SUPPORTING SUSTAINABLE DEVELOPMENT - RISKS AND IMPACTS OF PLANT INDUSTRIES ON SOIL CONDITION

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CONTENTS

1 SUMMARY

Currently, plant industry practices have little overall effect on the condition of the soil in the Northern Territory (NT), except in localised areas. However, climatic and soil characteristics of commonly used soils by plant industries in the NT suggest high risks of erosion, loss of carbon, surface crusting and sealing, soil acidification and off-target movement of soil nutrients, but low risk of salinisation.

Soil erosion is locally significant in the NT. There is considerable risk of water erosion in the Top End on uncovered soils due to intensity of rainfall and poorly structured soils. Wind erosion is less significant but still generally important, as current plant industry practices contribute little to accelerate it. Much work has been done on the mechanisms and processes of soil erosion and mitigation strategies in the NT. Further work is needed in this area, particularly in extension, to ensure the adoption of available technology to control both wind and water erosion.

Soil acidification has been detected in the NT. It is recognised as a risk in the semi-arid tropics, but little work has been done on it in the NT. Acidification can occur when cultivating specific species, especially legumes. The use of fertiliser may also lead to acidification. More work is needed to assess the extent of the problem and to develop ways to tackle it if it is significant.

NT soils are low in organic carbon and rapidly lose it when cultivated. There is, however, little information on the effect of plant industry practices on carbon levels in the soil, which requires further investigation.

Salinisation resulting from clearing of native vegetation is unlikely in the NT because of the characteristics of both our tropical areas (where leaching rains occur every year) and arid areas (where there is no risk of ground water rising as existing vegetation uses little water). There is some risk of soil salinisation due to the use of saline irrigation water, especially in Central Australia. Although this is not an issue at present, it should be monitored over time.

Crusting or surface sealing of soils is common in the NT, particularly in the Top End, which is related to the breakdown of the already limited structure of surface soils in the region after the removal of vegetation and/or cultivation. Crusting can be very detrimental to the emergence of seedlings in crops. It can be mitigated by frequent shallow cultivation or, more preferably, by retaining stubble and using minimum-till techniques.

Off-target nutrient movement, especially downward movement of nutrients beyond the root zone of desirable plants, is probable in the NT due to the light and well-drained soils being used by many plant industries. A limited amount of work has been completed on measuring such off-target nutrient movement. However, more research is needed, particularly in horticultural crops. Methods to reduce the problem, including the use of deep-rooted cover crops to harvest any deep nutrients in the soil, also need further investigation.

2 INTRODUCTION

The Northern Australia Land and Water Taskforce (Anonymous 2009) published a report on sustainable development of northern Australia, which states that rapid large-scale development in northern Australia can significantly affect social communities and that all potential impacts need to be rigorously assessed prior to development. Mosaic agriculture was also identified by this report as a form particularly applicable to the north, due to its relatively small geographical and environmental footprint. In relation to the soil, the report highlights the need to collate existing data and to collect new detailed information to support sustainable development. It also identifies risks of potential impacts on the soil, especially from plant industry activities. These activities will be identified and assessed in this Technical Bulletin and ways to minimise their effects will be explored. Plant industries in this Technical Bulletin, include any cropping, forestry or horticultural activities where the output of the enterprise is derived from terrestrial plants and is consumed or used by humans or domestic animals. Therefore, forages and improved pastures are included, but native pasture management is excluded.

This Technical Bulletin will address each of the practices in turn, reviewing available data on its probable impact on NT soils.

Figure 1. Cultivation can have both positive and negative effects on soil health

First, an overview is given of rainfall patterns and existing soil resources used by plant industries, since they affect degradation of the soils.

3 RAINFALL PATTERNS IN THE NT

The early wet season in the Top End (defined as all land of latitude north of Mataranka, which includes Darwin, Katherine, Douglas-Daly and Arnhem Land) is characterised by isolated convective thunderstorms, but most of the rain falls during the monsoon from late December to early March, often associated with tropical lows or cyclones (Dilshad 2007). Virtually no rainfall occurs in the dry season from May to September in most years. In Central Australia, rains can come from the tail end of northern monsoonal systems or cyclones, or the northern extensions of westward moving weather patterns that dominate southern Australia. Monthly average rainfall is therefore evenly distributed throughout the year, although the highest average monthly rainfalls are typically in the summer months (Smith 2008). Mean annual rainfall decreases in a steady gradient from over 2000 mm annually in the north to less than 500 mm in Central Australia (Smith 2008). Subsequently, there is more risk of water erosion in northern compared with Central Australia. However, rainfall variability is greater in Central Australia, leading to times when water erosion is a significant risk.

Figure 2. Monsoon activity brings heavy showers to Top End croplands from January to March (photo courtesy Greg Owens)

4 SOIL RESOURCES IN THE NT SUITABLE FOR PLANT INDUSTRIES

The NT lacks extensive areas of uniform soil types, few of which are considered suitable for plant industries. Most soils are highly erodible, have poor natural fertility and low water holding capacity. Surface textures range from sands to clay loams and vary from massive red, yellow and grey earths (Kandosols) to shallow ironstone gravels (Rudosols) and yellow lateritic podzolics (Chromosols). A common feature of most soils is a massive structure consisting of kaolinite clay and iron oxides (O'Gara 2010).

Soils of the Top End, with the exception of the coastal floodplains, are generally earthy, highly leached and low in soil carbon and fertility. Carbon levels are naturally low because these lightly-textured soils are oxidised during the long annual dry periods. This makes them inherently susceptible to erosion, independent of other landscape and land management factors. The leaching, low fertility and high permeability, not only decrease inherent salinity, but also increase the leaching and lateral movement of nitrates and phosphates. These same properties can also make soils susceptible to acidification because of the potential loss of basic cations.

The risk of irrigation salinity outside the coastal floodplains is generally restricted to the arid zone. Arid soils are inherently higher in natural salinity and, combined with slightly saline irrigation water, can potentially lead to soil salinity problems.

Figure 3 shows the location of soils used for plant industries in the NT. Table 1 shows a general range of soils used by plant industries in the NT. Although not fully comprehensive, the table covers the majority of soils shown in Figure 3.

