be taken into account when developing P fertilizer recommendations are:

- The P sorption index of the soil which will indicate how fertilizer P reacts with the soil.
- The length of time the soil has received applications of P fertilizer, which will provide an indicator of the build up of soil reserves of P.
- The length of time since the last application of P fertilizer.
- The amount of extractable P using the BSES P test (or an alternative test calibrated for sugarcane production systems).

On sites that have been under sugarcane for many years and have received frequent applications of P fertilizer in the past, it is appropriate not to apply any more P fertilizer, even on plant cane. Such sites would normally have levels of extractable P well in excess of 40 ppm P using the BSES test. Some sites in the Herbert have extractable P levels in excess of 200 ppm P. In these situations the main question is how long can the soil be cropped with sugarcane without applying any P fertilizer. This will depend on soil P sorption properties, crop uptake and on losses of P from the soil solution. Since annual crop uptake is of the order of 20 kg P ha^{-1} it would be appropriate to suggest that no P fertilizer needs to be applied for 1 crop cycle if BSES P >40ppm, for 2 crop cycles if BSES P >60ppm and for 3 crop cycles if BSES P >80ppm. On soils with a high P sorption index this period could probably be extended further. Regular soil testing, after each crop cycle, would be needed to support this recommendation.

On sites that have been under sugarcane for a number of years where BSES P is between 10 and 40ppm P, maintenance applications of 10-30 kg P ha^{-1} would be required depending on the soil's P sorption index. If BSES P was lower (<10ppm), applications of P fertilizer could be increased to 20-60 kg P ha^{-1}, depending on P sorption index.

On sites that are in their first crop cycle of sugarcane cultivation, and which have not been previously fertilized, applications of 40-80 kg P ha^{-1} are required on the first plant crop (40 on soils with a low P sorption index and 80 on soils with a very high P sorption index) and applications of 10-30 kg P ha^{-1} on ratoons.

Conclusions

Map 1 shows that there is significant variation in the ability of sugarcane soils in the lower Herbert to retain P and to supply it to crops. Map 2 shows that care needs to be taken in managing these soils as there are significant areas with a high potential for P loss when the soils are unprotected. Used together, these two maps provide a much improved basis for the delivery of recommendations for the management of P to cane growers in the lower Herbert. Extension advisers can play an important role in achieving this improved management when providing advice to growers on how much P fertilizer should be applied to a block of cane. It is suggested that P fertilizer advice be based on interpretation of the two maps, together with a recent soil test from the block, and reference to the fertilizer history of the block.

Further Reading

Bramley, R.G.V., Edis, R.B., White, R.E. and Wood, A.W. 1998. Environmentally sound phosphorus management for sugarcane soils. Final report on SRDC Project No. CSS3S. Sugar Research and Development Corporation, Brisbane.

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