Proceedings of the Australian Society of Sugar Cane Technologists, volume 41, 371–379, 2019

Peer-reviewed paper

Spatial distribution of potential soil constraints affecting nitrogen management in the Wet Tropics

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Abstract Position in the landscape and climatic conditions experienced during the growing season, especially following the application of nitrogen (N) fertiliser, has important implications for crop growth, N uptake and N losses. Understanding the spatial distribution of soils where crop growth and responsiveness to applied N may be constrained in wet or dry years will allow growers and advisors to refine N-management strategies. To identify soils where crop growth and responsiveness to applied N may be restricted, a system of grouping soils that better reflected agronomic performance under different climatic conditions was required. The categorisation system considered position in the landscape, N-mineralisation potential, soil water-holding capacity in both wet and dry years, propensity to waterlog in wet years and presence of a water table in wet years. In dry years, waterlogging and the presence of a water table do not impact crop growth to the same extent as moisture availability, and, hence, in dry years, it is more important to categorise soils based on water-holding capacity. The major sugarcane-growing soils in the Tully and South Johnstone mill areas were categorised using this system. This resulted in five soil groups to describe the impact on crop growth and N responsiveness in wet and dry years. Given the application of N fertiliser to ratoon crops predominately occurs around spring, wet years were defined as receiving high spring-summer rainfall, whereas dry years were defined as receiving low spring-summer rainfall. Classifying wet and dry years according to spring-summer rainfall also allows growers and advisors to refer to seasonal climate forecasting indices for guidance on the likelihood of experiencing a wet or dry year. In wet years, the impact on crop growth, responsiveness to applied N and potential for lower N uptake is greatest for soil group five. These soils tend to occur in the lowest positions in the landscape, experience severe waterlogging and a persistent water table. They are also subject to frequent water inundation following extreme rainfall events. The spatial identification of soil constraints will complement the development of whole-of-farm nutrient-management plans in the Wet Tropics region. Knowledge of soil constraints influencing sugarcane growth and responsiveness to N will allow growers and advisors to better identify areas where nutrient-management strategies may require further fine-tuning. This information may also be of value in improving other management decisions including varietal selection and harvest scheduling.

Key words Sugarcane soils, nitrogen, waterlogging, Tully, Johnstone

INTRODUCTION

The Wet Tropics region experiences one of the highest levels of rainfall and climate variability in the world (Nicholls *et al.* 1997). The impact of different climatic conditions on crop growth and yields (Kuhnel 1994; Everingham *et al.* 2001a, 2003; Salter and Schroeder 2012; Garside *et al.* 2014; Stringer *et al.* 2019) is well documented. Climate impacts on nutrient losses (Webster *et al.* 2009; Allen *et al.* 2010) and management decisions, including how much nitrogen (N) fertiliser to apply (Everingham *et al.* 2018; Schroeder *et al.* 2018), as well as commencement of the harvest season (Everingham *et al.* 2001b; Osborne *et al.* 2011). Spring-summer (September to March) rainfall has a strong influence on Tully cane yields (Skocaj and Everingham 2014). Sugarcane yields are significantly lower in years experiencing high-spring summer rainfall (Stringer *et al.* 2019), largely due to reduced solar radiation and excessive soil wetness through prolonged waterlogging, persistent shallow water tables and water inundation from flood events. It is also likely that in these years, responsiveness to applied N may also be limited due to poor crop growth and potentially higher N losses. However, soil type and position in the landscape also influences the degree of soil wetness, nutrient requirements (primarily N) and nutrient loss pathways. Grouping soils with similar agronomic performance under different climatic conditions would better identify these interconnected relationships.

Soil surveys have traditionally grouped soils according to their parent material. This helps with identifying distinguishing features among soil groups attributable to soil formation (e.g. well-drained versus poorly drained soils formed on alluvium). However, sometimes there are differences in how soil surveyors allocated soils according to parent material (e.g. Banyan series soil is a poorly drained soil formed on alluvium according to Murtha (1986) but Cannon *et al.* (1992) classified it as being of acid igneous rock origin). The agronomic behaviour of soils with the same parent material may also be quite different. For example, Murtha (1986) and Cannon *et al.* (1992) identified up to 10 poorly drained soils of alluvial origin. These soils occur in different positions across the landscape. Some are found on floodplains (e.g. Coom) and others on minor floodplain depressions and swamps (e.g. Bulgun and Timara series), whereas some occur on major floodplain depressions and swamps (e.g. Hewitt series). Position in the landscape has a major influence on soil wetness as soils occurring on major floodplain depressions and swamps will remain persistently wetter for longer than soils occurring on the floodplain, which are more likely to experience seasonal inundation. Grouping soils according to parent material does not recognise these differences.