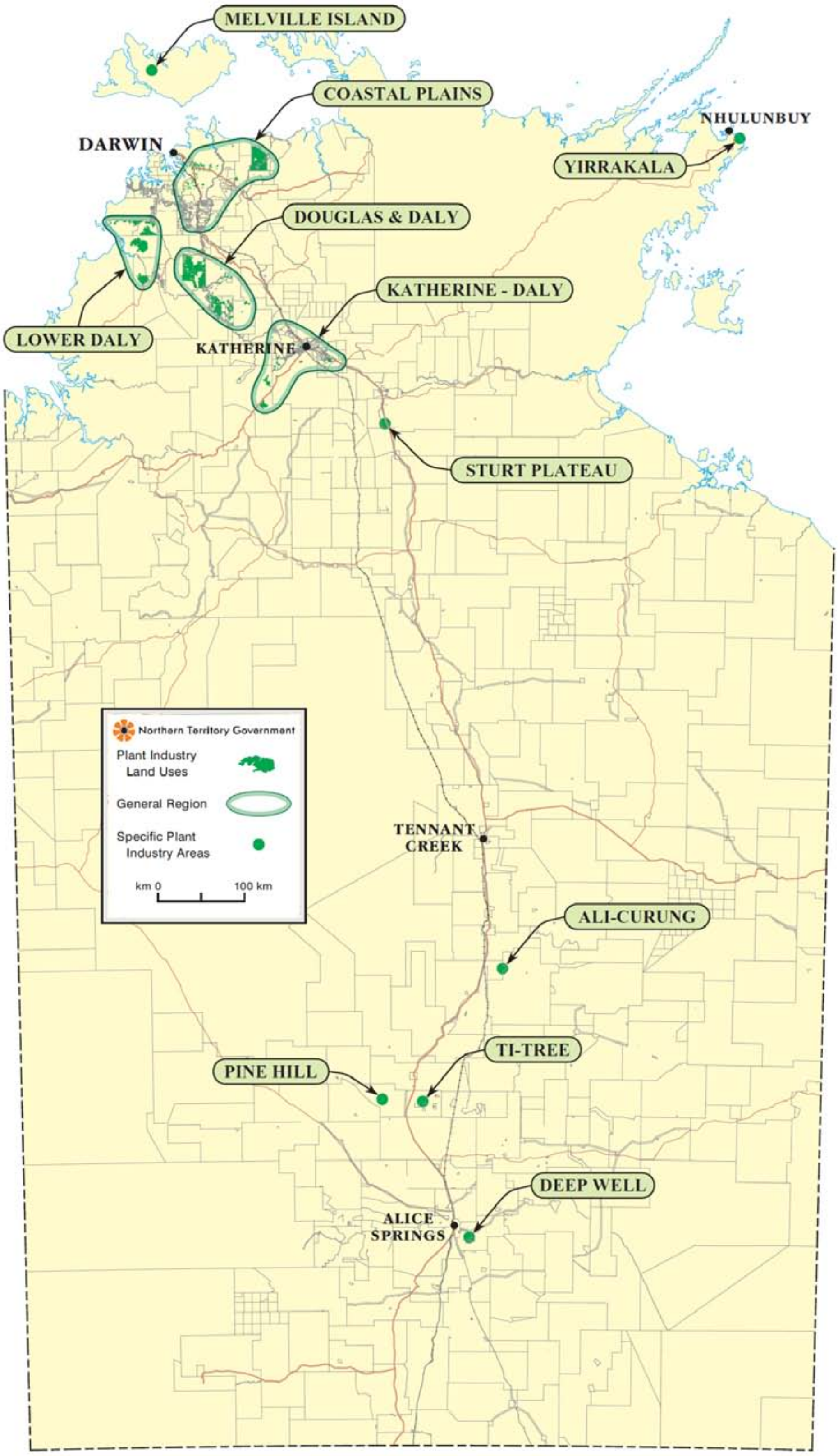

Figure 3. Plant industry land uses across the Northern Territory highlighting general regions and specific areas (Berghout et al. 2008)

Table 1. A general list of soils used by plant industries in the NT

Soil	Characteristics	Potential negative environmental impact	Geographical area	Plant industry land use
Deep red lateritic Kandosols (Berrimah soils).	Sandy and highly permeable; low fertility; increasing gravel at depth.	Prone to erosion if disturbed and possibly acidification under intense prolonged agricultural land use.	Coastal plains of the Top End, Yirrkala and Tiwi Islands.	Tropical fruits and vegetables, hay.
Deep sandy red Kandosols (Blain soils).	Highly siliceous at the surface; earthy; increases to loams at depth; low fertility; moderately acid; low water holding capacity.	Prone to erosion if disturbed; rapid solute movement; possibly prone to acidification under intense prolonged agricultural land uses.	Katherine, Douglas / Daly and Sturt Plateau.	Peanut, hay, timber, woodchips, melons and tropical fruits.
Deep loamy red Kandosols (Oolloo soils).	Light sandy loam grading to clay at depth; earthy; low fertility; slightly to moderately acid; higher water holding capacity than Blain soils.	Prone to erosion if disturbed; moderate solute movement; possibly prone to acidification under intense prolonged agricultural land uses.	Katherine and Douglas / Daly regions.	Peanuts, hay, timber, woodchips, melons and tropical fruits.
Deep clayey red Kandosols (Tippera soils).	Clay loams grading to clays at depth; earthy; slightly acid; higher water-holding capacity than Oolloo soils.	Erosion risk if disturbed; moderate solute movement.	Katherine and Douglas / Daly regions.	Peanuts, hay, timber, woodchips, melons and tropical fruits.
Deep clayey red Dermosols (Tindal soils).	Clays grading to structured heavy clays at depth; neutral to slightly alkaline; higher water holding capacity than Tippera soils.	Erosion risk if disturbed; slow solute movement.	Katherine and Douglas / Daly regions.	Peanuts, hay, timber, woodchips, melons and tropical fruits.
Shallow brown sandy soils over gravel (Koopinyah soils).	Loamy sand surfaces over light sandy clay loams; weathered material at shallow depths.	Prone to erosion if disturbed; rapid solute movement.	Coastal plains of Darwin and Marrakai.	Tropical vegetables.
Hydrosols (poorly-drained duplex clay soils on floodplains) (Marrakai soils).	Silty solodic soils of floodplains; sometimes with clear and abrupt texture increase; annually-flooded; possible highly sodic at depth; heavy clay subsoil.	Erodible if disturbed due to annual flooding and silty nature of soils; dispersive due to possible sodicity.	Upper floodplains of the Mary and Adelaide rivers.	Hay and melons.
Poorly-drained grey cracking clays (Aquic Vertosols) on coastal floodplains.	Relatively fertile compared with upland soils; poorly to very poorly drained; higher levels of soil carbon.	High natural soil salinity; potential loss of soil carbon; acid sulphate soil risk.	Top End coastal floodplains and lower Keep River.	Minor forages.
Deep sandy red Kandosols and Tenosols in the arid zone (arid red earths).	Highly siliceous; earthy; sand increasing to loams at depth (although sometimes remain sandy throughout); low fertility; neutral pH; low water-holding capacity.	Subject to wind and water erosion; vineyard soils prone to surface soil compaction; prone to surface soil pH and salinity increases due to irrigation.	Ti-Tree, Alice Springs, Ali Curung, Pine Hill.	Grapes and melons at Ti Tree, melons at Ali Curung, dates around Alice Springs.

