Striking the Balance

2nd EDITION

CONSERVATION FARMING AND GRAZING SYSTEMS FOR THE SEMI-ARID TROPICS OF THE NORTHERN TERRITORY

BALANCING PRODUCTION AND NATURAL RESOURCE PROTECTION IN FARMING SYSTEMS IN THE TOP END

Fergal O'Gara

Australian Government

Northern Territory Government

LANDCARE AUSTRALIA

Northern Territory Agricultural Association Incorporated

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Preface

If current land degradation trends continue, by 2050 the world will need to be producing around twice as much food as it does now, from less water, less land and less healthy soil. If soil and water resources are diverted from food to energy production, and if climate change leads to declining land and water availability, the pressure on the remaining soil and water resources will intensify further. The global situation suggests that major food exporters like Australia will have expanding markets, particularly in Asia. Meat consumption in East Asia is projected to double by 2050.

This has huge implications for water consumption and for the pressures on soil resources. Future demand for grain in East Asia is directly related to the changing consumption pattern towards more meat in the diet. There will be a demand for more sustainable and productive soil management practices worldwide, in both dryland and irrigated farming systems. This technology in which Australian agriculturalists have considerable expertise will be in growing demand.

Australia is one of the countries most affected by climate change. Agriculture is one of Australia's most exposed and vulnerable sectors. It will be possible to capture those opportunities only if there is a rapid improvement in the productivity and resilience of our farming systems especially with an increasingly variable climate and declining water resources. Unless Australian farming and grazing enterprises effectively tackle the challenges ahead, we will fail to capture the enormous export opportunities and as a nation will be unlikely to meet our greenhouse targets.

Traditional responses to increase agricultural production have been to clear and irrigate more land. However opportunities to expand irrigation globally are very limited, because most of the world's great food basins are effectively 'closed', with existing water resources already fully utilised or over-allocated. Therefore, the main opportunities for the world to meet its future food needs lie in making better use of existing irrigation water and better soil and water management in rain-fed agriculture.

This book is focused on the Top End of Australia, however the international context is important to keep in mind. The opportunities offered by changing global circumstances will only be captured if Top End agriculture and grazing systems can meet the production, marketing, environmental and institutional challenges that are just over the horizon.

If the world's increasing food needs are to be met, exceptionally good soil management is required in order to increase water and nutrient storage and improve agricultural efficiency.

Acknowledgements

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1 Introduction

The first edition of *Striking the Balance* was published in 1998 to describe the unique nature of the Top End environment and to outline the sustainable farming practices required to protect our natural resource base.

The second edition aims to preserve the experience, knowledge and wisdom of the past while continuing the same strong conservation farming message and framing it in a contemporary and global context. The book highlights the important regional and global issues such as erosion, water management and climate change which are now critical aspects of agriculture today.

There have been major changes in the world's political, economic and environmental circumstances since 1998. Global warming, biotechnology and genetic engineering, biosecurity and biodiversity, precision farming, carbon sequestration and emissions trading are very much part of any discussion on agriculture today.

Agriculture is a complex and demanding occupation. Farmers must understand and deal with these issues and new technologies as well as manage the day-to-day issues of producing and marketing their produce, protecting the resource base and balancing the ever increasing cost-price squeeze.

Readers are encouraged to follow up on two Federal Government reports, *Sustainable Development in Northern Australia, A report to Government by the Northern Australia Land and Water Taskforce (2009) and Northern Australia Land and Water Science Review 2009 Chapter Summaries* published by the Department of Infrastructure, Transport, Regional Development and Local Government. www.infrsatructure.gov.au

These reports provide further insight into water availability and sustainability issues in northern Australia.

The Northern Territory is not isolated from global environmental and economic events. When fuel and fertiliser prices rise as a result of global demand, it is felt more strongly in the NT than anywhere else in Australia. It impacts more on NT farming systems and profitability, due to the reliance on imported farm inputs and distance from suppliers and markets. While science grapples with the cause and effects of climate change, the best indications are that the Top End of the NT is likely to become hotter and wetter, with an increasing frequency and intensity of extreme weather events such as tropical cyclones and related storm surges over the next 50 years.

Temperatures in the NT are likely to rise by an average of 2° or 3°C over the next 50 years and there will be an increase in the number of days over 35°C. This will have major consequences for land management and productivity, water use and availability, crop and pasture production and animal welfare.

Conservation farming will be critical in reducing land degradation and minimising the effects of increasingly severe storms, which are predicted as a consequence of global warming.

While "big picture" issues are the pre-occupation of Government and policy makers, there has been a tendency to "gloss-over" the no less important issues of sustainability, farming systems and soil conservation. Primary producers are limited individually in their ability to influence global issues, but they have a direct and permanent impact on land management and the protection of natural resources. Collectively, farmers have a significant impact on carbon storage, the carbon balance and ultimately climate, by adopting sustainable land management.

There continues to be a stream of new producers, companies and developers coming to the Top End in search of better production opportunities. Some have little understanding of or experience in a tropical environment and many are totally unprepared for the issues they will face. Information on the practices and management required to protect the natural resource of the NT is imperative. *Striking the Balance* will inform and guide sensible and sustainable development, encourage the adoption of practices suited to this unique region and engender an ethic and culture of soil conservation and good land management.

PICTURE 1: Monitoring from crop establishment onwards is an essential part of crop management.

2 The physical environment of the Top End

"... there is no more difficult challenge to applied science in Australia than that presented by the environment of the north-west."

Sir John Crawford of the Australian National University made this statement at a conference on agricultural research in northern Australia in Darwin in 1983 and it is as true today as when it was originally made. The physical environment and the predicted climate change will continue to present increasing challenges for livestock, crop and pasture production and for the people involved in these industries.

The NT has two distinctive climatic zones. The northern climatic zone or Top End, from Darwin to about 600 km south, is characterised by having two distinct seasons, the wet and the dry. The wet season is hot and humid with a monsoonal period of four to five months. The dry season is arid with milder temperatures and experiences no rain for five to six months. The central desert region which includes Alice Springs, is arid with little rain falling during the hottest months from October to March.

These distinctive features, coupled with one of the most inherently variable climates in the world, means farming in northern Australia has always been extremely challenging. Climate change will increase this variability and will require that any successful development incorporates sophisticated risk management systems and high levels of expertise, adaptability and resourcefulness.

Intensive agriculture is possible in the portion of the NT commonly called the Top End. This geographical area above latitude 16° south is classified as part of the world's semi-arid tropics (SAT) or the wet-dry tropics. Elsewhere, the SAT consists of either part or all of 48 countries on three continents including Africa, South America and Asia. The physical environment of the Top End has more similarities with these areas than it does with southern or temperate Australia.

2.1 SEASONAL RAINFALL AND EVAPORATION

The wet season lasts for four to six months from November to April and over 90% of the annual rainfall is received during this time. Sporadic thunderstorms start in September/October and continue through to December. Rainfall is heaviest in January and February due to monsoonal activity and tapers off in March and April. May to October is the dry season when little or no rain is received in most years.

Cyclones are a feature of the Top End and can result in several days of continuous heavy rainfall. Tropical rain, on average, have bigger droplets and more energy than temperate rain and therefore has greater potential to damage the soil. Most of the region's rain comes as hard, intermittent tropical showers often associated with thunder and lightning or as monsoon troughs and tropical lows, which are often the remains of cyclonic depressions. Intensity of rainfall is a major factor in the susceptibility of soils to erosion. The highest recorded daily rainfalls at Mango Farm (Daly River), Douglas River and Katherine are 218 mm, 206 mm and 128 mm, respectively.

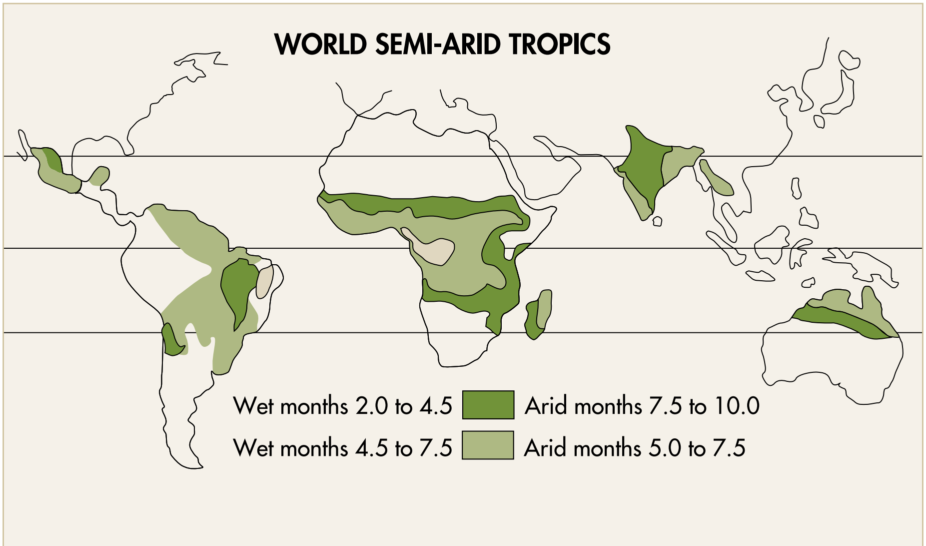


FIGURE 1: The distribution of the world's Semi-arid Tropics shows the relationship between the Top End and parts of Africa, South America and Asia.

Intense storms of 130 to 180 mm/hour lasting several minutes will occur every two years in the Top End. Longer duration (up to one hour) rainfall events of 40 to 60 mm/hour will occur every two years, subjecting the soil to intense erosive forces. Depending on soil condition, surface cover and degree of soil saturation, much of the rain will run off and potentially carry sediment with it.

Annual average rainfall in the Darwin region is about 1660 mm and decreases approximately 238 mm every 100 km south-eastwards. Average annual rainfall at Douglas Daly is 1250 mm, 1100 mm at Katherine and approximately 550 mm at Daly Waters. Seasonal rainfall variation is relatively low by Australian standards but weekly and fortnightly variations are high and may exceed 100%. The extreme variation within a season can result in intermittent periods of wet

Rainfall distribution, rather than total seasonal rainfall, largely determines crop and pasture performance in dryland farming in the tropics.

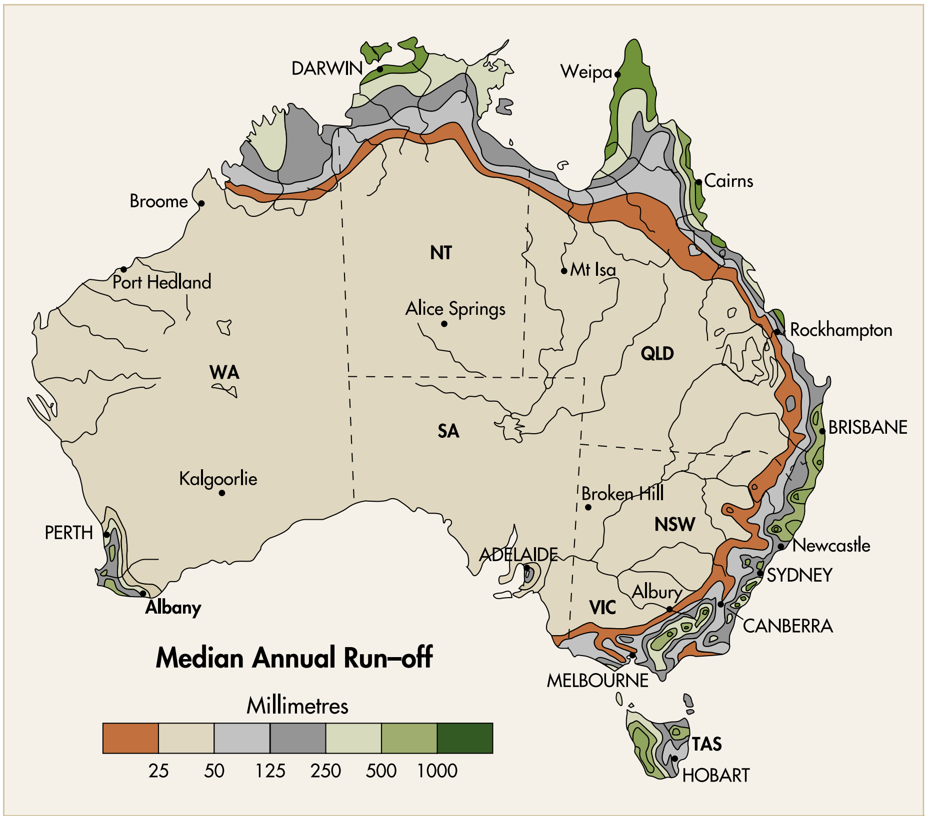


FIGURE 2: Runoff is very high in tropical regions (Courtesy of BoM).

and very dry conditions occurring within the same month or even the same fortnight.

Individual storms often provide surplus moisture which is subsequently lost as runoff or infiltrates beyond the root zone.

Up to 60% of the rainfall from a storm may run off depending on soil type and surface conditions. One or two heavy storms may result in a month's rainfall being received in a few days with the remainder of the month being dry. Several short "droughts" can occur within a wet season and these can vary from several days to several weeks. Evaporation exceeds rainfall in every month except January, February and March. In January and February evaporation ranges from about 150 to 200 mm increasing to 350 mm in October. Evaporation from the soil surface can account for up to 50% of moisture loss. Soil water availability, which is the principal factor determining plant growth, is influenced more by rainfall distribution and evaporation than by total rainfall.

2.2 TEMPERATURE

The average maximum wet season temperature is 32°C near the coast and 38°C in Katherine and inland areas. Temperatures in the "build-up" (from October to November) are generally 1° to 2°C higher but decrease slightly once the monsoon develops. The average maximum dry season temperature ranges from 25° to 31°C, while the average minimum temperature varies from 13° to 23°C. Frosts do not occur except on rare occasions in southern inland areas towards Ti Tree.

PICTURE 2: Tropical storms can unleash rainfall of over 100 mm per hour several times per season.