A system of grouping soils that better reflects agronomic performance under different climatic conditions will help identify productivity and potential N response constraints related to soil type for wet and dry years. Understanding which soils are morphologically similar but behave differently between wet and dry years may allow the industry to make more informed nutrient, pesticide and harvest management decisions. This paper provides additional detail on the soil grouping methodology initially highlighted by Skocaj *et al.* (2017) and the results of extending the methodology to include the South Johnstone mill supply area.

MATERIAL AND METHODS

We used four key stages to categorise major soils with similar agronomic performance under different climatic conditions. The stages encouraged identification of useful resources and major soils, categorisation of distinguishing soil features and development of meaningful agronomical soil groups.

Stage 1 – Collate relevant datasets

Information was sourced from soil surveys conducted by Murtha (1986) and Cannon *et al.* (1992), the agricultural land-use suitability assessment completed by Murtha and Smith (1994), the SIX EASY STEPS soil reference booklet for the Johnstone catchment produced by Schroeder *et al.* (2007) and expert local option.

Stage 2 – Identify major soils

Soil surveys conducted by Murtha (1986) and Cannon *et al.* (1992) identified up to 70 soil series in the Tully-Innisfail and Cardwell-Tully areas. Sugarcane is not grown on all the soils described by Murtha (1986) and Cannon *et al.* (1992). However, in the Tully mill area, for example, sugarcane is grown on 53 different soils. Our analysis focused on only the major sugarcane growing soils. We identified these using cane block and soil survey geographic information system (GIS) layers and defined them as occupying more than 1% of a mill area.

Stage 3 – Categorise distinguishing soil features

Given the importance of spring-summer rainfall on sugarcane growth in the Wet Tropics, the water-holding capacity, propensity to waterlog and presence of a water table for the major soils were qualitatively assessed for wet and dry years using available resources and expert local knowledge. The soil N mineralisation potential (based on soil organic carbon content), chemical and physical properties, including position in the landscape, were also considered.

We used five categories describe the water-holding capacity and propensity to waterlog for the major soils: very low, low, moderate, high or very high. The presence of a water table was described as being "not applicable", "periodic" (water table is quick to recede), "prolonged" (water table is slow to recede) or "persistent" (water table is present most of the time).

The soil organic carbon (%) values for soil tests taken from the SIX EASY STEPS reference sites (Schroeder *et al.* 2007), previous nitrogen response experiments (Schroeder *et al.* 2009; Hurney and Schroeder 2012; Skocaj *et al.* 2012; Skocaj 2015) and knowledge of soil test results from commercial sugarcane blocks were used to determine the N mineralisation category of the major soils. The N mineralisation categories used were based on those included in the SIX EASY STEPS nutrient management program (Schroeder and Wood 2001; Schroeder *et al.* 2005) that uses soil organic carbon (%). It was also another way of checking the soil groups were sensible, as the organic carbon (%) value of a soil is also related to soil colour and position in the landscape (Bruce 2000; Schroeder 2000).

The agricultural land-use suitability assessment completed by Murtha and Smith (1994) was then reviewed to see if information provided on soil water supply and soil wetness could be used to further refine the soil groupings. The soil water supply categories did not accurately reflect differences in the performance of well-drained and poorly-drained alluvial soils under different climatic conditions. However, the wetness categories, which to some extent consider the soils position in the landscape, helped verify the soil groups. The wetness categories used by Murtha and Smith (1994) to identify limitation classes for growing sugarcane were: Class 1 – suitable with few or no limitations; Class 2 – suitable with moderate limitations; Class 3 – suitable with significant limitations; Class 4 – marginal land, currently unsuitable with severe limitations (N/A); and Class 5 – unsuitable land with extreme limitations (N/A).