Figure 4. A profile of a Blain soil (deep sandy red Kandosol) - very important for peanuts, hay, timber, woodchips, melons and tropical fruits in the NT

5 SOIL CONDITION INDICATORS AND POTENTIAL NEGATIVE IMPACTS

5.1 INTRODUCTION

At present the impact of plant industry practices on soils across the NT is small and localised due to the small size of plant industry activities. The area of land utilised for plant industries covers approximately 60 000 ha out of a total area of 134 912 900 ha, 0.01% of the NT. However, plant industries can alter the soil's physical, chemical and biological conditions.

Published information on the impacts of plant industries on soil condition is reviewed. The National Land and Water Resource Audit (www.nlwra.gov.au) specified four main soil condition indicators to measure general soil health. They are soil acidification, soil carbon status, water erosion and wind erosion. In addition to these nationally set indicators, this Technical Bulletin includes soil salinisation, soil surface crusting and sealing, and off-target nutrient movement.

Soil studies in the NT have generally not targeted soil condition indicators, but 40 years of soil data collection has built a significant knowledge of soil-landscapes and the way they behave under different land use pressures. Initially, soil studies were undertaken to assess agricultural capability and pastoral development; but more recently, soil investigation and mapping have increasingly focused on catchment management to protect against potential detrimental offsite impacts of development. Although soil data is limited to some regions of the NT and has generally not targeted potential detrimental impacts of plant industries, soil-landscape information collected since the 1960s can indicate the potential impacts of particular land uses on soil-landscapes.

5.2 WATER EROSION

5.2.1 Introduction

An extensive number of land unit and soil survey reports published in the NT and other studies, including the recently-published soil and land resource study of northern Australia (Anonymous 2011) and modelling work (Dilshad 2007), indicate that most NT soil-landscapes are prone to water erosion if disturbed. Soil erosion has been reported as endemic on some NT soils, even on slopes of less than 1% (Dilshad and Jonauskas 1992). Almost all reports highlight water erosion as an important land management issue for northern Australia.

5.2.2 The mechanism of water erosion

The main cause of natural and accelerated soil erosion in the NT, especially in the Top End, is through water erosion. Water erosion occurs when energy from the impact of rain or overland flow breaks up and transports soil (Richards 1978).

Water erosion of soil progresses as soil particles detached by incident rainfall move by shallow flow to small channels or rills. Water may then move preferentially to depressions in the soil surface, such as wheel ruts (Richards 1978). Rill erosion can then occur by soil detachment of the walls and floor of the rills by concentrated runoff (Lal 1985). Erosion is exacerbated by increasing slope length and slope angle, and gullies may form that branch and extend upstream into their catchments (Richards 1978).

5.2.3 Soil erodibility

How easily a particular soil type erodes is called its erodibility. The erodibility of a soil depends on inherent soil characteristics, such as structural stability and infiltration rate (Dilshad 2007). The greater the structural stability of a soil, the greater is its resistance to being broken down by raindrop splash and overland flow. In addition, if it has a high infiltration rate, more water can percolate in the soil per unit time, which minimises shallow surface flow.

Arable NT soils are generally earthy and lightly-textured, therefore highly erodible in their natural state and even more so when their protective vegetative cover is removed (Motha et al. 1995).

5.2.4 Rainfall erosivity

Rainfall erosivity is a measure of the ability of a rainfall to cause erosion based on its energy. It has been mapped for Australia (McFarland and Clinnick 1984). Not surprisingly, rainfall erosivity is high in tropical areas. Erosivity over a 30-minute duration (EI_{30}, tonne-metre/ha/hour) for north west Australia ranges from 300 to above 750 tonne-metre/ha/hour, due to high-intensity storms in the wet season, which run from November to March (Dilshad et al. 1996b).

Figure 5. Wet season storms in the NT are highly erosive

5.2.5 Current status of water erosion in the Top End

The reconnaissance survey of soil erosion in Australia conducted in 1989-90 gives an indirect measurement of the amount of water erosion on some cropping sites in the Top End of the NT (Elliott et al. 2002). Of 16 sites sampled in the NT, 14 were from rangeland grazing and two from cropping sites in the Douglas-Daly region. The two from cropping sites were most affected by water erosion. This work was based on a technique utilising the characteristics of the fallout and soil adsorption of the radio-active isotope Caesium (^{137}Cs) after nuclear tests in the 1950s. In stable sites, ^{137}Cs is only lost to decay (half life of 30.2 years), but in eroded sites, it is lost by both decay and soil erosion, and it accumulates in areas of deposition. Erosion and deposition can therefore, be calculated by the measured ^{137}Cs in soil.

On cropping sites, there was substantial soil loss just below the hill crests and deposition at the foot of the slopes (Elliott et al. 2002). Table 2 is a summary of results from this study, which shows the soil erosion rate on soils subjected to cropping on slopes of between 2 to 3% per year to be between 2.28 and 6.46 t/ha/year. If soil formation rates are approximately 0.5 t/ha/year, then the rates of loss would be unsustainable (Elliott et al. 2002). It should be noted that on at least one of those sites, soil conservation techniques were not used in the first cropping cycle, but rather after the potential loss was realised in the first season, when soil conservation techniques were adopted over the whole district (Dave Howe, pers. comm.).