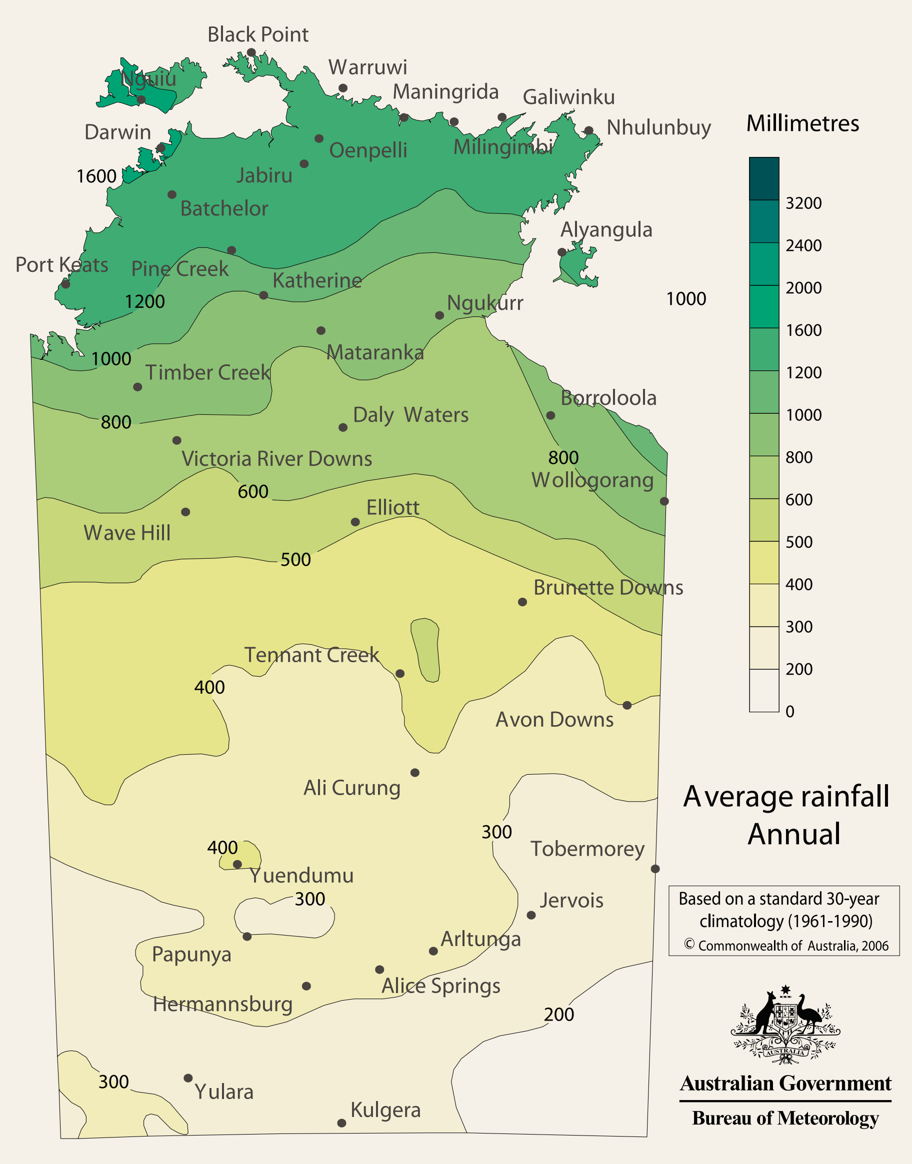


FIGURE 3: Average annual rainfall for the Northern Territory.

Day length in the Top End varies little throughout the year, ranging from 11.2 hours in June to 13 hours in December. Sunshine hours peak in August with 300 hours/month and can go as low as 100 hours/month in February at Darwin. Inland areas experience more sunshine during the wet season due to shorter periods of cloud cover.

The tropical climate is extremely demanding and sustained physical work becomes stressful. When measured in terms of human discomfort there are over 200 stress days per year in the Top End compared to with five to 10 in southern areas of Australia.

2.3 CLIMATE CHANGE AND POTENTIAL EFFECTS IN THE TOP END

The evidence of warming of the Earth's climate is unequivocal, with increases in average global air and ocean temperatures, melting of snow and ice, and rising sea levels. Recent observations in carbon emissions, temperature and sea levels and a new understanding of feedbacks, imply more severe climate change through the 21st century and increasing risks of serious impacts, notably for water availability.

For the eastern seaboard and southern and south-western Australia in which most people live and most food and fibre is produced, the greenhouse effect is leading to a hotter, drier climate on average, marked by more extreme weather events, but less rainfall and even less runoff overall.

Notwithstanding the predicted decline in average annual rainfall in southern regions, rainfall events are likely to be more intense, exacerbating erosion risk.
Climate change is real and will not go away for at least the next century, irrespective of current actions. It has huge implications because Australia will be one of the countries severely affected and agriculture is among the most exposed and vulnerable sectors.

The Top End is likely to become hotter and wetter and the Centre hotter and drier. Although little change in annual rainfall is expected, the frequency and intensity of extreme weather events such as tropical cyclones or storm surges, are likely to increase. This will potentially affect transport both in and out of the NT due to more flooding and damage to roads and associated infrastructure.

The Earth is getting warmer and climate change is no longer a question of "if" ...but rather of ..."how", "where" and "how fast".

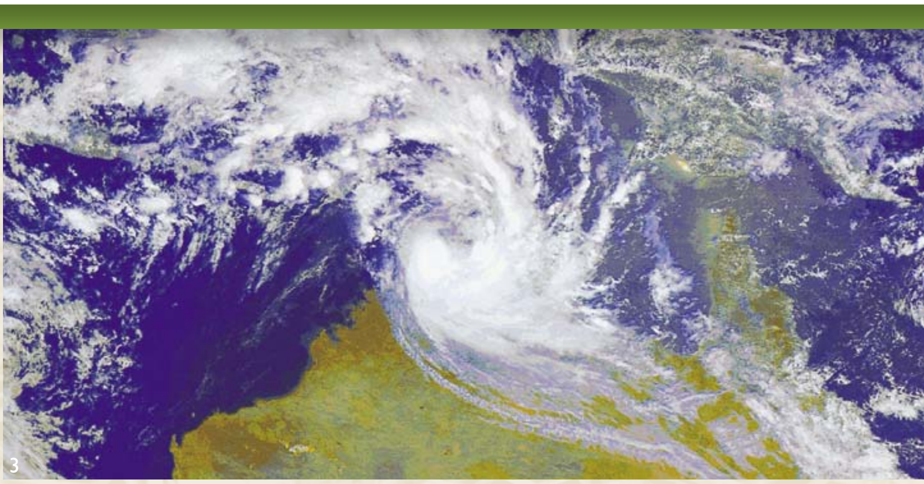
Adapted from Campbell (2008)

A rise in average temperatures of 2° or 3°C and an increased number of very hot days over 35°C for longer periods of time will have a serious impact on fragile ecosystems and may cause irreparable damage to iconic sites. Climate change could cause the number of days over 35°C in Darwin to increase from 11 a year to between 28 and 69 by 2030 and between 49 and 308 by 2070.

Rising sea levels, increased frequency of tropical cyclones and extreme weather events are likely to significantly impact on biodiversity, critical habitats, tourism, food and cultural values important to traditional land owners. A rise in sea level would have significant impacts on the infrastructure of Darwin and regional and remote coastal communities. Many coastal buildings, together with harbour and port facilities, are vulnerable to sea level rise.

Agricultural production in southern Australia has already been affected by climate change. Many areas have had significantly lower production and less water availability over the past five years due to the highest recorded temperatures and the longest drought in Australia's history. Climate change is likely to put at risk a substantial proportion of agricultural production, particularly cattle production, in the more southern and central areas of the NT.

The Top End may not be subjected to drought or lower rainfall. However more severe and frequent storms and cyclones will increase the likelihood of soil erosion and



PICTURE 3: Cyclone Rachel over the Top End in 1997. Cyclones and associated rainfall depressions can deliver several hundred millimetres of rain per day.

land degradation. There could be more intermittent wet and dry spells within a season, with negative impacts on crop and pasture production. Rainfall distribution may become more erratic and seasons more variable with the result that dryland crops and pastures may be more difficult to establish and harvest. Late cyclones may become more frequent, damaging crops and interfering with harvesting operations and fodder conservation.

Crops will also be more susceptible to stress and increased pest and disease pressure due to wetter conditions and higher temperatures. This could lead to higher crop protection costs and lower yields. Warmer temperatures and increased rainfall may also lead to higher animal husbandry costs and animal losses due to increased stress and disease. Higher dry season temperatures will increase evaporation rates and crop water demand for irrigated crops.

As the number of days above 35°C increases, people and livestock are likely to suffer from heat-related illnesses and tropical diseases may become more common. The current prediction is for heat-related deaths in those over 65 years to rise from two per year to between 37 and 126 by 2050. The Top End has the highest number of "human discomfort" days (an index of the combined effect of temperature and humidity on the human body) than anywhere else in Australia and this statistic is likely to increase with climate change.

Despite the negatives there are new opportunities for agriculture as increasing world demand for food and energy will create major economic opportunities for exporting countries like Australia. NT agriculture will capture these opportunities if our farming systems increase in productivity and resilience and can cope with an increasingly variable and difficult climate. Exceptionally good soil management will be required to deal with climate change, increase soil water and carbon storage, improve water quality and reduce greenhouse gas emissions from agricultural soils.

2.4 WHAT CAN AGRICULTURE DO ABOUT CLIMATE CHANGE?

Agriculture is the second largest contributor of greenhouse gases in Australia (after energy consumption), making up about 16% of total emissions. Agriculture is also the largest source of methane (CH_4) and nitrous oxide (N_2O) emissions due to ruminant fermentation, inefficient nitrogen fertiliser use and burning crop residues and savannahs, accounting for 58% and 85% of the net national emissions of CH_4 and N_2O respectively. Ruminant livestock contribute the largest share (70%) of agriculture's greenhouse emissions, equivalent to about 11% of the nation's total (The Australian National Greenhouse Accounts 2009).

Methane is 21 times more potent than carbon dioxide (CO_2) as a greenhouse gas and is released by ruminant livestock during the fermentation of fodder. Methane emissions represent a loss of up to 15% of potential energy that could otherwise be used for animal production.

PICTURE 4: Minimising cultivation and maximising soil cover is a high priority in tropical farming systems.

Agricultural practices have the potential to store more carbon in the soil than farming emits through land use change and fossil fuel combustion.

It is now acknowledged that there is a relationship between feed quality and CH_4 emissions. By maintaining pastures of high quality and digestibility, less energy is required in the fermentation process and less CH_4 is expressed from the rumen. Reductions in CH_4 emissions from livestock will potentially have the biggest environmental benefit. This will be a major area for research and development and become a critical aspect of grazing and pasture management in the future.

Cultivation is the main cause of organic matter breakdown and CO_2 emission from the soil. Inefficient use of nitrogen fertilisers and burning organic matter is responsible for emissions of N_2O. The loss of N_2O and carbon from soils represents a loss of nutrients that could otherwise be used for plant production.

The soil is a huge carbon store. Of the estimated 3060 gigatonnes of carbon in the terrestrial biosphere, 82% is in soils. Conservation farming and grazing practices which promote strong and robust perennial plants will accumulate soil carbon. While the incremental increases in stored carbon per hectare may be modest, the areas involved are vast and soil carbon sequestration can commence relatively quickly compared with other practices which are widely promoted, such as forestry.

Good agricultural practice which promotes healthy nutritious pastures, builds soil organic matter and natural fertility through legumes and crop rotation and avoids cultivation, stubble burning and over use of nitrogen based fertilisers will significantly reduce greenhouse gas emissions and help moderate the effects of climate change.

There is a strong imperative for Australian farmers to acknowledge their role and capacity in helping to moderate climate change and for policy makers to encourage sequestration of soil carbon and discourage practices that lead to large emissions of all greenhouse gases. It is possible that Government will institute policies that directly impact on agriculture as it tries to meet its national emissions target and help communities adapt to unavoidable climate change.

Agricultural industries will need to become more involved in addressing greenhouse gas emissions and develop improved farming and grazing systems in conjunction with State and Federal government initiatives. This will become more important as agriculture approaches a time when it may be included in a national emissions trading scheme.

2.5 SOILS

The distribution of soils in the Top End is variable and the region generally lacks extensive areas of uniform soil types. There are about 30 recognised soil types but only a few that are considered suitable for agricultural production. Soils are generally better in the south due to less leaching and weathering. Most soils are highly erodible, difficult

PICTURE 5: Lateritic ironstone gravel soils common in the Darwin region.

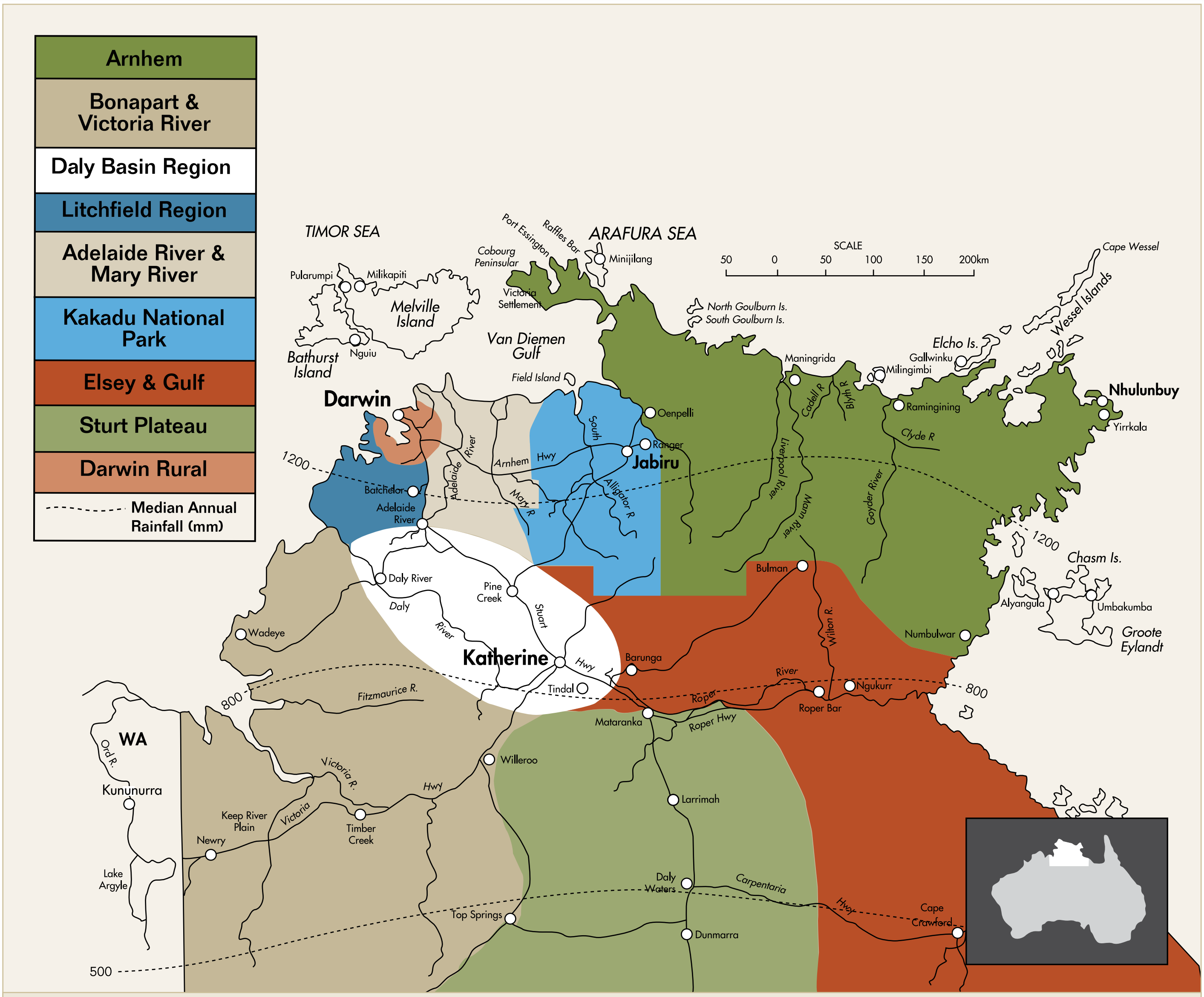


FIGURE 4: Broad geographical–agricultural regions of the Top End.