Information from soil surveys (Cannon *et al.* 1992; Murtha 1986) on soil texture, colour, particle size distribution, bulk density and soil-moisture parameters was not available for all of the major soils (e.g. Silkwood series). Information on particle size for some of the major soils differed among surveys because of differences in the reference site locations. Despite this, information from soil surveys is extremely useful in helping to identify differences in potential N loss pathways between the major soils.

Stage 4 – Develop agronomical soil groups for wet and dry years

The final soil groups were developed on the water-holding capacity, propensity to waterlog, presence of a water table, N-mineralization potential and position in the landscape. Given the importance of spring-summer rainfall, we classified major soils into groups for wet and dry years. Following Skocaj *et al.* (2015), wet years were defined as receiving more than 2200 mm of rainfall from October to March and dry years less than 1500 mm of rainfall from October to March.

In wet years, soil groups were based on water-holding capacity, propensity to waterlog and presence of a water table. In dry years, waterlogging and the presence of a water table do not impact crop growth (Rudd and Chardon 1977) to the same extent as moisture availability, hence it was more important to rate the major soils according to water-holding capacity for dry years.

RESULTS AND DISCUSSION

The major sugarcane growing soils occupying more than 1% of the Tully and South Johnstone mill supply areas and the associated soil formation groups are shown in Figure 1. Collectively, these major soils represented approximately 88% of the Tully and 92% of the South Johnstone mill supply areas in 2017.

Traditionally, these soils would have been grouped on formation and parent material. For example, well-drained soils of alluvial origin include the Innisfail, Liverpool, Mossman, Silkwood and Tully series, whereas the poorly drained soils of alluvial origin include Bulgun, Coom, Hewitt, Ramleh, Warrami and Timara series. The major sugarcane-growing soils in the Tully and South Johnstone mill supply areas based on soil formation are grouped as well drained or poorly drained soils of alluvial origin, soils of acid igneous or metamorphic rock origin, basaltic soils, soils formed on beach ridges and soils of the swamp and tidal zone (Murtha 1986; Cannon *et al.* 1992).

We note that in the Tully mill area, there are no major soils of basaltic origin (e.g. Pin Gin, Eubenangee, Mundoo, Garrandunga), metamorphic rock origin (e.g. Galmara) or the swamp and tidal zone (e.g. Babinda). However, there are minor soils of metamorphic rock origin and swamp and tidal zone where sugarcane is grown.