Table 2. Summary of net soil loss on cropping locations in the NT (Elliott et al. 2002)

Site	Region and average slope (%)	Soil erosion rate (t/ha/year)
Ruby Downs 1	Daly Basin 2	6.46
Ruby Downs 2	Daly Basin 2	4.12
Bonalbo 1	Daly Basin 3	2.28
Bonalbo 2	Daly Basin 3	5.75

Direct measurements by (Dilshad et al. 1996b) showed observed hill-slope water erosion of between 1.9 and 8.1 t/ha/year, which corresponds well with (Elliott et al. 2002). (Dilshad 2007) went further to use observed values to model hill-slope erosion and sediment delivery in the Daly River catchment. For this study, the Sediment River Network Model (SedNet) predicted long-term mean annual hill-slope erosion on croplands with soil conservation banks as 1.86 to 10.54 t/ha/year. Figure 6 shows the map of the Daly Basin with predicted hill-slope erosion in each area. There appears to be no other published information on soil loss outside this region.

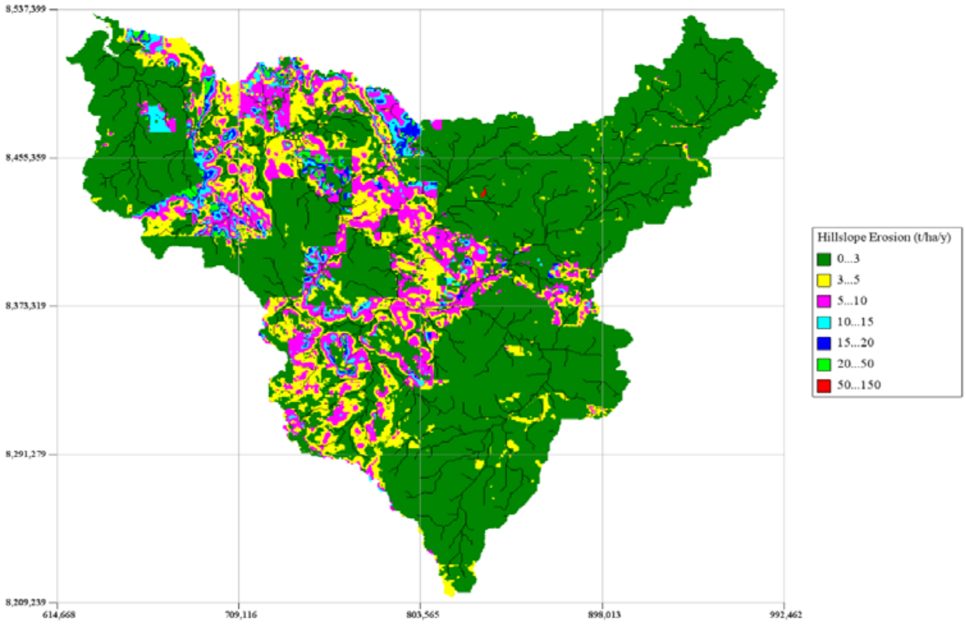

Figure 6. Hill-slope (sheet and rill) erosion (t/ha/year) in the Daly River catchment under current land use scenarios

5.2.6 Management

Since rain splash and water movement over the soil surface are the main agents of water erosion, mitigation activities are aimed at reducing the impact of these processes. According to Elliott et al. (2002) the basic principles for water erosion control involve:

a) Preventing soil detachment by the energy from raindrop impact.
b) Improving structural stability of the soil surface and improving its water retention by slowing surface flow and improving transmission properties, which provides more time for water to infiltrate.
c) Decreasing runoff rate and its velocity by providing appropriate surface drainage systems for safe conduct of water into a pre-designed surface storage systems (Lal 1985).

Much of the above can be achieved by using reduced or no-till techniques in ground preparation, which retains vegetation (attached and non-attached) on the soil surface to reduce raindrop impact, while maintaining the structure of the soil, slowing surface flow and allowing more time for water to infiltrate. Dilshad et al. (1994), for example, found a strong relationship between attached vegetation cover and surface runoff with suspended sediment in the Douglas-Daly region. Once attached vegetation cover fell below 40%, exposing the soil to significant rain splash, losses of soil in runoff increased rapidly. Litter on the soil surface (non-attached cover) was also important, but could be washed away in high intensity storms, reducing its effectiveness (van-Cuylenburg 1989).

Figure 7. Green manure crops, such as this sorghum plot, protect soil from heavy rainfall

Conservation banks, constructed along contours, also slow runoff rate and velocity, decreasing water erosion (Dilshad et al. 1996a); however, it is essential that these are designed properly and have suitable outlets.

Research at the Douglas-Daly Research Farm in the 1980s (Dilshad et al. 1996b) investigated the impact of tillage and conservation bank spacing on surface hydrology and erosion. The method was: direct measurement of runoff from micro-catchments (4.4–7.8 ha) fitted with Parshall flumes. Sediment samplers were used to measure suspended sediment loss (Dilshad et al. 1996b).

Figure 8. The conservation bank on the left of this photograph protects this young African mahogany plantation in the Douglas Daly region on Blain soil

The treatments for this work were:

a) Conventional till (maize, soybean rotation) – with double-spaced conservation banks.
b) Conventional till (maize, soybean rotation) – with single-spaced conservation banks.
c) No-till (maize, soybean rotation) – with double-spaced conservation banks.
d) No-till (maize, soybean rotation) – with single-spaced conservation banks.
e) Minimum-till (maize, soybean rotation) – with single-spaced conservation banks.
f) Woodland (area of intact native vegetation) – with single-spaced conservation banks.
g) Pasture (verano – *Stylosanthes hamata*).

The results indicated that runoff events were more likely to occur under conventional till, with virtually no vegetation cover, than under any other treatment. The highest incidence of runoff events occurred in the two conventional till treatments over three wet seasons. Conventional till also produced, in each season, larger volumes of runoff than the no-till, woodland and pasture blocks. No-till bays produced less runoff than conventional till but more than pasture or woodland blocks. The total ratio of runoff (mm) produced by a treatment to the total runoff (mm) produced by all bays in a season is presented in Table 3. Around 95% of the runoff in this trial occurred in the period from December to February (wet season).