PICTURE 6: Clay loam furrow slice showing sod and root matter which is destroyed with cultivation.
PICTURE 7: Red Earth (Kandosol) profile showing massive structure.

to manage under conventional cultivation and have relatively poor natural fertility and low water holding capacities. Surface textures range from sands to clay loams and vary from massive red, yellow and grey earths (Kandosols)[1] to shallow ironstone gravels (Rudosols) and yellow lateritic podzolics (Chromosols). There are considerable areas of shallow stony and sandy soils interspersed with massive red and yellow earths throughout the Top End. A feature common to most soils is a massive structure consisting of kaolinite clay and iron oxides.

The most suitable agricultural soils in the Top End are the massive red earths (Red Kandosols). There are two broad groups based on surface texture: the sandy surfaced soils such as the Venn, Oolloo and Blain soil types; and the loamy surface soils which include the Tippera, Tindall and Emu soil types. These soil types have been described in Aldrick and Robinsons's report on the land units of the Katherine-Douglas area (1972).

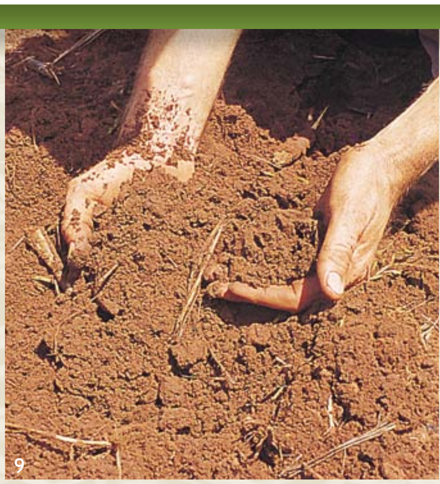
Red earths are characterised by having massive dark reddish brown profiles which increase in clay content at about 40 cm and are naturally free draining with a pH of around six to neutral. They are generally deficient in nitrogen (N), phosphorus (P), sulphur (S) and many trace elements. Blain and other sandy surfaced soils have low cation exchange capacities, low organic matter content and are low in all the essential nutrients. The sandy surfaced red earths can have over 80% sand in the top 20 to 40 cm and a clay content of around 7%. Clay may increase to 50% at depths of 60 to 90 cm. As a result they have low water holding capacities of around 40 to 75 mm/m of soil depth depending on soil condition and clay content. As clay content varies through the profile so does water holding capacity.

The loamy red earths have a clay content of about 24 to 50% increasing to about 70% clay at about one metre and have a higher water holding capacity and better nutrient retention than the sandy soil types. The dominant clay mineral is kaolinite. Clay loams are massive and hard setting soils which often form a surface seal (crust) when rainfall follows cultivation. Total water holding capacities of clay loams varies from about 80 to 140 mm of water per metre of soil depth depending on soil condition and clay content.

Other soils of economic importance in this region include yellow earths, lateritic Podzolics and grey, brown and red clays also described by Aldrick and Robinson (1972). Black and brown cracking clay soils (Vertosols) occur to a limited extent throughout the Top End and are common on the seasonally flooded coastal areas.

Katherine-Daly Basin and Sturt Plateau

The major soil types used for intensive agriculture in the Katherine-Daly Basin and Sturt Plateau are red earths (Red Kandosols) described above. A large proportion of the arable soil types consist of sands commonly referred to in the old literature as Venn, Blain and Ooloo soil types and loamy red earths, which include the Tippera, Tindal and Emu soil types. There are also large areas



[1]Different soil classification systems have been used over the last 60 years of soil survey in the Top End. The new Australian Soil Classification (Isbell 2002) is the accepted standard and these terms are indicated in brackets.

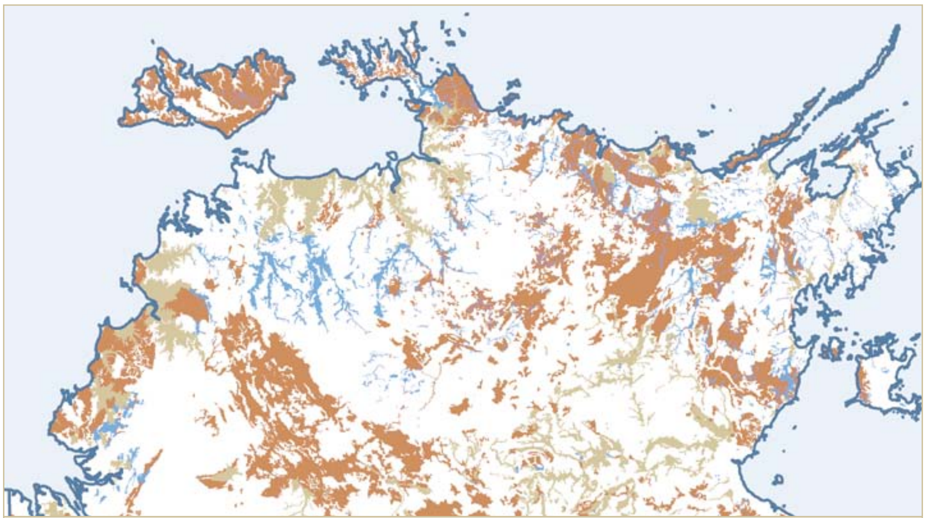
PICTURE 8: Clay loam red earths are important agricultural soils of the Daly Basin and Sturt Plateau.
PICTURE 9: Sandy surfaced Blain and Oolloo soils are ideal for peanut and horticultural production.

of Coolibah and Banyan soil types which are seasonally inundated dark grey brown silty clay loams to clays which are used for extensive grazing.

Sub-coastal, upper Top End and Darwin areas

Parts of the sub-coastal plains of the Adelaide, Mary, Finniss, Daly and Moyle Rivers consist of dark, heavy textured soils subject to deep and sometimes prolonged flooding in the wet season. The massive cracking clays vary in their natural fertility. They crust and crack when dry and are boggy and un-trafficable when wet.

The other major group of soils of the sub-coastal regions of the Adelaide River, Marrakai plains and Darwin region are the: solodic yellow and grey earths (Sodosolic Redoxic Hydrosols) or "bull-dust" soils; the more recent red earths; the yellow and lateritic podzolics (Chromolic Redoxic Hydrosols); and some discrete areas of red earth soils. The soils of the upper Top End are highly variable, many with imperfect drainage and subject to seasonal waterlogging. Surfaces vary



deep massive earths cracking days 'bull-dust' soils

FIGURE 5: Overview of agricultural soils of the Top End. (Source: NRETAS)

from light sandy loams to massive clay loams which are hard-setting. They are highly leached, often with a moderate to high percentage of iron stone gravel in the surface and generally have low levels of natural fertility and a low water holding capacity.

Due to the highly leached, light textured soils which dominate Top End land systems, most arable soils have low natural fertility and low water holding capacities. Growing crops on stored moisture as practised on heavy textured soils in southern Australia, is not feasible due to low storage capacity and high evaporative demand throughout the season.

2.6 AGRICULTURAL LAND CLASSES

Extensive land surveys were undertaken in 1960 and 1970 by CSIRO and the Land and Survey Branch of the NT Administration to identify, describe and map units of land which had recurring patterns of

PICTURE 10: Sandy surfaced red earths are extermely prone to erosion when exposed and unprotected.

topography, soil type, vegetation and physical characteristics such as drainage. These units of land were then classified according to their potential for agricultural development.

A land unit, soil, water and vegetation assessment should be undertaken prior to development to ensure sustainable productivity and protection of natural resources.

A comprehensive report by Aldrick and Robinson on the Katherine-Douglas area (1972) is still relevant and describes in detail the land units and their agricultural potential. Identifying and selecting the most suitable land units for development is critical to the sustainability of agriculture. Developing inferior land units and soil types will result in higher costs and lower returns through poor crop and pasture performance.

The following is a classification of land units derived from the report.

Class A

Arable with few or slight limitations. Mainly loamy and sandy red earths. Flat to gently undulating terrain (slopes generally <2%).

Class B

Arable with slight to moderate limitations. Primarily deep sandy Red Earths or Earthy Sands. Gently undulating terrains (slopes up to 3% or 5%).

Class BW

Potentially arable with slight to moderate limitations – seasonally wet. Generally Gleyed-Podzolics, Grey Brown and Red Clays and Rendzina soils. More extensive, flat or gently sloping drainage floors and back plains. Quite limited experience with crop production on these land units but more experience with pastures. May require development of appropriate production, water control and soil conservation technologies to realise potential.

Class C

Marginally arable suited to permanent improved pastures given minimal soil disturbance at establishment. Wide variety of soils - loamy Red Earths, Siliceous Sands, Earthy Sands, Yellow Earths, Podzolics. Often erosion prone - lower slopes and drainage floors, undulating upper or middle slopes or crests.

Class CW

Marginally arable suited to permanent improved pasture given minimal soil disturbance at establishment - seasonally wet. Wide variety of soils including Yellow Earths, Grey Earths, Red Earths, Siliceous Sands, Grey, Red and Brown Clays. Drainage and valley floors, low lying and seepage areas, flat to sloping terrain, swamps and margins.

Class D

Non-arable, marginal country potentially suitable for rough native pasture grazing or surface established, semi-improved pastures at low stocking rates. Hilly or gently undulating slopes and crests, rocky terrain or severe gilgai.

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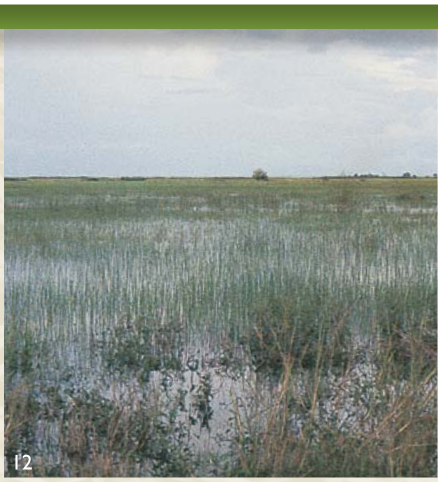

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PICTURE 11: Cracking black clay of the coastal floodplain.
PICTURE 12: Floodplain in the Adelaide River area, suitable for rice production.

3 What is conservation farming?

Conservation farming, also referred to as conservation agriculture, is any system or practice which aims to conserve soil and water by using surface cover (mulch) to minimise runoff and erosion and improve the conditions for plant establishment and growth. It involves planting crops and pastures directly into land which is protected by a mulch using minimum or no-tillage techniques.

Conservation farming aims to achieve sustainable and profitable agriculture and improved social, economic and environmental outcomes through three basic principles:

- **Minimal soil disturbance**
- **Permanent soil cover**
- **Crop rotations.**

CONSERVATION FARMING SYSTEMS ARE DESIGNED TO:

- reduce soil erosion and land degradation through mulch cover
- reduce soil temperature and conserve moisture
- increase organic matter and improve soil structure and fertility
- enhance soil health through increased soil biodiversity
- reduce CO_2 emissions and build carbon levels
- reduce reliance on cultivation and fossil fuel use
- reduce fuel and labour inputs
- achieve viable and sustainable productivity
- improve yields over the long term
- reduce vulnerability to climate change
- improve environmental and social outcomes in terms of cleaner air and water and more resilient and stronger communities.

3.1 THE BACKGROUND TO CONSERVATION FARMING

Conservation farming was first investigated in the 1940s in Nebraska, USA where mulch was used to control wind erosion. Since the 1960s development of the technology has accelerated with the introduction of new herbicides and specialised machinery. Much of the technology has been developed in South America in the high rainfall farming areas of Brazil and Argentina.

Many individual practices can be integrated into a conservation farming program as outlined in the adjacent text box.

No-tillage

No-tillage is also referred to as "zero-tillage" or "direct-drilling" and is a system in which crops are established without cultivation. Soil disturbance only occurs as the sowing implement engages the soil when sowing or drilling the seed. Mulch cover is maintained at a maximum level. Herbicides are used in lieu of cultivation for weed control.

CONSERVATION FARMING - COMPONENTS AND PRACTICES

- no-tillage
- agro-forestry or farm forestry
- minimum and reduced tillage
- trap cropping for insect control
- cover and green manure cropping
- alley cropping
- contour farming and strip cropping
- organic and biodynamic farming
- stubble mulching
- integrated pest management (IPM)
- crop and pasture rotation.

Conservation farming in the NT is largely based on crop and pasture rotations using no-tillage, minimum tillage and integrated pest management.

Minimum tillage

Minimum tillage involves some primary cultivation for weed control, mulch management and seed bed preparation. Herbicides are usually used in conjunction with tillage. Minimum and no-tillage can be used alternately, depending on conditions which will vary from paddock to paddock and season to season. Conservation farming is a flexible system where tillage practice is chosen to suit the particular situation.

Conservation farming will reduce erosion, increase soil moisture and build soil carbon levels. Reducing cultivation and maintaining soil surface cover are the keys to achieving this.

3.2 CONSERVATION FARMING – A GLOBAL PERSPECTIVE

Conservation farming is now recognised globally as the most important integrated farming system with the potential to

PICTURE 13: Cavalcade (***Centrosema pascuorum***) establishing in mulch.
PICTURE 14: Disk coulters - an essential requirement for no-till farming (Source: Rogro Machinery).

Conservation farming is now recognised as the system best capable of addressing the world's growing food needs while simultaneously reducing soil degradation and moderating climate change.