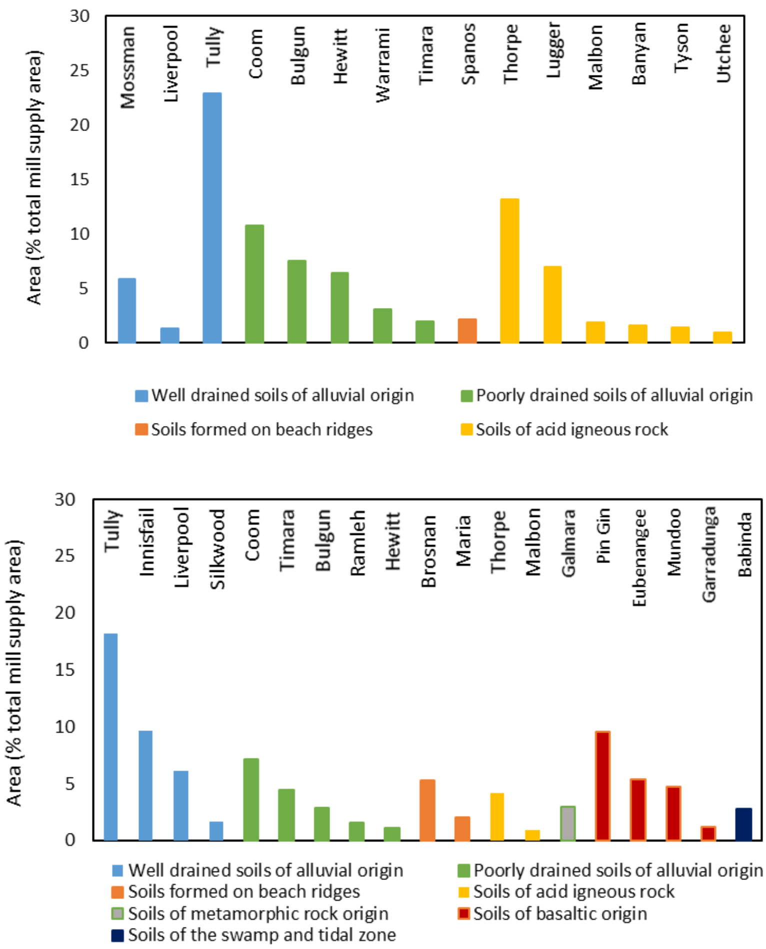

Figure 1. Major series soils for the Tully (top) and South Johnstone (bottom) 2017 mill supply areas colour coded according to soil formation (taken from Murtha 1986).

The major soils were classified into five soil groups based on the water-holding capacity, propensity to waterlog and presence of a water table in both wet (Table 1) and dry (Table 2) years.

Use of parameters such as soil texture, colour, particle size distribution, bulk density and soil moisture were initially investigated as methods of grouping soils. Although they did not produce sensible results, they were useful in determining water holding capacity, propensity to waterlog and N mineralisation potential. These concepts, when used in combination with position in the landscape, became useful in identifying possible nutrient loss pathways.

Unlike traditional soil formation groupings, the groups shown in Tables 1 and 2 contained soils of different parent material. For example, in wet years, soil group four contains well-drained soils of alluvial origin, poorly drained soils of alluvial origin and soils of acid igneous rock. This is because soils with different parent material can be morphologically similar and found in similar positions in the landscape.

The spatial distributions of the soil groups for wet and dry years in the Tully and South Johnstone mill-supply areas are shown in Figures 2 and 3, respectively. In wet years, the impact on crop growth, responsiveness to N and potential for environmental losses of N is greatest for soil group five. These soils tend to occur in the lowest positions in the landscape, experience severe waterlogging and have a persistent water table. They are also subject to frequent water inundation following extreme rainfall events. Responsiveness to applied N is likely to be limited in wet years due to poor crop growth and increased potential for N losses primarily via denitrification reducing N uptake and the ability of the crop to produce biomass. However, responsiveness to applied N may be limited in other soil groups if conditions are conducive to N losses (the N loss pathway is likely to differ between soil groups). For example, in wet years for soil group 1, N may be more susceptible to leaching losses if rainfall occurs too soon after application of N fertiliser.

Table 1. Wet-year (high spring-summer rainfall) groupings for the major soils occurring in the Tully and South Johnstone mill supply areas and associated water-holding capacity, waterlogging severity and water-table ratings.

Wet-year soil group	Soil series	Water-holding capacity wet year	Waterlogging severity	Water-table presence	Position in the landscape
1	Brosnan	L	V	n/a	Beach ridges
	Utchee	L	VL	n/a	Low hills and mountains
	Pin gin	M-L	VL	n/a	Strongly undulating to low hills
	Galmara	M-L	VL	n/a	Low to high hills
	Maria	M-L	L	Prolonged	Reworked beach ridges
	Spanos	M	VL	n/a	Beach ridges
	Eubenangee	M	L	n/a	Gently undulating flow surfaces and foot slopes
	Garradunga	M	L	n/a	Alluvial plain
2	Tyson	M	VL	n/a	Upper slope colluvial fan
	Mundoo	M-H	L	n/a	Gently undulating alluvial fan
	Innisfail	M-H	L	n/a	Stream levees / floodplain
	Silkwood	M-H	M-L	Periodic - n/a	Prior stream levees / lower rises
	Liverpool	H	M-L	Periodic	Lower terraces
3	Thorpe	H	M-L	Periodic	Mid slope colluvial fan
	Tully	H	M-L	Periodic	Stream levees / floodplain
4	Lugger	H	M-H	Prolonged	Lower slope colluvial fan
	Malbon	H	M-H	Prolonged	Mid to lower slopes low angle colluvial fans
	Banyan	H	M-H	Prolonged	Swamps and drainage depressions low angle colluvial fan
	Ramleh	H-VH	H-VH	Prolonged	Alluvial plain
	Mossman	H-VH	H-VH	Prolonged	Stream levees / floodplain
	Coom	H-VH	H-VH	Prolonged	Floodplain
	Bulgun	VH	H-VH	Prolonged	Minor depressions floodplain
5	Timara	VH	VH	Persistent	Minor depression floodplain
	Warrami	VH	VH	Persistent	Lower slope alluvial plain
	Hewitt	VH	VH	Persistent	Major depressions / swamps
	Babinda	VH	VH	Persistent	Swamps