Table 3. Mean ratio of runoff to total runoff (%) for land uses in the Douglas-Daly region (Dilshad and Jonauskas 1992)

Treatment	Mean ratio of runoff to total runoff (%)
Conventional till (maize, soybean rotation) – double-spaced conservation banks.	22.1
Conventional till (maize, soybean rotation) – single-spaced conservation banks.	23.1
No-till (maize, soybean rotation) – double-spaced conservation banks.	17.1
No-till (maize, soybean rotation) – single-spaced conservation banks.	12.5
Minimum-till (maize, soybean rotation) – single-spaced conservation banks.	16.2
Woodland – single-spaced conservation banks.	<1
Pasture (verano – Stylosanthes hamata).	9.0

Conventional till increased runoff, but no-till or minimum-till treatments that retained plant material on the soil surface, protected the soil against the energy of rain splash and slowed surface flow. Soil conservation banks were also used in this study to slow runoff velocity, but there was little difference between single and double-spaced conservation banks in this instance (Dilshad and Jonauskas 1992).

Concurrently, van-Cuylenburg (1989) found that on four different soil types in the Douglas-Daly region (Ejong, Tippera, Blain and Oolloo), no-till reduced soil movement compared with conventional till. This work also showed that no-till led to higher soil moisture, higher soil strength, lower surface temperature, higher weed incidence and lower grain sorghum yield than conventional till. Weed management was the greatest challenge when using this system.

Melville (1987), published an extension booklet summarising best practice on soil conservation methods in cropping areas. This booklet gives practical recommendations for the application of soil conservation principles to reduce soil loss in the Douglas-Daly region. The publication recommended following the three steps below:

a) Select the right land (before clearing existing native vegetation), and collect data on land form, slope, site drainage and soil properties, including fertility, depth, texture, structure, aggregate stability, infiltration and water-holding capacity. It was recommended that this was done in the context of a whole farm plan.
b) Protect with earthworks, which includes the judicious use of graded banks, diversion banks, waterways and gully control structures (contour banks break a single long slope into a series of slopes, which are too short for overland flow to cause interbank rilling, runoff collected in the channels behind the banks is conveyed to safe disposal points at non-erosive velocities).
c) Use conservation till techniques. Conventional cultivation of soil to produce a fine tilth was not recommended because of the tendency of Top End soils to slump and surface-seal. Till techniques that retain plant residues as a barrier against the impact of rainfall on the soil surface were encouraged, such as minimum-till/or reduced till techniques.

These principles are still applicable in the context of cropping in the semi-arid tropics and are referred to in *Striking the Balance* (2nd Edition) (O'Gara 2010).

5.3 WIND EROSION

Wind erosion is the simple detachment and movement of surface soil from the action of wind. It is exacerbated by frequent wind conditions of sustained strength, flat land with few natural landscape interruptions and bare, non-vegetated soil. If wind velocity is high enough, soil particles are suspended in the air, forming dust clouds. Such clouds were common in the Alice Springs district on texture contrast soils before being stabilised by buffel grass planting (Richards 1978). The dust was deposited as air movement slowed (Keetch 1985). Some wind erosion has also been reported in the Katherine and Douglas-Daly region, especially after long dry seasons on land not covered with vegetation. In these cases, it was found that standing stubble reduced wind velocity at the surface, protecting against wind erosion (van-Cuylenburg 1989). However, the impact of wind erosion caused by cropping activities is minimal, but where it exists, mitigating strategies for water erosion apply equally well to wind erosion in most instances.

5.4 Soil Acidification

Soil acidification occurs at a slow rate in natural ecosystems. Naturally acid soils are more prevalent in areas of higher rainfall, especially where the soil is old and where the parent materials are low in basic minerals (such as carbonates and calcium and magnesium silicates) where they buffer the soil pH against acidification. The light- textured nature of cropping soils of the Top End and the Daly means they have low buffering capacity. The natural acidity of soils in tropical Australia is presented in Figure 9. A recognition that soils across the northern parts of the NT are slightly to strongly acid is the basis on which government and industry should plan to deter this occurring in future.

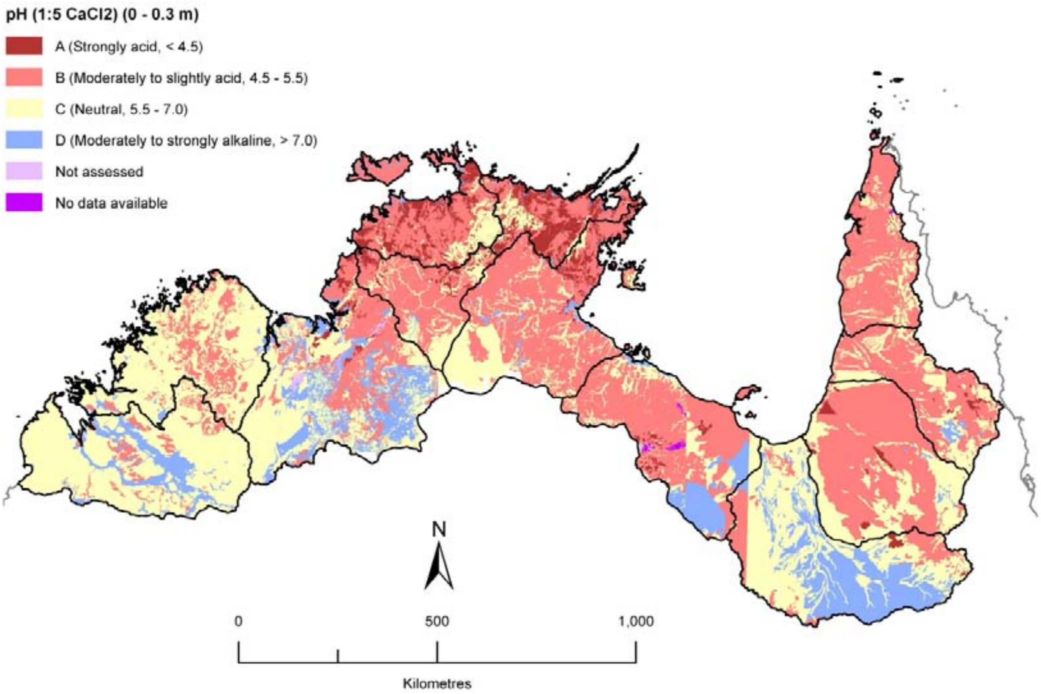

Figure 9. Soil pH data extracted from Australian Soil Resource Information System for northern Australia (Anonymous 2011)

Organic matter accumulation and profile leaching of nitrate with associated basic ions are the most important processes leading to acidification. Legumes gain most of their nitrogen from symbiotic fixation. Therefore, they take up more cations than anions overall and excrete H+ ions to maintain electrical neutrality. This leads to acidification (Ellington 1985). Other processes for acidification include conversion of ammonia to nitrate, ammonium uptake by plants and removal of plant or animal matter from a system (Ellington 1985). Agricultural and pasture ecosystems are characterised by faster rates of acidification because of product removal, the addition of acidifying nitrogen fertilisers and increased opportunities for nutrient leaching (Williams and Chartres 1991). There is evidence that the use of ammonium fertilisers leads to soil acidification (Ellington 1985), where 200 kg/ha lime was needed to neutralise 28 kg of ammonium in a Victorian environment.