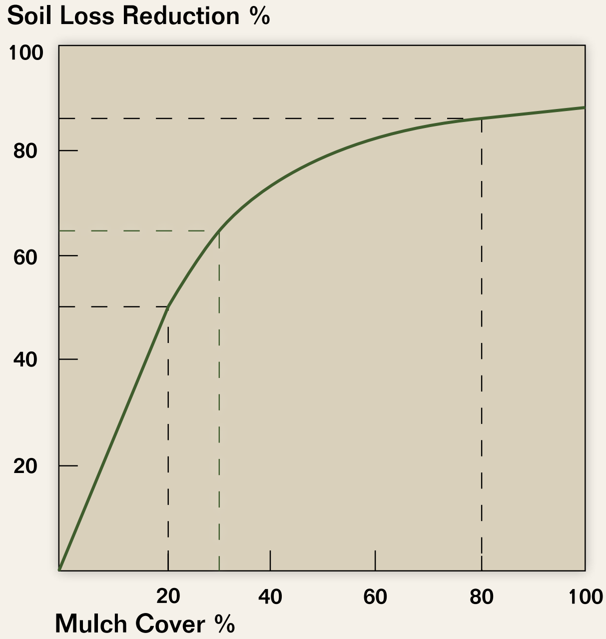

FIGURE 6: The effect of soil surface cover in reducing erosion. With 80 to 100% mulch cover there is a 90% reduction in soil loss.

reduce the impacts of agriculture, improve and protect the natural resource base, address carbon emissions and climate change and improve social and economic outcomes for farming communities all over the world.

The global concern about soil degradation is helping to support policies towards conservation farming at the international level. The link between carbon sequestration in soil, global warming and the role of conservation farming is now recognised by agricultural policy makers world-wide.

There is an estimated 95 million hectares of no-tillage and conservation farming in the world, of which about 85% is undertaken in South and North America. The benefits of conservation farming in reducing land degradation in the United States has been estimated at up to US$280 million. Conservation farming has been particularly successful in tropical rainfall zones like Latin America where yields have increased 5 to 20% and fertiliser and herbicide inputs dropped by an average of 30 to 50%. In addition, soil erosion rates have fallen from 3.4-8.0 t/ha to 0.4 t/ha with the adoption of no-till.

The European Conservation and Agriculture Federation (ECAF) has membership from 14 countries and is devoted to the development and adoption of conservation agriculture. The Food and Agriculture Organisation of the United Nations (FAO) is extending conservation agriculture in developing countries to combat soil degradation and global food shortages.

In Australia conservation farming is conducted on about 8.5 million hectares and is promoted by the Conservation Agriculture Alliance of Australia and New

Zealand (CAAANZ). Members include the South Australian, Western Australian and Victorian No-Till Farmers Associations, Conservation Farmers Incorporated of Queensland and Northern NSW, the Central West Conservation Farmers Association and the New Zealand No-Tillage Association, representing over 4000 conservation farmers.

If agriculture in the Top End is to continue sustainably and responsibly, conservation farming must be an integral part of the production system to ensure we are in step with global trends and environmental imperatives.

3.3 WHY WE NEED CONSERVATION FARMING

Agricultural land can lose over 100 tonnes of soil per hectare when cultivated.

Soil loss occurs on all land regardless of cover and management. However natural rates of soil loss on protected, undisturbed land is very low compared with soil loss on exposed

BENEFITS AND COSTS	Incidence		
	Local	National & regional	Global
Benefits			
Reduction in on-farm costs: savings in time, labour and mechanised machinery	√		
Increase in soil fertility and retention of soil moisture, resulting in long-term yield increase, decreasing yield valuations and greater food security	√	√	√
Stabilisation of soil and protection from erosion leading to reduced downstream sedimentation		√	
Reduction in toxic contamination of surface water and groundwater		√	
More regular river flows, reduced flooding and the re-emergence of dried wells		√	
Recharge of aquifers as a result of better infiltration		√	
Reduction in air pollution resulting from soil tillage machinery		√	√
Reduction of CO_2 emissions to the atmosphere (carbon sequestration)			√
Conservation of terrestrial and soil-based biodiversity	√	√	√
Costs			
Purchase of specialised planting equipment	√		
Short-term pest problems due to the change in crop management	√		
Farmer needs new management skills – requiring farmer's time commitment to learning and experimentation	√		
Application of additional herbicides	√	√	
Formation and operation of farmer groups	√	√	
High perceived risk to farmers because of technological uncertainty	√	√	
Development of appropriate technical packages and training programmes		√	

TABLE 1: Potential economic benefits and costs associated with conservation agriculture and their incidence.

Mulch cover will reduce runoff and evaporation and conserve more moisture for crop and pasture growth.

and cultivated land. Over 40% of tropical storms result in runoff with the potential to cause erosion. High energy raindrops dislodge soil particles which are carried away in runoff water. In the 1960s when large tracts of land in the Daly region were repeatedly ploughed and left exposed, 150 mm of soil was eroded from some areas, equating to a catastrophic soil loss of over 2000 t/ha. Soil losses over 100 tonnes/ha/year from exposed land are common under cultivation. Where farming practices expose soil to initial wet season storms, the complete layer of top soil (50 to 100 mm) can be lost, exposing the massive infertile subsoil.

Mulch and plant cover protects the soil by absorbing raindrop impact, increasing infiltration and slowing the speed water runs over the land, thereby reducing soil movement to negligible rates. A study in the Daly Basin showed that conventionally cultivated areas produced twice the runoff and lost on average 1.5 to 6 times more soil than no-tillage areas despite all areas being protected by soil conservation banks. In some seasons no-tillage areas suffered negligible soil loss while cultivated areas lost up to 8 t/ha. Average soil loss in conventional farming systems in the Top End may range from 20 to 40 t/ha with extremes in excess of 100 t/ha. Continued losses of this magnitude would result in a loss of 1 to 2 cm of top soil over five to ten years.

Erosion severity is determined by storm intensity, soil type and conditions, slope and cultivation practice. Soil surface cover and good pastures will dramatically increase infiltration and reduce runoff and soil loss.

Soil temperatures of 55° to 60°C will kill seedlings

Dry conditions at, or after, planting are accentuated by high soil temperature. Many crop seedlings are adversely affected by soil temperatures over 30°C. Bare soils, especially those with sandy surfaces can reach temperatures of 55° to 60°C, which will kill seedlings and significantly reduce plant stands. Protecting the soil with mulch has the combined effect of conserving moisture and reducing temperatures by 8° to16°C. Maintaining mulch is the best way to reduce soil temperature in dryland agriculture in the tropics.

Conserve moisture and increase yields

Moisture availability determines crop and pasture productivity. Crop failures can occur despite ample rainfall, mainly because much of the moisture is lost through runoff and evaporation. In the Top End exposed soil can lose 60% of the rainfall through runoff and up to 50% of soil moisture can be lost through evaporation directly from the soil surface.

Mulch retention can halve runoff and decrease evaporation, making more moisture available for plants. Specific studies in tropical regions have shown that by maintaining mulch, yield could be increased by up to 80%, 78% and 33% in sorghum, upland rice and peanuts respectively.


15


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PICTURE 15: Erosion is a common occurrence following full cultivation on Top End properties.
PICTURE 16: Sorghum seedlings dying due to high soil temperature and lack of protective mulch. Temperatures over 55°C are common on sandy surfaced soils at establishment.

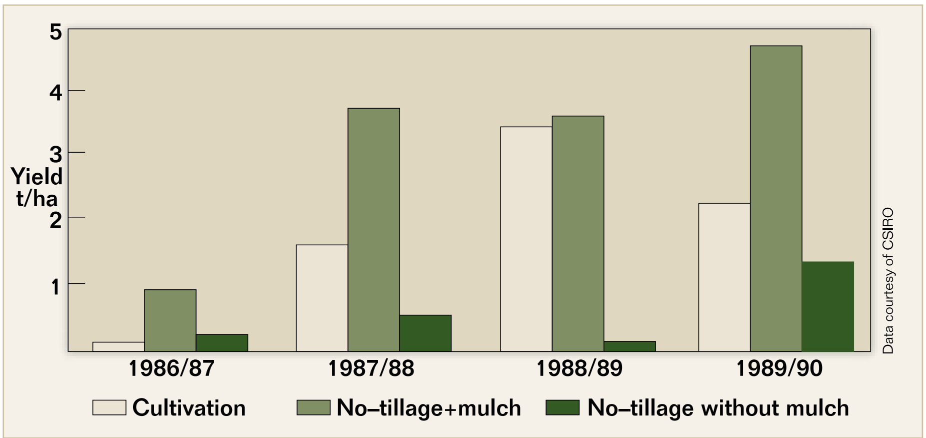


FIGURE 7: The effect of tillage practice and mulch cover on sorghum grain yield over four years at Katherine. No-tillage with mulch produced on average six times more grain than no-tillage without mulch, highlighting the importance of mulch in the system.

Better crops and healthier soil

Soil is one of the most diverse habitats on earth and contains an abundance of diverse organisms. It is one of nature's most complex ecosystems and plays a fundamental role in the carbon and water cycles, as well as being the engine room of food production. Protection of the soil with mulch is essential to preserving biodiversity and these functions. Maintaining mulch and producing legumes are also critical components of a sustainable system and are two of the rare win-win situations for soil management.

Mulch plays a vital role in promoting the uptake and cycling of plant nutrients. Earthworm numbers and beneficial micro-organisms increase under mulch, improving soil structure and increasing its capacity to hold water and nutrients. Up to 90% of the nitrogen (N), phosphorus (P) and potassium (K) lost from farming systems can occur as erosion and loss of organic matter. Mulch reduces these losses and acts as a storehouse for many essential nutrients which are gradually released and used by plants. Conservation farming provides more reliable yields than conventional tillage. In a four year study at Katherine, no-tillage

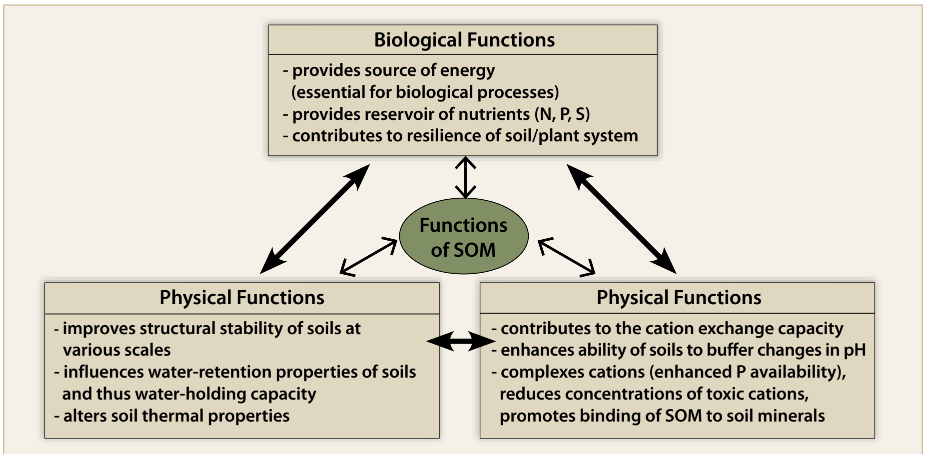


FIGURE 8: The functions of soil organic matter (SOM) (Source: Campbell 2008).

PICTURE 17: Cavalcade seedlings emerging through mulch.

grain sorghum averaged 3.22 t/ha while conventionally sown crops averaged 1.80 t/ha. At Douglas Daly Research Farm, no-till maize and soybeans, on average, out yielded conventional crops by 33% and 31% respectively over nine years. In dry seasons, conservation tillage has produced double the yield of conventionally sown crops in the same area.

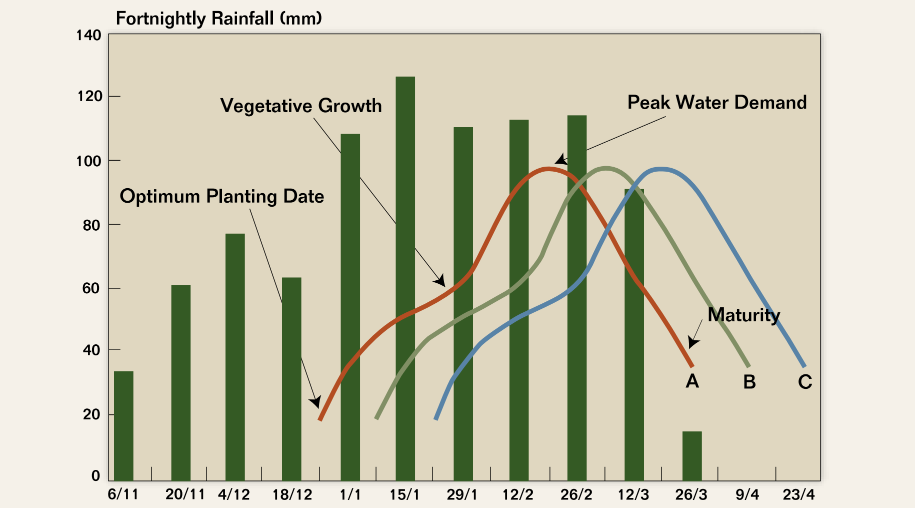


FIGURE 9: The effect of three different planting dates on relative water demand for grain sorghum at Katherine.

LINE A: represents the relative water requirement of a crop sown at the optimum time. Peak water demand occurs during a reliable rainfall period. There is a high probability of a good crop yield.

LINE B: represents a later sown crop where peak water demand occurs when the likelihood of rainfall is reduced, decreasing the chances of a good yield.

LINE C: represents a crop sown well beyond the optimum date. Peak water demand occurs when the reliable rainfall period is over. There is a high probability that this crop will fail. This principle applies to any dryland crop sown in the Top End.

Poor crop emergence and surface sealing

Cultivation prior to sowing temporarily opens the soil surface, however within one intense storm the surface is pounded, compacted, baked dry by the sun and sealed. Repeated cultivation eventually depletes organic matter and destroys soil structure. This is a particular problem on the heavier clay and hard setting clay loam soils and can result in total crop failure as seedlings fail to emerge. When this happens, poor seed quality, herbicide or insect damage is often blamed.

While other factors may contribute, surface sealing and crusting is one of the principal causes of many crop emergence failures on hard setting soils in the tropics. The maintenance of organic matter and mulch helps maintain soil structure and prevents drying and sealing of the soil surface promoting better establishment.

Optimum planting time gives optimum results

There are many reasons for poor crop performance but two factors are largely responsible in this environment:

- The failure to sow at the optimum time.
- The failure to achieve adequate plant populations.

The optimum sowing window for any wet season, dryland crop in the Top End is about seven to 14 days. In many seasons only one or two sowing opportunities may occur when moisture and other

PICTURE 18a+b: Cultivated soils without mulch protection are prone to crusting and sealing. This results in poor crop establishment, low water infiltration and high runoff rates.