Table 2. Dry-year (low spring-summer rainfall) groupings for the major soils occurring in the Tully and South Johnstone mill supply areas and associated water holding capacity ratings.

Dry-year soil group	Soil series	Water-holding capacity dry year	Position in the Landscape
1	Babinda	H	Swamps
	Hewitt	M-H	Major depressions / swamps
2	Eubenangee	M	Gently undulating flow surfaces and foot slopes
	Innisfail	M	Stream levees / floodplain
	Tully	M	Stream levees / floodplain
	Mossman	M	Stream levees / floodplain
	Coom	M	Floodplain
	Bulgun	M	Minor depressions floodplain
	Timara	M	Minor depressions floodplain
3	Galmara	M	Low to high hills
	Ramleh	M	Alluvial plain
	Banyan	M-L	Swamps and drainage depression low angle colluvial fan
	Liverpool	M-L	Lower terraces
	Lugger	M-L	Lower slope colluvial fan
	Malbon	M-L	Mid to lower slope low angle colluvial fan
	Garradunga	M-L	Alluvial plain
	Mundoo	M-L	Gently undulating alluvial fan
	Thorpe	L	Mid slope colluvial fan
	Warrami	L	Lower slope alluvial plain
4	Maria	L	Reworked beach ridges
	Pin gin	L	Strongly undulating to low hills
	Silkwood	L	Prior stream levees / low rises
	Tyson	VL	Upper slop colluvial fan
	Spanos	VL	Beach ridges
	Utchee	VL	Low hills and mountains
5	Brosnan	VL	Beach ridges

DISCUSSION

In dry years, crop growth and responsiveness to applied N is most restricted in soil group five. A key difference in the dry-year soil groupings between the Tully and South Johnstone mill supply areas is the Brosnan series soil. Positioned on beach ridges, the Brosnan series soil, most prevalent around Mourilyan (and locally referred to as the Mourilyan sand), exhibits extreme moisture stress in dry years. Crop growth may also be restricted in soil group four in dry years, but it is unlikely that crops growing on soils in this group will exhibit as severe moisture stress. In these situations, management strategies may include delaying fertiliser application until the crop is actively growing and there is sufficient soil moisture, split application or trialing lower N rates in comparison to the SIX EASY STEPS N rate.

Management strategies to improve nitrogen use efficiency (NUE) are likely to differ among soil groups and between wet and dry years. However, all these practices will focus on trying to better match N supply to crop demand (e.g. application timing and rate), protecting N from environmental losses (e.g. use of enhanced efficiency fertilisers, split application) and improving crop growth (e.g. adequate drainage, mounding, correct variety selection, carefully considering time of harvest).

It is important to remember there are often subtle differences within series soils (e.g. differences in Tully series soils at different locations), codominant and subdominant series associations (e.g. Tully-Coom series) that represent the complexities around soil formation and uncertainty around the mapping unit scale. This adds another level of complexity to using the soil grouping system reported in this paper. Maps of soil surveys label codominant soil associations whereas subdominant series information is only reported in the soil survey GIS layers. Differences within a series are often noticed in soil test results and can be caused by a range of factors, including natural soil formation process, different management histories and codominant soil occurrence. In addition, there is often more than one soil encountered at the block scale, sometimes these soils may occur in different soil groups (as shown in the insert of Figure 2) and accurately identifying soil boundary changes at the block scale is affected by the resolution of the soil surveys (1:50,000). Therefore, when considering block specific nutrient management refinements, it will be important to consider, not only which soil will most constrain productivity and N responsiveness, but also the proportion of area within the block, soils in adjacent blocks and other limiting factors.