Soil acidifying legume species are important in the NT. Approximately 30 000 ha of *Acacia mangium* have been planted on Melville Island for wood chip and paper production. Pongamia is a native leguminous plant being trialled for biofuel production. Various introduced legumes, such as stylo, lucerne and Cavalcade, have been introduced in the NT for hay and fodder production. In horticulture, beans are increasing in importance. Thus the use of such legumes constitutes an obvious risk of increased acidification of soils in the NT.

Figure 10. Soil pH testing - acidification of the soil is a risk in the NT

There is also unpublished evidence of acidification in areas where non-legumes are grown, such as the Douglas Daly Research Farm. This data shows that soil pH has dropped in some areas under continuous cropping over a number of years.

There is evidence of soil acidification in the semi-arid tropics from *Stylosanthes*- dominated pastures in both Queensland and the NT (Manbulloo, near Katherine) (Noble et al. 1997). In that study, the pH of paired sites from developed and undeveloped areas containing stylo or native grass were measured, with most soil samples from stylo sites showing some degree of acidification down to a depth of 70 cm. The rate of acidification from stylo was a function of soil, climate and population density. Lighter soils with less pH buffering were more susceptible to acidification, as were areas with high rainfall and deep-rooted stylo, where there was more chance of nitrate moving from the site of mineralisation (the surface) to depth, and being removed from that depth by plants.

Activities to mitigate soil acidification may include planting companions with legumes to use excess nitrate before it is leached and to reduce legume-based cropping and acidifying fertilisers. There is little published information on soil acidification from cultivated plants in the NT to enable the establishment of mitigating practices.

5.5 CARBON LOSS

Compiled broad-scale soil resource information from across the northern part of the NT indicates that soil carbon levels in well-drained earthy soils are generally less than 1% in the surface horizon, falling away abruptly at depth (Lynch 2010). The mineral fraction of most soils has very low cation exchange capacity. Therefore, soil organic matter often contains much of the soil's reserves of nutrients and, in particular, nitrogen. Under natural conditions, soil organic matter reaches an equilibrium controlled by erosion, climate and vegetation, but changing land use, such as clearing native vegetation with or without cultivation, leads to a new equilibrium (Williams and Chartres 1991). Current research by CSIRO indicates that agricultural soils across Australia are generally still in a period of carbon decline (Baldock 2010). The inherent low organic matter content of well-drained soils in the semi-arid tropics, including the Top End of the NT, decreases more rapidly during crop cultivation than that in soils in temperate regions (Lal 1985; Lynch Unpublished). This flux in soil carbon associated with land use change is a key component of Australia's greenhouse gas balance (Lynch 2002). The level of carbon change has been measured in the Douglas-Daly region where land use had changed from native vegetation to cropping (Lynch Unpublished). Organic carbon levels dropped 56% after four seasons of cultivation. Mean organic carbon in virgin soils was 2.16% in the 0-1cm depth (using the method developed by (Walkley and Black 1934)) but after cropping, had declined to 0.95%. Unpublished soil monitoring data from the Douglas Daly Research Farm also indicates a potential loss of soil carbon under conventional till compared with zero till.

Soil management systems are needed that maintain organic matter at adequate levels in the semi-arid tropics (Lal 1985). Work in a semi-arid subtropical climate in Queensland by (Wang *et al.* 2004) showed that no-till, stubble retention and the addition of nitrogen fertiliser significantly improved carbon sequestration in soil. Soil organic matter was maximised by reducing oxidation of soil organic matter through minimising removal of vegetation and cultivation, and adding extra organic matter through green manuring, cover cropping or keeping a highly productive crop on the soil surface.

Figure 11. Green manure crops are important to maintain organic carbon levels in vegetable cropping systems in the NT

Unpublished data from mango crops in the Darwin area indicates that increasing soil carbon during the wet season can be achieved to some degree, but is difficult to maintain during the following dry season (Greg Owens, pers. comm.).

It is necessary to ensure that farming practices for the semi-arid tropics are designed to maintain or increase soil carbon levels. However, more work is needed to quantify the importance of various practices.

5.6 SALINISATION

5.6.1 Dry-land salinity

Dry-land soil salinisation is caused by the clearing of native woodland for crops and pastures, reducing evapotranspiration, which leads to rising water tables, bringing dissolved salt from subsoils to the topsoil. This type of salinisation affects large areas in southern Australia, particularly Western Australia. The likelihood of this process becoming a problem in northern Australia is low (Tickell 1994). This is because deep- rooted vegetation is abundant in the Top End, which lowers salt levels in ground water. Therefore, rising ground water does not carry enough salt to salinise topsoils. In addition, annual monsoonal rains lead to substantial deep drainage and leaching of salts. Because rain is concentrated over a short period of time, there is an opportunity to fully recharge the profile and generate water movement deep into the profile beyond the root zone (Williams and Chartres 1991). In arid areas however, where ground water is saline, the native vegetation is shallow–rooted and its removal would not cause ground water to rise.

Although the risks of salinisation from rising ground water are low, they should be accounted for in any proposal to clear native vegetation.

5.6.2 Irrigation salinity

Salinisation through the use of saline water for irrigation is a separate issue. Since most of the water used for irrigation in the NT is ground water, its quality, especially salinity, needs particular consideration before use (Smith 2008). Groundwater quality parameters generally follow a distinct trend as one moves from the north to the south of the NT, as the water contains increasing amounts of total dissolved solids, sodium, calcium, magnesium, chloride, sulphate, alkalinity and hardness (Tickell 1994). This increases the risk of salinisation from the use of ground water for irrigation in Central Australia compared with the Top End. In the Ti Tree groundwater province, for example, there is approximately 1800 km^2 of land overlying ground water with total dissolved solids of less than 1000 mg/L (ideal for drinking and irrigation), 4300 km^2 overlying ground water with total dissolved solids from 1000 to 1500 mg/L, which can be used on tolerant crops; and 2500 km^2 overlying ground water with total dissolved solids higher than 1500 mg/L, which is not recommended for cropping because of the significant risk of salt building up in soil (Anonymous 2002). Horticulture in this region is currently based on aquifers of lower salinity and there has been no evidence of soil salinisation.