Conservation farming allows sowing operations to be carried out earlier, provides a better environment and moisture retention for the emerging crop, resulting in more reliable yields.

factors are favourable. Optimum conditions may last for as little as 24 to 48 hours and missing such an opportunity may result in sowing late or sowing into declining moisture. This invariably results in poor establishment or moisture stress at the end of the season.

By maintaining a mulch cover and avoiding cultivation, the ground has better trafficability so that sowing can be carried out as soon as moisture conditions are favourable, avoiding delays associated with cultivation. Moisture is retained for longer enabling plants to better withstand dry spells after sowing. The ability to sow crops earlier into optimum moisture is one of the major advantages of conservation tillage and this translates into better yields.

Farming with less energy, labour and machinery

Machinery and fuel costs have risen over ten fold in the past 20 years. Fuel is the largest single cost, with tillage consuming over 11% of total energy used on farms. Ploughing and cultivating can use between 6 and 17 L/ha of fuel while no-tillage uses between 2 and 4 L/ha depending on the operation. Conservation tillage can reduce fuel consumption, tractor hours, maintenance and labour by 50 to 70%.

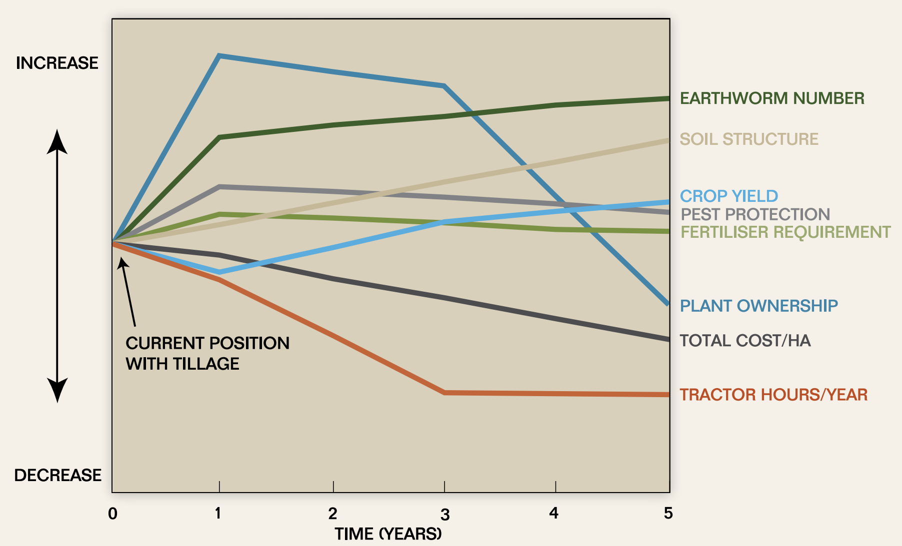
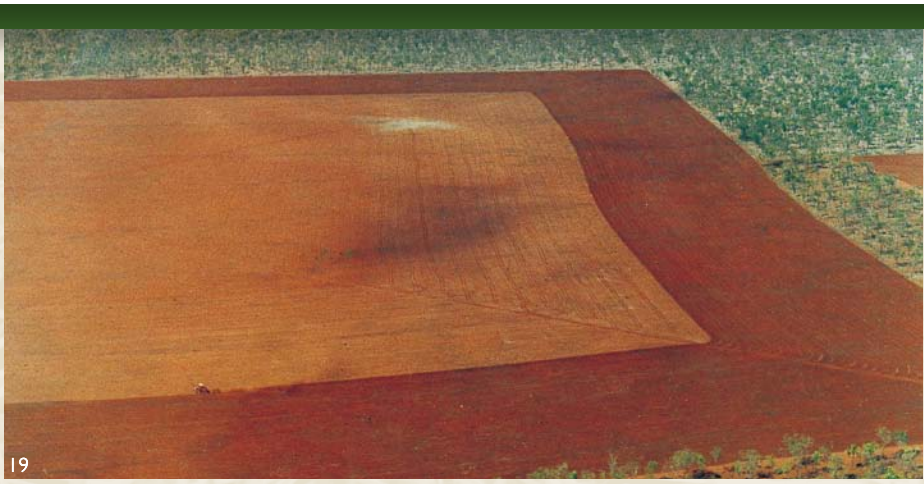


FIGURE 10: Likely outcomes resulting from conservation farming in the NT. Average crop yields are likely to improve and be more stable than conventional farming once experience with the system has been developed.

CONSERVATION FARMING OFFERS MANY BENEFITS INCLUDING:

- reduced erosion and improved soil structure
- improved infiltration and moisture efficiency
- improved soil health and nutrient retention
- lower soil temperatures and better establishment
- increased planting opportunities and flexibility
- lower machinery, labour and maintenance costs
- less time on the tractor with more time for other activities
- more consistent and reliable yields.



PICTURE 19: Conventional cultivation requires high inputs of labour, time and energy.

4

So what's the catch?

No single farming system or technique is perfect for all applications and conservation farming is no exception. Conservation farming involves planning, management and a commitment to sustainability. Trade-offs are necessary and extra costs may be incurred in the initial years. Herbicides and specialised machinery are needed in most conservation farming systems.

Precision seeders, trash handling combines, straw spreaders, self propelled spray buggies, global positioning systems (GPS) and associated software are part of modern conservation farming systems and contribute to its overall efficiency.

Conservation farming will not always result in higher yields especially in seasons where rainfall is ample and well distributed, but will in most cases provide much improved soil protection. The effectiveness of some herbicides is reduced or "tied-up" by high rates of organic matter on the soil surface. Fertilisers such as nitrates and herbicides may leach more readily through the soil due to higher infiltration rates under conservation tillage in some wet seasons. However, runoff losses will be reduced and there will be less potential for off-site movement of soil and nutrients. Timing fertiliser application to match crop demand will greatly reduce these losses. Improvements in fertiliser and herbicide formulation, application technology and better management practices are also addressing these issues.

Conservation farming systems are dynamic and call for continual learning and improvement. Well managed grazing, weed, insect and fertiliser programs are required for successful conservation farming and it takes time and experience to develop these skills. A good understanding of the interaction between plants, the soil system and the environment is necessary. Conservation farming systems need to be flexible and responsive and to work within the constraints and opportunities of the environment and not against it.

MANAGEMENT ASPECTS OF CONSERVATION FARMING INCLUDE:

- longer term planning and commitment to sustainability
- commitment to learning and developing a workable system
- skills in mulch management, weed control and herbicide use
- skills in soil nutrient and pest management
- understanding soil, plant and animal interactions
- rotations and integrating crops, pastures and livestock
- specialised or modified planting machinery.

No technique devised by mankind has been as effective at halting soil erosion and making food production truly sustainable as no-tillage.


No-tillage mungbean.

5 Planning a conservation farming program

Conservation farming should initially be undertaken on a small scale and developed gradually in line with skills and experience. Learning from others is a vital part of the process and all sources of information including other farmers, advisers, government departments and publications should be used. Conditions for conservation farming do not occur automatically. They are created by design and management.

CONSIDERATIONS IN PLANNING CONSERVATION FARMING SYSTEMS ARE:

Long term

- locality and environment
- land and soil types
- financial resources
- machinery and labour requirements
- markets, costs and returns
- personal preferences and objectives
- skills and experience
- sources of information.

Short term

- crop selection and rotations
- current markets
- grazing system and stock control
- pasture and crop compatibility
- weed spectrum
- mulch management
- insect and disease control
- sources of information.

5.1 PLAN FOR HIGH RISK PERIODS

There are specific periods in the year when there is a particularly high risk of runoff and erosion. The break of the wet season when the first storms occur and soil surface cover has been reduced is a high risk period. Bare soils exposed to highly erosive forces at this time are likely to be damaged. Other high risk periods occur when tropical monsoon or cyclonic conditions have developed, resulting in continuous high intensity rainfall. These conditions usually occur later in the wet season when the soil profile is full of moisture and high volume runoff occurs.

Developing and clearing new country

Developing new country and preventing soil loss is a major challenge. Heavy cultivation, stick raking and secondary tillage are required to remove stumps and roots and to prepare an arable surface for sowing. In the process, soils are left exposed to intense and damaging storms. Erosion control and soil conservation should be an integral part of all clearing and development plans. It only takes one storm to initiate erosion, and the potential for further land degradation increases with each rainfall event.

The NT Government has a comprehensive set of Land Clearing Guidelines (NRETAS, in preparation) that need to be consulted before embarking on a land development program. There are a number of legislative requirements and State and Federal Acts that a clearing application must meet. A clearing application needs to be approved and a permit issued by the relevant consent authority before any land development can commence. The potential for erosion is greatest on bare, cultivated or overgrazed land early in the wet season, when frequent high intensity storms occur.

The best way to develop country and avoid erosion is to implement staged development and maintain buffer strips of intact vegetation along the contour. Spacing and width of buffer strips will be determined by the slope and soil type. Contour banks, diversion banks and grassed waterways may need to be incorporated into the initial clearing

HIGH RISK SITUATIONS OCCUR AS A CONSEQUENCE OF:

- clearing and developing new country late in the dry season
- high intensity, early season storms falling on bare ground
- late dry season fires destroying ground cover
- over-grazing during the dry season
- early cultivation for crop/ pasture preparation
- production of low mulch crops in the previous season
- monsoonal and cyclonic conditions and high volume runoff from unprotected soils.

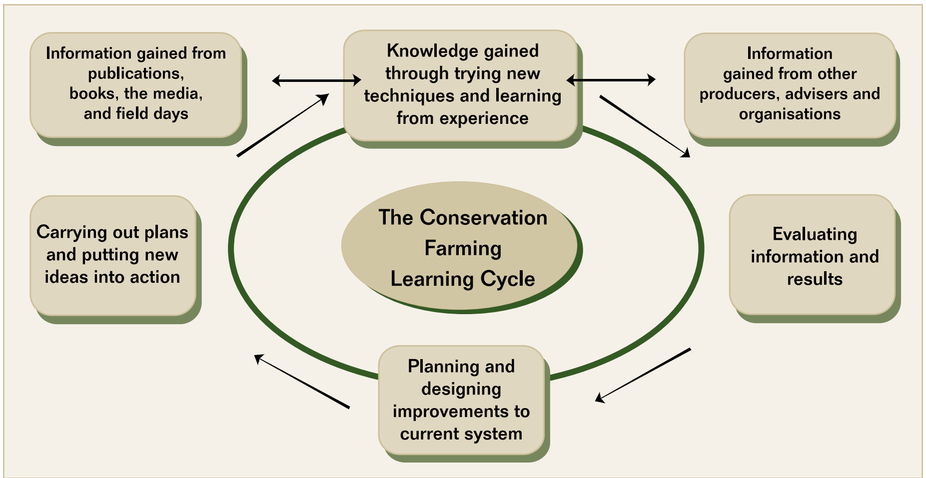


FIGURE 11: The conservation farming learning cycle is a process of seeking information, planning, doing and evaluating results. With each cycle there is an increase in knowledge and experience leading to continual improvements.

PICTURE 20: Stick raking and preparing newly cleared country, can leave the land exposed and susceptible to erosion.
PICTURE 21: Diamond or disk type harrows are an alternative to full cultivation and ideal for land preparation while maintaining partial surface cover.

Achieving a balance between agricultural and natural ecosystems will provide the best environmental, economic and social outcomes for the Top End.

plan and application. Professional advice and/or soil conservation and sediment control plans should be formulated prior to development.

Late dry season fires or overgrazing

Late dry season fires or overgrazing have the same effect of stripping the land of protective mulch and predisposing soils to erosion. Maintaining effective fire breaks and managing grazing pressure will help to ensure sufficient mulch cover is maintained to protect the soil from early season storms. Overgrazing also compacts the soil leading to surface sealing, lower infiltration and increased runoff and erosion. A good level of vegetation and soil cover should always be maintained in grazed paddocks. Soil cover should ideally be at least 60 to 80% in this environment.

Land preparation

Land preparation involving cultivation usually coincides with early wet season rains. Cultivation exposes the soil at a time when heavy storm activity is prevalent. The amount of mulch incorporated will vary according to the implement used and the number of operations.

Soil protection can be achieved by reducing the number of operations and by leaving the soil surface in a rough tilth until just prior to planting. Using tined implements (such as chisel ploughs and trash workers) rather than disk implements will help to maintain mulch. Cultivating on the contour and leaving undisturbed grass strips between cultivated areas will minimise runoff and erosion.

New conservation farming implements are constantly being developed which can be used to prepare the surface for seeding without undertaking complete cultivation. These include diamond harrows, prickle chains and crocodile seeders, all of which have a place in conservation farming systems. (See Pictures 21 and 22)

Low mulch crops

Some crops produce lower biomass than others and once harvested leave the ground relatively exposed. Sesame, mungbean and peanuts usually leave the ground exposed at the beginning of the next wet season. Making hay from annual legume crops dramatically reduces cover and soil protection. Ideally, the remaining organic matter should be left on the soil surface or lightly grazed. Rotating low mulch crops with high mulch crops such as sorghum, millet or improved pasture will increase surface cover and provide more protection. Using no-tillage to sow low mulch crops into existing pastures will greatly protect the soil.

Biodiversity and conservation farming

Biodiversity is a shortening of the term "biological diversity" and refers to the variety and abundance of plant and animal life in a particular habitat, environment or ecosystem. A high level of biodiversity is desirable. Native vegetation and well managed agricultural systems can both provide and maintain biodiversity. While agriculture results in a complete change of habitat and environment, many native animals and birds benefit from farming activities by gaining a source of food and shelter. Healthy agricultural systems are also essential in maintaining soil biodiversity, critical in nutrient cycling and plant productivity.

PICTURE 22: Prickle chains are ideal for incorporating seed and fertiliser while maintaining some surface cover.

PICTURE 23: Biodiversity – an important aspect of agriculture and natural resource management in the Top End.

Native vegetation provides essential biodiversity in the range and variety of plants, animals and other organisms it makes up. It provides food and shelter for a wide variety of animals, insects, reptiles and birds many of which are unique to the Top End. Different types of native vegetation provide a suite of plants and habitats to support plant and animal communities.

Biodiversity, its importance and function in preserving and protecting our unique plants and wildlife, must be considered when developing an agricultural or grazing enterprise. Clearing land has an impact on biodiversity on both a regional and a global scale. However these effects can be minimised by well planned development where agriculture is integrated into the landscape and where native vegetation is preserved in an interconnected way.