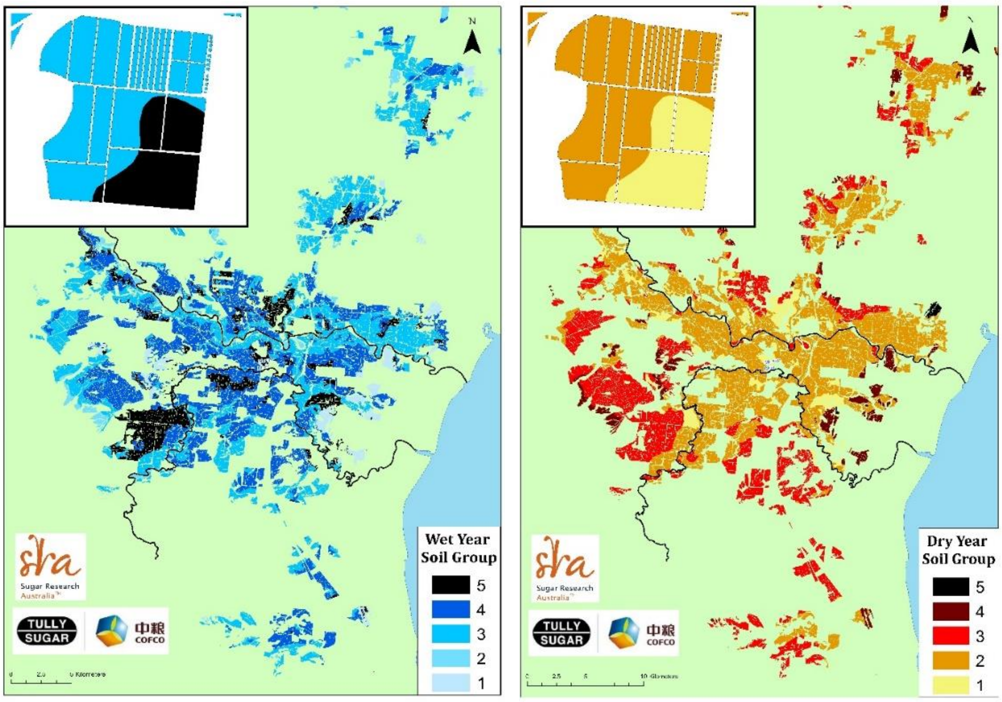

***Figure 2**.* Spatial distribution of soil-constraint categories clipped to the 2018 cane block layer for wet years (high spring-summer rainfall) on the left and dry years (low spring-summer rainfall) on the right for the Tully mill area. The Tully SRA farm, inserted in the top left corner, provides an example of how growers and advisors could use this information at a finer spatial resolution.