There are two other areas in the Top End that have been intensively studied for their risk to develop topsoil salinity from irrigation: Keep River Plains, located on the NT side of the Ord development zone and the Douglas-Daly and Katherine regions. Of the 10 600 hectares proposed for development in the Keep River Plains, 5000 hectares have natural saline soil and ground water 1 metre or lower under the surface. (Tickell *et al.* 2007) investigated the possibility of irrigation leading to rapid salinisation of these plains. They found that the salt in the soils was concentrated from the transpiration of rainfall, not from infiltration from nearby estuaries. There were no layers showing abrupt decreases in hydraulic conductivity, such as hard pans, so the formation of perched water tables was unlikely. Also, efficient lateral groundwater flow to Keep River and Sandy Creek would slow any water table rise for decades. The study concluded that as long as adequate monitoring took place, there would be ample time to take remedial action to check any potential soil salinization.

In the Douglas-Daly/Katherine region, probably the most important agricultural region in the NT, it is unlikely that salinisation would occur from irrigation because of the highly transmissive carbonate aquifers, the very strong connectivity of the ground water and incised drainage lines, which serve to ensure a steep hydraulic gradient to drive lateral groundwater flow. This would not preclude site-specific hydro-geological assessments to ensure good management of deep water drainage to prevent salinity (Petheram et al. 2008).

5.7 CRUSTING AND SURFACE SEALING

Tillage of soil after the removal of vegetation exacerbates negative impacts in many ways by disrupting soil structure and increasing soil surface area to volume ratio, which accelerates many chemical processes. This can happen after removal of both native and introduced species. Crusting or surface sealing is the process by which the surface layer of soil hardens. It commonly occurs after the removal of vegetation and cultivation. The results of this process can have profoundly negative effects on plant growth, especially for germinating seeds and young seedlings. It also reduces water infiltration and increases runoff, increasing the probability of soil erosion.

There is little published work that quantifies crusting and soil sealing from cropping activities in the NT. However, there is anecdotal evidence that it is common after cultivation in soils containing high levels of soil-dispersible clays, such as Tippera (deep red clayey Kandosols), which are used in agriculture in the Douglas-Daly/ Katherine region (Arndt 1964; Lal 1985; O'Gara 2010). Arndt (1964) found that repeated wetting and drying cycles increased mechanical impedance on the surface, which could be interrupted with repeated shallow cultivations. In addition, Lynch (Unpublished), directly measured the effects of cultivation on the physical properties of a Tippera soil (deep red clay loamy Kandosol) in the Douglas-Daly region. A small increase in bulk density at the surface (0-1 cm) was found after cultivation, more so as the soil dried out. This compaction mostly happened between cultivation and planting, rather than between planting and harvest. The soil in question was apedal (few soil aggregates) on the surface; the action of rainfall on cultivated soil broke the structure into a hard-setting and massive state. These soils were high in fine sand and silt, low in flocculating clay and organic carbon, which led to poor production of aggregates and therefore low structural stability (Lynch Unpublished).

Two soil pits described in the inter rows of a vineyard at Ti Tree in Central Australia that were sampled for chemical and physical properties showed high bulk densities in the surface horizon; in one case, the highest in the profile to 1.8 m. Although further sampling would be required, these initial results could indicate some surface soil compaction, perhaps from orchard traffic (Edmeades, 2010).

Although not directly related to plant industries, Mott et al.(1979) also investigated the appearance of “scalds”, or areas in grazed native pasture characterised by lack of plant growth and poor infiltration, in similar surface soils around Katherine. They found that macropores in the soil surface had been destroyed from the trampling of grazing animals, causing slumping and subsequent crusting. It is assumed that a similar process occurs under cultivation. To remedy the appearance in scalds under grazing, further work was completed to determine the best species mix to use to maximise macropores in surface soil (Bridge et al. 1983).

Strategies to mitigate the risks of surface sealing or structural change include the use of minimum-till or no-till practices for crop establishment, that include retaining as much attached plant material as possible on the soil surface. Also, the use of permanent traffic lanes, with the assistance of Global Positioning Systems in crops limits compaction to smaller areas. No literature was found, however, that reports on the impacts of these mitigating activities in the NT, perhaps due to their low level of current adoption.

5.8 OFF-TARGET NUTRIENT MOVEMENT

Most plant industries rely on some form of fertiliser to increase production. A wide range of different fertilisers is used, from chemical to organic amendments, in cropping, forestry and horticulture. There are some risks associated with these nutrients moving from where they are needed - in the root zones of desirable plants - to underground water systems, or off the soil surface into surface waterways or native vegetation areas. If this happens, there may be unwanted biological changes in these systems, such as algal blooms, or risk to human health through nitrite contamination of ground water used for drinking. There is an increased financial risk in the NT if fertiliser moves away from intended plant roots, since fertiliser constitutes a significant production cost due to higher freight costs. This is the context in which much of the work on nutrient movement has been conducted in the NT.

Figure 12. It is important to use soluble fertilisers, such as urea, in a way that minimises off-target distribution

Movement of nutrients with rainfall or irrigation water below the root zone of plants and into groundwater systems is one of the risks of using fertilisers. Wetselaar (1962) studied the movement of nitrate in Tippera (deep red clay loamy Kandosol), Blain (deep red sandy Kandosol) and Florina (poorly-drained sandy Hydrosol) in the Katherine region. That work showed that in Tippera soil, after 602 mm of rain, nitrate (and chloride) on bare soil had moved from the surface and the majority had reached a depth of between 610 mm and 914 mm. It was found that the relationship between mean movement of nitrate (y) in the soil and rainfall (x) was $y = 1.075x$. The movement of chloride was the same as that of nitrate. The correlation between rainfall and mean nitrate movement was high ($r = +0.946$, $p = 0.01$). This showed that for every unit of rain that fell, the nitrate moved approximately one unit of depth in the Tippera soil.