Farming and land development in the NT is small in area compared with other states. Only about 1% of native vegetation has been removed for all types of development. The broad-scale clearing, which occurred in other states and small parts of the NT in the early to mid 1900s is no longer acceptable or practised. Throughout the Top End significant areas of native vegetation have been preserved, maintaining the region's biodiversity. Discrete areas of good agricultural land are selected for development which enhances the productivity of individual farms while maintaining optimum biodiversity values.

Clearing permits are required for the removal of native vegetation. Permits ensure that development is in accordance with good environmental values.

Well managed agricultural systems and land development can be successfully integrated with areas of natural vegetation which support natural ecological processes. Healthy farm and pasture lands are a vital part of agricultural biodiversity, a subset of biodiversity. Agricultural systems support biodiversity which is comprised of the animals, plants and microorganisms necessary for the production of food and fibre.

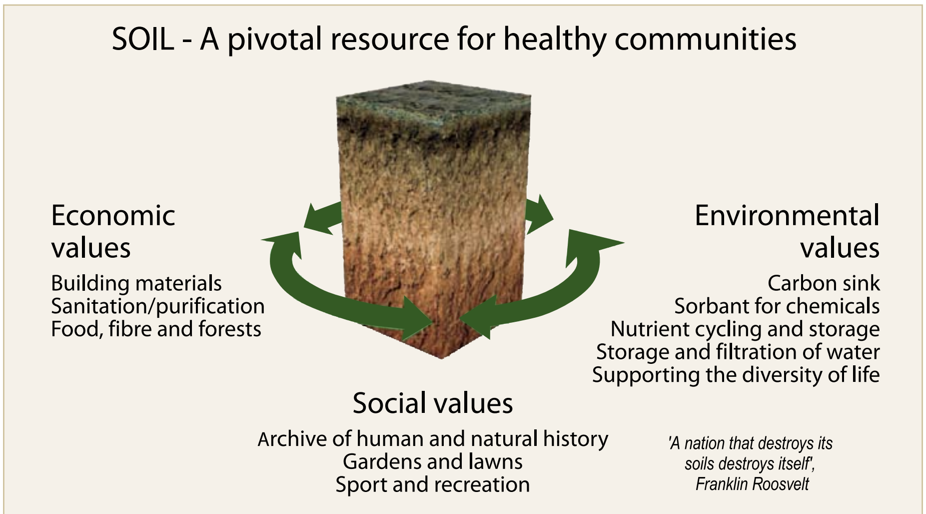


FIGURE 12: Soil provides economic, social and environmental values to healthy communities. (Source: Campbell (2008), photo by David Maschmedt, graphic by Noel Schoknecht)

PICTURE 24: Brolgas and other wildlife coexist well with agriculture; however in high populations some species cause considerable damage and require innovative management.

Mulch management is the key to conservation farming. It is critical for controlling runoff and erosion, conserving moisture, insulating the soil and building soil carbon.

Agricultural biodiversity and agro-ecosystems are as critical to natural processes and human activity and survival as natural ecosystems.

AGRICULTURAL BIODIVERSITY PROVIDES:

- sustainable production of food and fibre
- diversity of plant and animal genetic resources for production systems
- biological systems (i.e. soil micro-organisms, pollinators, natural insect and disease control agents) that support conservation and sustainable production systems
- ecological and social services such as landscape and wildlife protection, soil protection, nutrient and water cycling and carbon sequestration.

5.2 MULCH AND SOIL SURFACE MANAGEMENT

Mulch is defined as any dead or living vegetative matter which protects the soil from the effects of sun, wind and rain.

MULCH PLAYS A VITAL ROLE IN:

- reducing raindrop impact on the soil surface
- slowing surface water flow and reducing erosion
- increasing infiltration and conserving moisture
- building soil moisture holding capacity
- insulating the soil and reducing soil temperatures
- building organic matter, soil structure and fertility
- suppressing early weed growth
- building organic carbon, enhancing carbon storage and reducing green house emissions.

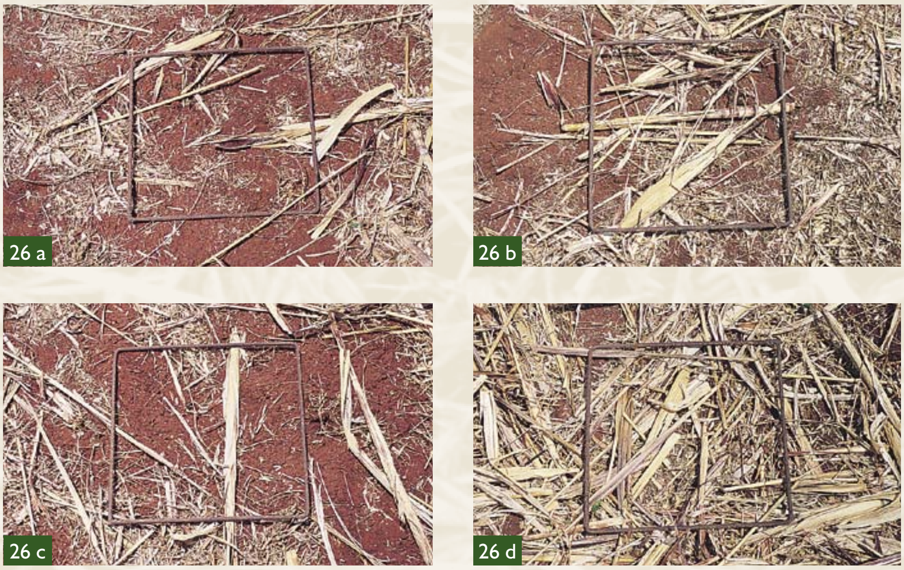
Mulch may consist of stubble from previous crops or a combination of pasture remnants, weeds and actively growing vegetation. Prior to the wet season, mulch is predominantly dead material but live vegetation becomes more prominent as moisture becomes available.

Mulch levels can be described in terms of percentage of soil covered or in tonnes of material per hectare. Over 3 t/ha, and as close as possible to 100% soil cover is desirable in the Top End. Crops such as sorghum, maize, rice and many pastures provide excellent mulch. Mulch allows crops to be established without cultivation and is the key to no-tillage farming. No-tillage without mulch rarely works in this environment and usually results in excessive soil temperatures, surface crusting, dramatically reduced water infiltration and erosion. (See Figure 7 on page 26.)

Managing mulch for soil protection, while avoiding planting difficulties, is an ongoing balancing act. Too much or too little mulch will pose problems, requiring strategies such as changing grazing pressure, slashing, cultivation or strategic herbicide use. Rotating crops and pastures and integrating with livestock is an ideal way of managing mulch in no-tillage systems. When there is too much mulch prior to planting, delays caused by blockages and inconsistent seed placement can occur. However modern farming equipment has been designed to cope with large amounts and various types of mulch.

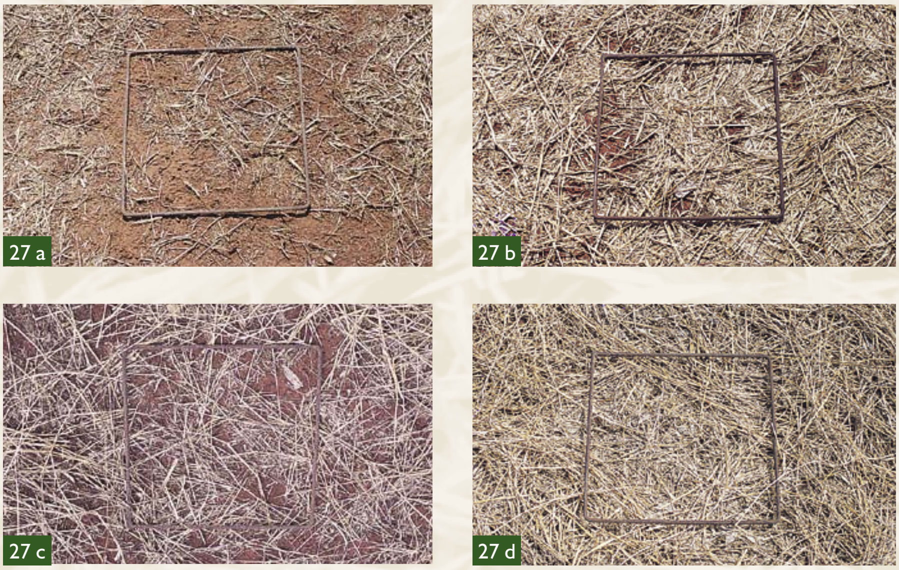
PICTURE 25: Mulch levels can be effectively managed through grazing.

Managing mulch levels through the dry season is necessary to achieve adequate protection prior to the first damaging storms.



PICTURE 26: Different levels of sorghum stubble mulch.

a) 0.6 t/ha
b) 1.6 t/ha
c) 3.0 t/ha
d) 4.2 t/ha



PICTURE 27: Different levels of summer grass and Cavalcade mulch.

a) 0.75 t/ha
b) 2.0 t/ha
c) 4.5 t/ha
d) 7.0 t/ha

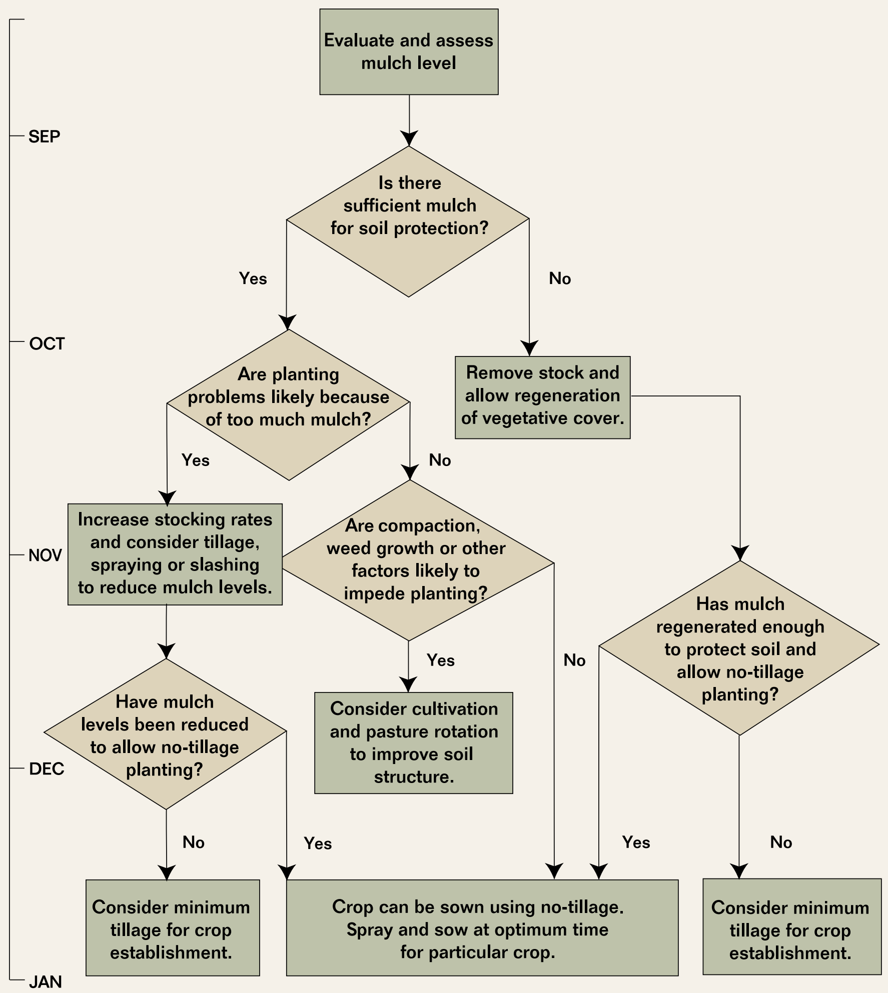


FIGURE 13: Decision chart for mulch management in conservation farming systems. Mulch management is an ongoing process and should start well before the onset of the wet season.

DECISIONS ON MULCH MANAGEMENT INCLUDE:

Strategies to reduce mulch

- straw spreading at harvest
- slashing or harrowing
- baling for fodder
- grazing
- selective cultivation
- strategic herbicide use
- strategic burning.

Strategies to preserve/ increase mulch

- leaving stubble intact
- removing livestock
- sowing a cover crop or pasture
- rotating low-mulch crops with high-mulch crops or pastures
- delaying sowing until sufficient mulch grows.

5.3 PLANTERS FOR CONSERVATION FARMING

A conservation farming planter or seed drill must be capable of effectively sowing seed through mulch into an unprepared seed bed and achieving an optimum plant

PLANTERS NEED THE FOLLOWING CHARACTERISTICS:

- robustness for hard conditions
- effective seed-to-soil contact
- effective trash handling/cutting ability
- avoidance of "hair-pinning" of mulch
- minimum soil disturbance
- accurate metering of seed of various sizes
- accurate placement/banding of fertiliser
- good penetration in tight soils
- accurate depth control and seed placement
- flexibility for different row widths
- soil moisture conservation, i.e. ability to cover and protect the seed furrow from dessication.

stand. It must accurately deliver and place seed at a uniform depth and achieve good seed to soil contact.

Several different planter designs have been used in the NT and new planters and components are constantly being produced. However, the best results and crop emergence in dryland farming are achieved with planters that have good trash handling ability in both wet and dry conditions, create minimal disturbance to the inter-row space, provide close seed-to-soil contact and have a mechanism to close over the furrow to minimise moisture loss from the seed zone.

Planter components: Disk coulters and row-sweepers

Disk coulters are essential components and are needed to slice or cut through mulch to allow tines to pass without blockage. Planting without coulters is often difficult, in light mulch, but is practically impossible in heavy mulch. Some types of coulter are available including straight, fluted and twin-inclined coulters which have been designed for specific purposes. Different coulters will perform differently depending on soil type, moisture conditions and mulch type and quantity.

The most common and effective coulter used in the Top End, is one with a plain flat disk measuring about 560 mm in diameter. When fitted with cleaners or scrapers, these disks perform well under various moisture, mulch and soil conditions. Coulters can be retro-fitted to conventional combines at a relatively low cost and have proven to be an efficient way of undertaking no-tillage in the NT. Fluted or wavy coulters can cause excessive disturbance to the row and become clogged with soil, especially on wet clay loams. This prevents their efficient operation and can result in blockages.

Row-sweepers resemble "mini stick rakes" fitted in front of the furrow opener, that sweep or rake mulch away from the immediate furrow, to prevent blockages. These work well if adjusted correctly to deal with the specific conditions and mulch levels.

Sowing points and furrow openers

Sowing points and furrow openers are critical components as they determine the accuracy with which seed is placed within the soil. Soil openers need to be narrow in

PICTURE 28: Not all disk and planting configurations are suitable for all the soil types, mulch levels and conditions in the Top End.
PICTURE 29: Careful selection of no-till equipment is essential. Soil type and moisture conditions have a big influence on planter performance.