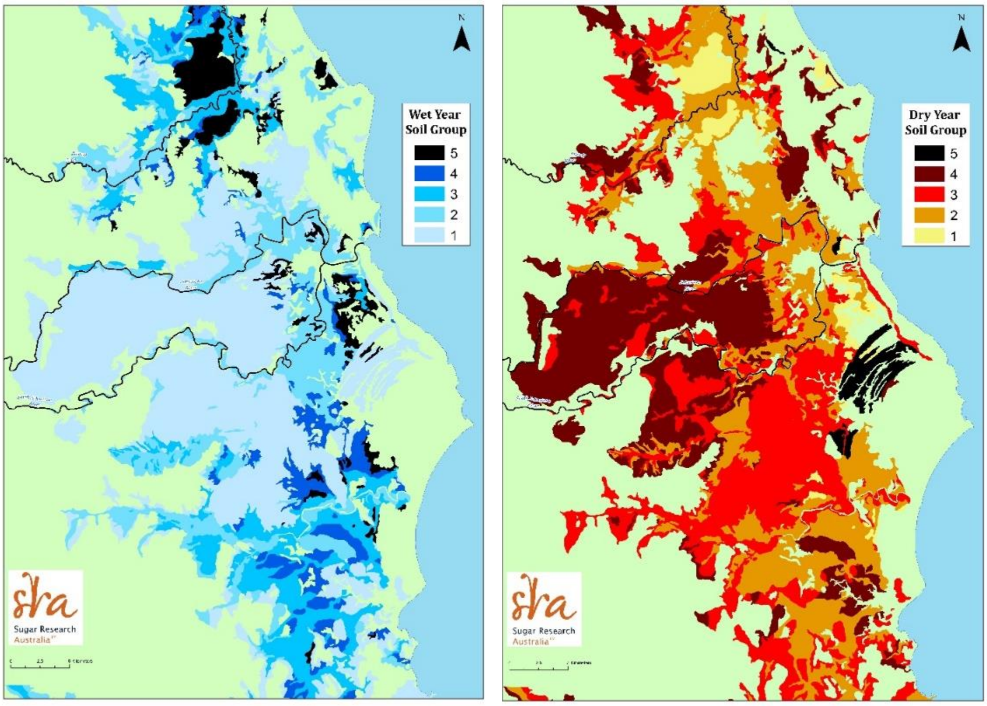

Figure 3. Spatial distribution of likely soil-constraint categories for wet years (high spring-summer rainfall) on the left and dry years (low spring-summer rainfall) on the right for the South Johnstone supply area. As the maps are not clipped to the sugarcane production area, the spatial distribution covers the entire soil survey area from approximately Silkwood to Babinda.

Spatial representation of these soil groups and knowledge of key limitations in wet or dry years is an extremely useful resource, which will complement the development of whole-of-farm nutrient-management plans in the Wet Tropics. It will also become a useful addition to the SIX EASY STEPS Toolbox. Knowledge of soil differences for sugarcane growth, responsiveness to N and potential for N losses will allow growers and advisors to better identify areas where nutrient management strategies may require further fine-tuning. For instance, in the Wet Tropics, in wet years, for soils in group five, it may be appropriate to reduce N application rates, consider split application of N fertiliser or trial alternative N products (e.g. enhanced efficiency fertilisers instead of normal urea). In addition, if not already completed, improvements to surface and subsurface drainage may become a key priority when the block is next fallowed and ensuring the block is harvested early in the season. These strategies may also vary spatially within a mill area due to spatial and temporal climate variability (Sexton *et al.* 2017). For example, in a wet year, crop growth and N responsiveness for soil group five is likely to be more constrained in the wetter northern climate zone of Tully than the drier southern climate zone.

Further refinements to the soil groupings may be possible following wider industry consultation, reviewing additional soil testing information and completing productivity analyses. A sufficient time series of productivity data referenced against dominant soil type is required before suitably validating yield differences for these soil groups in wet and dry years. For instance, the Tully block-productivity database has only recently included soil type information and the constituent years have generally been limited to normal to dry climatic conditions. Validating the soil groups against productivity data may allow further refinement of soil groups for wet and dry years into the future and generate new information on variety suitability to specific soils.

Future work includes matching the soil groupings to the cane block layer for the South Johnstone mill supply area. This would greatly enhance the spatial representation of soil groups in this region. The ability for growers and advisors to use GIS software to view soil groupings at a finer spatial resolution (e.g., farm and block scale) and produce individual map layers would greatly assist whole-of-farm nutrient management planning and other decision-making processes (e.g. varietal selection, harvest scheduling). As part of the Major Integrated Project (MIP) in the South Johnstone basin, reference to these soil groups is helping highlight opportunities for block-specific nutrient-management refinements.

CONCLUSIONS

The development of meaningful agronomic soil groups for wet and dry years and spatial representation of these groups is an extremely useful resource for the development of whole-of-farm nutrient-management plans. Knowledge of sugarcane growth, responsiveness to applied N and potential N loss pathway differences among soil groups will allow growers and advisors to better identify areas where nutrient-management strategies may require fine-tuning. These soil groups linked with productivity databases, will also be useful for investigating differences in productivity and variety performances among seasons (e.g. wet vs dry) and among soils (e.g. soil group one versus five). Making these maps available to growers, millers and advisory staff will facilitate wider industry consultation and allow further refinements to then be incorporated into these soil groups. This framework can be easily modified and applied to other sugarcane growing regions.

ACKNOLWEDGEMENTS

This work was funded by Sugar Research Australia Limited and the Queensland Department of Environment and Science. We are grateful to Tully Sugar Limited and MSF Sugar for kindly providing access to information allowing the identification of major soils within the Tully and South Johnstone mill supply areas.

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