On Florina soil, the relationship between mean anion (nitrate and chloride) movement (y) and rainfall (x) was $y = 0.99x$ (for every unit of rain, the anions moved approximately one unit) while for Blain, a coarser soil, $y = 2.12x$ (approximately two units of anion movement for one unit of rainfall). Both Blain and Florina soils are sandy and have approximately 5% clay in the top soil. Florina has, however, high silt content in the topsoil compared with Blain. Therefore, Florina soils exhibit higher runoff and less rainfall infiltration, which may have influenced the results. Therefore, leaching of anions is quicker on more permeable soils, as expected (Wetselaar 1962).

It was found that nitrate and chloride move downwards in the soil at the same rate and in the same way. In Tippera soil, however, the rate of downward movement was not uniform, as there was a tailing effect at greater depth, which is consistent with a change in soil texture with depth, since in Tippera the clay content increased gradually from 20% in the top 15.25 cm to 50% at the 90-180 cm depth. This tailing effect due to increased clay content at depth was also evident in Florina and Blain soils, but not to as great an extent as in Tippera soils (Wetselaar 1962).

Anion movement was primarily downward in this case, although it was shown that upward movement can occur in the top foot of soil by capillary action in dry spells during the wet season (Arndt 1964).

The practical implications for plant industries is that by the time sowing of wet season crops occurs around mid-December, any nitrate formed by mineralisation of organic matter in the dry season is probably at a depth below 15 cm due to early season rain. No substantial plant growth then occurs until four weeks after planting, when much of the root system would not be more than 30.5 cm deep. By this time, 75% of the nitrate in the soil is below the top 30 cm of soil. This represents a substantial loss for shallow-rooted plants, which would not be able to access the nitrate. Wet season crops, therefore, need to be deep-rooted to access nitrate applied at planting or mineralised during the ground preparation process.

Wetselaar and Norman (1960) found that bulrush millet drew nitrate out of the soil down to a depth of 1.5 m, while forage sorghum and Sudan grass only drew nitrogen out of the profile down to 60 cm. As these grasses recovered less nitrogen than bulrush millet, millet would be the best crop to utilise deep soil nitrogen in the wet season. Also, Myers (1983) showed that not all nitrogen applied was recovered from the soil and in plants when grain sorghum was grown on a red earth at Katherine, and that there was a possibility that deep-leaching of nitrate occurred (beyond the rooting depth of the sorghum) with further losses from de-nitrification and volatilisation of ammonia. Also, Day (1977) found that during the grain sorghum growing season on three different soils (Tindall (deep red clayey structured Dermosol), Blain (deep red sandy Kandosol) and Emu (deep red fine sandy Kandosol) in Katherine, leaching displaced fertiliser nitrate to between 45 and 105 cm, 75 and 180 cm and 60 and 165 cm, respectively. The rate of leaching was highly dependent on the soil texture, with heavier horizons leaching slower than lighter horizons.

In horticultural production, Smith (1991) showed that there was no significant leaching of nitrate in a trial in a highly productive watermelon crop at Katherine and that leaching was unlikely to occur if management was careful with fertiliser and irrigation. Since then, however, the system of production has changed markedly to underground (tape) irrigation and fertigation. No information has been published on fertiliser movement in these modern systems in the NT.

A strategy to mitigate deep nutrient loss from top soils includes the use of cover crops to recover deep drained nutrients over the wet season, which is a common practice in melon and vegetable farms in the NT. Monitoring leaching, using probes with electric conductivity meters, could also be used to limit deep drainage of fertiliser salts. Precise fertiliser and irrigation application and timing to suit plant development during dry season cropping together with improved timing of fertiliser application in the wet season are also methods that may be used to limit possible risks of off-target fertiliser movement.

6 CONCLUSION

Plant industry land use across the NT is currently restricted to small areas scattered across a number of regions. For this reason, with the exception of some specific investigations, comprehensive research and monitoring of the potential negative effects of plant industries on soil-landscapes and offsite environments has so far not been conducted. Having said that, a substantial amount of published and unpublished soil data has been collected for a variety of purposes over the past 40 years. Although that data was not generally collected for the purpose outlined in this TB, it is extremely useful in highlighting problems and guiding future research and monitoring of negative effects of plant industries on soils in the NT.

Priority issues to be addressed have been listed in Table 4. In the northern part of the NT, they currently include water erosion, movement of solute and potential acidification under some scenarios. Toward the Western Australia border and the Ord, given its landscape history and land use, important issues include monitoring for potential salinisation. In the arid zone, potential negative impacts include water erosion due to the fragility of arid sand and calcareous earths.

Negative impacts can affect either productivity or the environment, often both. As such, it is essential that they are dealt with through a strategic approach.

Table 4 summarises the status of the issues identified in this Technical Bulletin and the required work in each area.

Table 4. Potential issues that could impact on soil due to plant industry activities in the NT and recommended research to minimise their effect

Land management issues	Level of knowledge	Current adoption	Extension priority	Research priority
Water erosion.	High.	Medium.	Recommended, particularly with new entrants to the industry.	Not immediate, but may need more work with precision agriculture and standing stubble retention.
Wind erosion.	Moderate.	High, especially in the arid zone.	Recommended. Adoption of strategies to retain attached cover on soil will also mitigate wind erosion.	Not immediate but may need more work with precision agriculture and standing stubble retention.
Acidification.	Low, very little work done.	Low.	Recommended, but very little information available for extension.	Essential, with need for analysis of long term soil data.
Carbon loss.	Low, very little work done.	Medium. Stubble retention and use of minimum-till for erosion management will help.	Recommended, especially the use of green manure cropping and minimisation of cultivation.	Essential. Analysis of long term soil data is needed and further work be initiated in this area.
Salinisation.	High. Well researched.	Little need for practices at present, apart from monitoring.	Not immediate.	Not immediate, although monitoring needs to continue.
Crusting and surface sealing.	Low. Little research done.	Medium. Stubble retention and use of minimum-till for erosion management will help.	Recommended.	Not immediate, but should be noted in research on precision agriculture methods.
Off target nutrient movement.	Low. Some research has been done on grains; little in horticulture.	Low. Very little deliberate mitigation activity occurring on this issue.	Recommended, especially the use of deep-rooted green manure crops.	Recommended. Nutrient movement under horticultural crops needs to be investigated.

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