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profile to reduce soil disturbance, enable efficient soil penetration and create a protected furrow.

Lucerne points and disc or slot openers are the preferred tools. Several designs are available to suit various conditions and soil types. The development of a specialised winged opener (the Baker Boot®) which creates an "inverted T" slot, has been designed for conservation tillage to minimise compaction and to create a protected seed zone for improved seedling emergence. Its advantage over other points under NT conditions has not yet been fully ascertained.

Presswheels and seed firming wheels

Presswheels and seed firming wheels are designed to improve contact between the seed and soil thereby increasing the availability of moisture immediately around the seed. Some presswheels compact soil over the seed, whereas seed firming wheels are designed to lightly press the seed into the bottom of the furrow. When used correctly and on the appropriate soil types, presswheels and seed firming wheels promote more rapid and higher rates of germination and emergence.

Once the seed has been pressed into the soil, the furrow should then be backfilled with loose soil and mulch to protect the seed zone from drying and allow seedlings to emerge unhindered.

Careful selection of planting machinery for this environment is essential. Many planters and components perform differently depending on soil type, moisture conditions and mulch type and quantity.

Compacting soil on top of the seed should be avoided especially on heavier soil types and the red earths. Compacted clay forms a hard seal on drying creating a barrier above the germinating seed which significantly reduces emergence. Presswheels should ideally press the seed gently into the furrow rather than compact soil on top of the seed and therefore need to be chosen to suit the specific soil types and conditions.

Covering tools

Covering tools and the nature of the furrow cover have a major impact on seedling emergence. Covering tools are designed to return soil and distribute mulch over the furrow, minimising moisture loss. Finger harrows, chains, covering discs, presswheels, rollers and tyres have all been used to close or backfill the furrow. Rollers have been successfully used on sandy and gravelly soils but chains or harrows are recommended for heavier soils to prevent compaction above the seed. New machinery designed to cover and incorporate seed and fertiliser without complete cultivation is constantly being developed and exhibited by machinery companies. Southern agricultural field days are good sources of information in this regard.

Row-crop planters versus combines

Row-crop planters are precision implements designed to sow crops in row widths of 0.5 to 1.0 m. They


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PICTURE 30: Row sweepers clean the furrow area of mulch to prevent blockages.
PICTURE 31: No-tillage combine.

consist of individual planting units fitted with seed and fertiliser boxes on a common tool bar. Some row-crop planters may be less robust than combines and should be used on land which is free from stumps and stones and where precision is required, as in maize or peanut production. However heavy duty row-crop planters are available at additional cost.

Combines are suited to a wider range of conditions and are generally more versatile but some may not offer the precision of many row crop planters. Combines can be used to sow a wider range of crops and pastures including small seeds. The choice of planter will ultimately depend on budget, range of crops and conditions in which crops are to be grown.

Modifying existing planters

Conservation farming machinery is continually being improved as knowledge and experience develop. Farmers regularly modify machinery to suit their specific situations and requirements. Modification is an alternative to buying new machinery when first adopting conservation farming.

STANDARD COMBINES CAN EASILY BE MODIFIED BY CARRYING OUT THE FOLLOWING PROCEDURES:

- removing cultivating tines
- spacing planting tines to appropriate row widths
- fitting narrow points to assist soil penetration
- fitting row sweepers
- fitting disk coulters
- adding seed firming or presswheels
- using a covering device i.e. harrow or chain
- increasing tine break-out force.

5.4 THE ROLE OF CULTIVATION IN FARMING SYSTEMS

Edward H. Faulkner in his 1943 book *Plowman's Folly* stated... "The truth is that no one has ever advanced a scientific reason for plowing." While this may not be totally accurate it illustrates that people have questioned the need for ploughing for several decades. Cultivation has been used since the domestication of crops by ancient societies. Cultivation has definite benefits if used sparingly, strategically and in the right situations.

Cultivation is beneficial and necessary when developing new country, dealing with degraded or compacted soils or preparing a seedbed in specific situations. Strategic cultivation is used to control hard-to-kill weeds, open and aerate the soil and break up compacted layers, improve infiltration and to incorporate mulch and nutrients. However, over-reliance on cultivation will cause irreparable damage to soils and predispose the land to degradation and erosion. Continuous cultivation or heavy grazing will lead to soil compaction, sealed and crusted surfaces and "hard pans", excessive runoff and declining production.

When soils are compacted and sealed, cultivation is generally the only option prior to crop establishment. An open soil of good tilth will more effectively trap and conserve moisture than one which is compacted. No-tillage

PICTURE 32: Twin inclined press wheels designed to close the furrow and achieve good seed to soil contact.
PICTURE 33: Planter with several coulter configurations and furrow opener.

It is the continuous and inappropriate use of cultivation which leads to soil erosion declining productivity and the loss of structure, organic matter and fertility.

does not work on bare compacted soils but minimum tillage (where the soil surface is broken-up so seed can be sown) can achieve good results on degraded land. Once vegetation is established, every effort should be made to maintain it.

Cultivation should ideally be carried out along the contour of the land (i.e. along points of equal height) to slow the flow of water and prevent it from running directly down the slope. This allows more time for water to infiltrate and reduces the risk of erosion. Contour cultivation and leaving vegetated strips at intervals down the slope is a proven strategy for minimising runoff and erosion.

Tillage implements are designed for specific purposes and vary in the amount of mulch they incorporate. Tined implements such as chisel ploughs and scarifiers leave more mulch on the surface than disk ploughs and are preferred for conservation farming systems.

Implement type	Mulch lost in each pass/operation (%)
One-way disk	50
Tandem disk	35
Wide-line cultivator (9 cm shank)	35
Scarifier (25 cm shank)	30
Chisel plough (30 cm shank)	25
Sweep plough (0.9 metre)	15
Blade plough (1.8 metre)	10

TABLE 2: Tillage implements and associated mulch losses.

CULTIVATION IS BENEFICIAL IN THE FOLLOWING SITUATIONS:

- preparing or developing new ground
- opening up compacted or crusted soils
- breaking up plough layers.
- aerating the soil
- incorporating excessive mulch
- increasing infiltration in low mulch areas
- controlling weeds where herbicides cannot be used or are restricted
- controlling difficult and hard-to-kill perennial weeds or woody regrowth
- incorporating herbicide or fertiliser
- ameliorating previously damaged or eroded land.


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PICTURE 34: Square ploughing results in soil inversion and assists in controlling perennial weeds but should be used sparingly.

6

Soil conservation and erosion control

Conservation of soil and the maintenance and improvement of soil health are inextricably linked with sustainable agriculture. A healthy agricultural environment is crucial for all primary industries and society in general which depends on fertile soils and clean and adequate water supplies.

As the world confronts the need to reduce greenhouse gas emissions and increase carbon sequestration, soil management assumes even greater importance, given the enormous capacity of soils to both release and store carbon.

Soil provides a wide range of functions, from food and fibre production to the storage, break down and filtering of many chemicals and subsequent prevention of air and water pollution.

Global demand for food will double by 2050 and yet soil degradation is still a major problem. Significant areas of land are lost each year to degradation and urban encroachment. Over the past 40 years over 30% of the world's farmland has been degraded through erosion with an estimated two billion hectares damaged and three billion people struggling against increasing land degradation. Erosion results in the loss of the biologically active top soil, depletes nutrients and organic matter and reduces crop and pasture productivity and farm viability. Prevention of soil degradation is always substantially cheaper than the cost of restoration.

Rates of soil loss may not be obvious. However one millimetre of top soil eroded per year represents a loss of around 15 tonnes per hectare of the most fertile top soil. Overgrazed or cultivated paddocks throughout the Top End potentially lose several centimetres of valuable top soil. This is not sustainable in our fragile and nutrient poor soils.

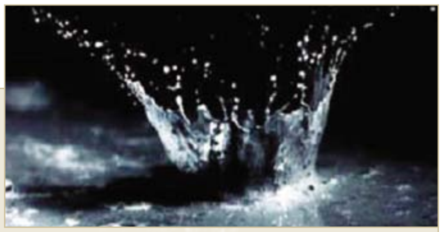
Soil erosion is one of the biggest threats to the sustainability of agricultural systems in the tropics and is directly influenced by farm practices and land management.

6.1 EROSION PROCESSES

In the Top End, water or hill-slope erosion is the major and most serious form of land degradation. Wind erosion is serious in the more arid regions of the NT and in Central Australia and affects many remote and indigenous communities.

Soil erosion is the detachment of soil particles and their transportation and deposition at another site. Splash erosion (see Figure 14) is the first stage of water erosion. It occurs when raindrops hit bare, unprotected soil and soil particles are detached. The splashed particles can rise 60 cm above the ground and move 1.5 m from the point of impact. The detached particles are washed into the pores sealing the soil surface, decreasing water infiltration and increasing runoff. Surface sealing is very common on cultivated and overgrazed soils in the Top End, especially on Tippera clay loam soils and on most soils where the top soil has been lost.

Wind erosion occurs when the lifting power of the wind is greater than the force of gravity and the cohesive forces between the soil particles. Dust storms occur when small particles are held in suspension in the air. Larger particles are carried or "bounced" by the wind in a process called saltation and then rolled along the ground, forced by the wind or other particles in a process called soil creep.



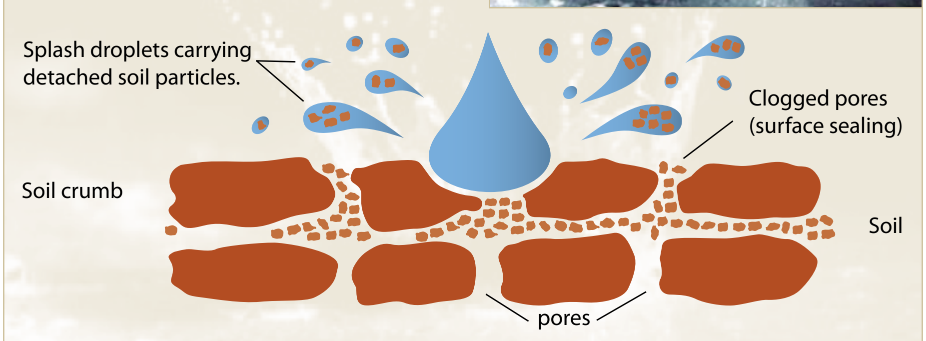


FIGURE 14: A raindrop hitting bare soil, detaching soil particles and blocking pores. Splash droplets carrying detached soil particles.

6.2 TYPES OF EROSION

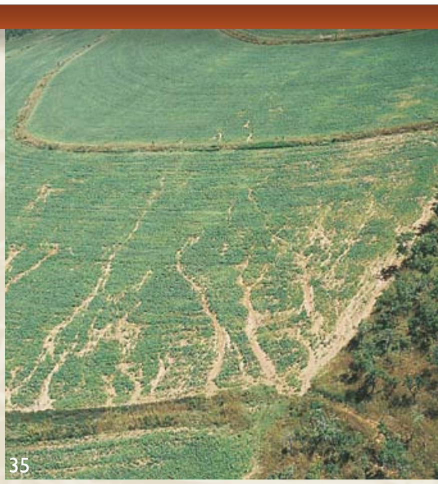
The main types of erosion that affect cropping and pasture lands in the Top End are sheet, rill and gully erosion. These and other types of erosion are outlined below.

Sheet erosion

Sheet erosion occurs when layers of topsoil are removed and washed down slope. It is not always obvious that sheet erosion is taking place until significant amounts of top soil have been removed.

Sheet erosion is common on large gently sloping fully cultivated paddocks or areas heavily grazed and denuded of vegetation. Sheet erosion removes the most valuable

PICTURE 35: Severe rill erosion; earth works must be combined with soil surface cover to be effective.
PICTURE 36: Crusted soil prevents water infiltration and seedling emergence.



and most fertile portion of the soil and results in depressed yields and productivity.

One sign that sheet erosion is taking place is the exposure of plant roots or the formation of plant pedestals. One result of sheet erosion is the lowering of the rate of water infiltration and exposure of the underlying sub-soil. This leads to a significant decrease in available water and nutrients for plants and results in further runoff and erosion. On heavier red earths sheet erosion can result in large "scalded" areas with virtually no permeability or infiltration. Rainfall constantly runs off the site which prevents any future vegetative growth. Cattle usually preferentially graze the edges, increasing the size and severity of the scalds.

Rill erosion

A rill is an erosion channel up to 30 cm deep. Rill erosion is usually initiated on bare soil in areas where there is a concentration of runoff. On grazing lands it may be one of the first signs that sheet erosion is taking place. Rilling is also one of the first signs of erosion on roads, tracks, firebreaks and fence lines. Small rills should be rectified before they become major erosion issues and costly to repair.

Gully erosion

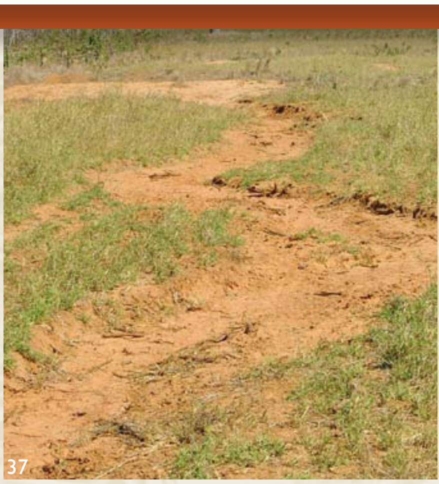
A gully is an erosion channel that is deeper than 30 cm and usually occurs as a result of poorly positioned roads, tracks, firebreaks or fence lines. On existing roads, tracks, firebreaks and fence lines and on new areas where it is not possible to exclude an erosion risk, appropriate erosion control measures, such as diversion or rollover banks may be needed. Gullies can take the form of fan or finger gullies. Fan gullies erode in an upward and sideward pattern, creating the appearance of a fan. These appear in areas with highly dispersible subsoils and continue to get bigger even with relatively light rainfall intensity. Fingers start off as narrow deeply incised gullies found on alluvial soils. Over time they tend to widen but they always maintain a characteristic "U" shape. Finger gullying often occurs as a secondary stage of erosion in fan gullies.

Tunnel erosion

Tunnel erosion is the result of holes or slumps on the surface connected with horizontal underground tunnels. Tunnelling occurs mainly on dispersive soils, when water reaches a dispersible lower layer, usually through a crack in the soil, and carries the dispersed material to a gully head. Soils in the Top End are not generally dispersive and tunnel erosion is minor compared to the other forms.

Stream bank erosion

With the intense rainfall events and seasonal conditions experienced in the Top End, stream bank erosion will always be part of the natural process. Erosion can vary from minor to extreme but if livestock and or feral animals have access to river banks, the impacts of natural processes will be exacerbated. Stock disturb the ground, damage banks, create tracks and denude river bank vegetation, all of which contribute to degradation of the banks. The solution is to exclude livestock from the river banks and this is practised on most properties in the Top End. Driving vehicles into sensitive areas, burning protective vegetation and driving boats at excessive speeds are also major causes of stream bank erosion.



PICTURE 37: Rill erosion.
PICTURE 38: Mounding will in most cases concentrate water flow and can result in gullying adjacent to the mound.

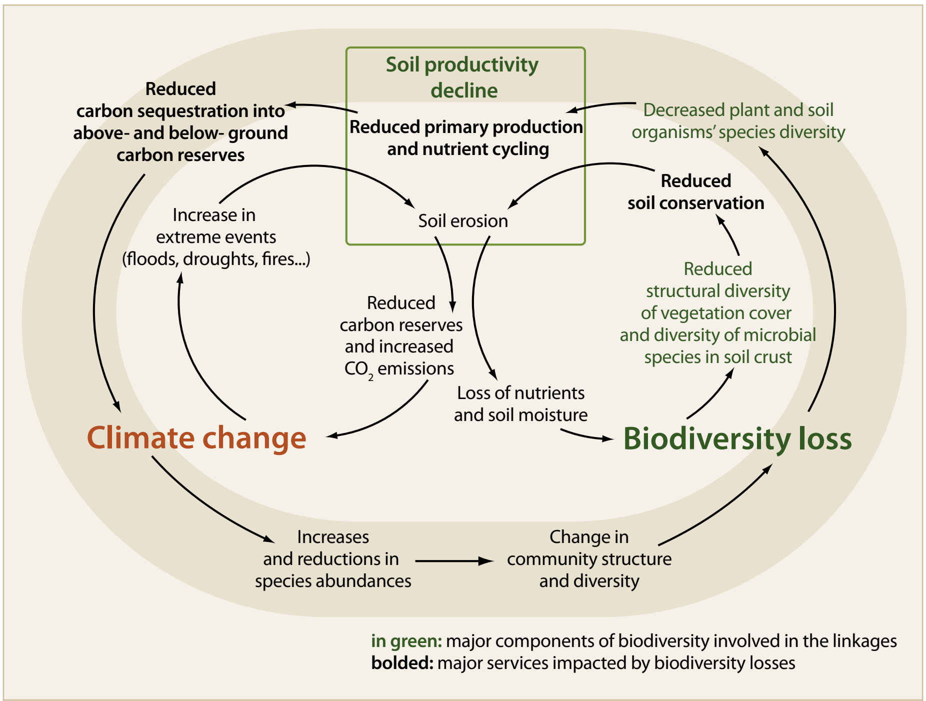


FIGURE 15: Linkages and feedback loops between soil exhaustion, biodiversity and climate change (Source: Millennium Ecosystem Assessment by Hassan et al 2005)

6.3 SOIL EROSION AND CLIMATE CHANGE

Climate change in the Top End will undoubtedly lead to more extreme rainfall events and therefore greater erosion. Soil erosion rates are expected to change in response to changes in climate for a variety of reasons. The most direct is the change in the erosive power of rainfall. Other reasons include:

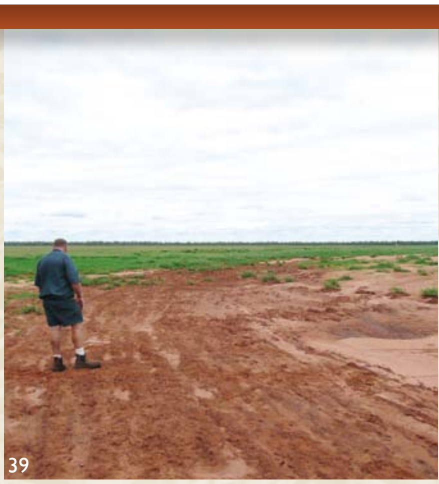
- Changes in ground cover caused by plant residue decomposition rates, driven by temperature and soil microbial activity as well as plant biomass production rates.
- Changes in soil moisture due to change in rainfall patterns and evapotranspiration rates, which changes infiltration, biomass production and runoff ratios.
- Increased erodibility due to decreased soil organic matter and structural decline causing surface sealing and increased runoff rates.

6.4 FACTORS AFFECTING THE DEGREE OF WATER EROSION

Erodibility is the soil's susceptibility to erosion, and is determined by how easily soil particles can be detached and transported from the soil surface. Larger soil particles such as sand are more easily detached. Smaller particles such as clay are more easily transported. Highly erodible soils can be up to 10 times as susceptible to erosion as less erodible soils. Several factors determine the erodibility of a soil and these factors combine to determine the degree, severity and frequency of erosion events which may occur on a given area.

These include:

- soil type
- slope
- vegetation and mulch cover
- intensity and duration of rainfall
- concentration of overland flow
- practices or activities which exacerbate soil erosion.



PICTURE 39: Erosion has completely removed the valuable top soil and exposed the massive unproductive sub soil.
PICTURE 40: A fully cultivated, sloping paddock is an extremely high erosion risk and should be avoided in this environment.

The value of vegetative cover cannot be overstated. Mulch can mean the difference between having little or no erosion and having catastrophic land degradation.

Soil type

Soil type is not the sole determinant of erodibility, but some soils are definitely more susceptible to erosion than others. Light, sandy poorly structured soils (i.e. Venn sands, Blain sandy loams) which occur in the Stray Creek area of Douglas Daly and the Venn area south of Katherine, are very prone to both water and wind erosion if left in a bare, exposed condition. Heavier textured soils with more clay and structure may have more resistance to erosion in their natural state. However, with continuous cultivation all soils suffer structural decline and are more easily eroded. Medium textured loamy soils are the most erodible due to the high proportions of fine sand and silt in the surface layers. Once the soil surface is disturbed, compacted or denuded of cover by cultivation, grazing or fire, the outcome is erosion.

Factors such as sand, silt and clay proportions, organic matter, permeability and structure determine a soil's inherent ability to resist erosion. The dominant agricultural soil types in the Daly include the sandy and loamy Blain and Oolloo red earths (Kandosols). These soils have a massive structure, a fragile sandy surface and are highly erodible, especially under cultivation and conditions of low surface cover.

The NT Government's Natural Resources Department produces land unit maps and factsheets on soil types, their occurrence and susceptibility to erosion and other information on soil erosion and sediment control. This information will assist land managers with property development and management practices. Maps and other information are available from relevant government websites.

Slope

Slope determines the potential velocity and thus energy of runoff from a given area. The greater the slope the greater the speed of overland water flow. As the speed of the water flow increases, so does its energy, erosive force and the resultant damage. The length of the slope has a major bearing on the potential for erosion. Long, gentle slopes of 1 to 2% can suffer considerable damage due to the energy and speed of the water flowing over the site. The longer the slope, the greater the velocity of the overland flow and erosion risk. However land with slopes of 2 to 3% which extend over a relatively short distance and have good protective cover throughout the wet season, may suffer minimal or negligible erosion.

Vegetation and mulch cover

Vegetation and mulch cover is the most important management tool in soil conservation. Vegetation protects the soil surface from rainfall impact and overland water flow. It provides a protective cover and barrier from the destructive power of raindrop impact. The greater the vegetative cover the less soil that is exposed to erosive forces. Mulch also slows the runoff down and reduces soil movement and loss. It is essential that sufficient vegetation remains at the start of the wet season to ensure the protection of the soil.

The type and quantity of mulch cover determines its effectiveness as an erosion control agent. Mulch which consists of remnant crop or pasture stubble attached to the soil will be more effective than loose

PICTURE 41: Massive sheet erosion as a result of cultivation on light sloping soils.

mulch lying on the surface. There needs to be three or more tonnes per hectare of mulch cover and at least 60 to 80% of the soil surface covered, but other factors such as soil type and slope will also determine how much mulch should be maintained.

Intensity and duration of rainfall

Tropical storms by their very nature are intense, high energy events that deliver high volumes of water in a relatively short time. This leads to sustained runoff with the potential to cause significant soil erosion. The initial rain from the early stages of a storm, rapidly soaks into the soil. However as the ground eventually becomes saturated, and the rainfall exceeds the capacity of the soil to absorb it, water flows across the ground in increasing volumes and with increased velocity and energy. This force then carries detached soil particles and increases the potential for erosion.

Short intense storms lasting 10 minutes and delivering 90 to 100 mm/hour can occur every year in the Douglas Daly region. Higher intensity storms occur further north with the possibility of up to 180 mm/

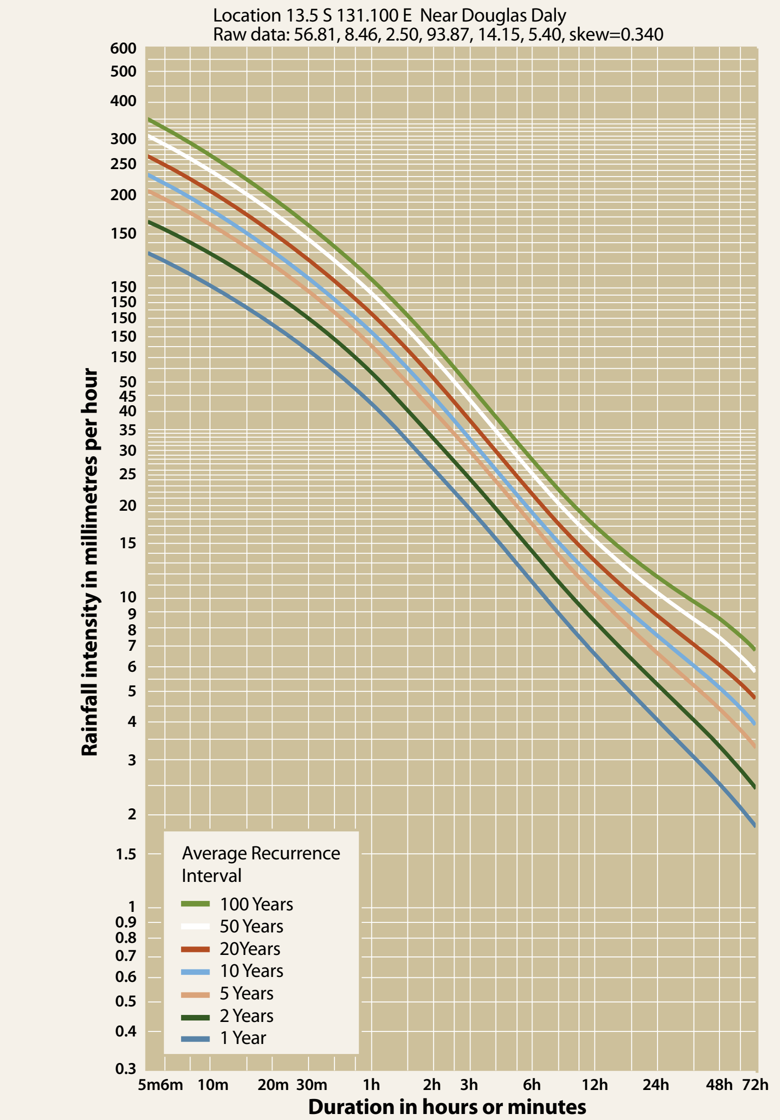
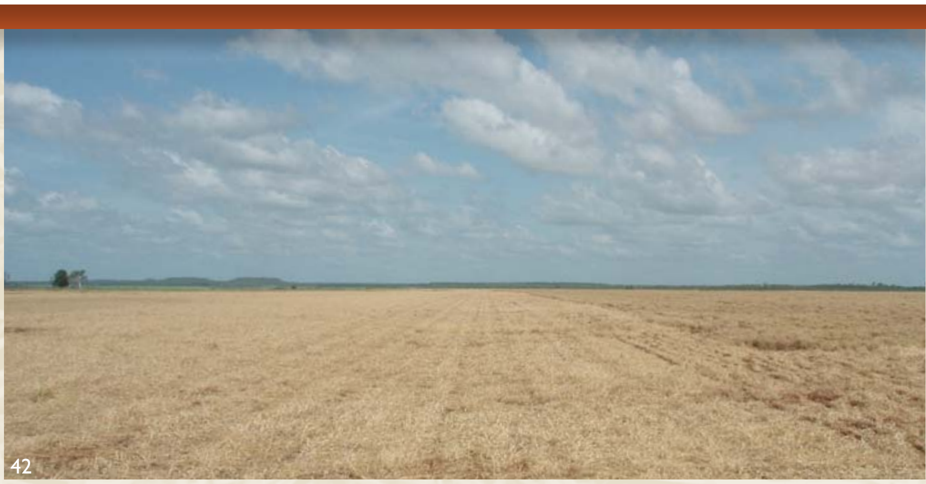


FIGURE 16: Rainfall intensity and recurrence interval for Douglas Daly NT. (Source: Bureau of Meteorology)



PICTURE 42: Mulch protects the soil from erosion, excessive temperatures and moisture loss.

hour events occurring every two years in Darwin. Figure 16 shows rainfall intensity and its recurrence at Douglas Daly indicating that highly damaging storms of 100 mm/hour and above occur every year in the region.

Frequent high intensity storms expose the land to repeated and extreme erosive forces every season. Soil conservation practices need to be part of regular and ongoing farm management.

Concentration of overland water flow

Water initially flows in a broad sheet across the land. Eventually it is channelled into stable drainage lines. Structures which obstruct the natural flow will concentrate water and cause erosion, unless specifically designed for soil conservation purposes. Natural and man-made obstacles such as mounds of soil, rocks or vegetation left by a dozer or wheel tracks will concentrate the flow into narrow channels and create considerable damage.

When clearing and developing land, windrows should be aligned down the slope and not across it, as is often the practice. There is a misconception that the windrows will act as barriers and help stop water flow on newly cleared land. In most instances large windrows will concentrate water until it finds a gap, or flows around the windrow at higher than normal velocity, causing extensive damage. Windrows are not contour banks and should be aligned down slope to minimise water collection and concentration.

Practices or activities which exacerbate soil erosion

Soil in the Top End is exposed to four to five months of intense storm activity and high volume monsoonal rains. It requires a high degree of protection in the way of mulch cover and sustainable cropping and grazing practices designed specifically for the environment. The obvious causes of erosion are over cultivation, overgrazing and leaving the soil bare and exposed. Evidence of these practices is clearly seen in all agricultural areas. However there are other practices and activities undertaken on farms which should be avoided to minimise land degradation.

Many agricultural practices have been inherited from temperate areas in southern Australia and are unsuitable for the conditions experienced in the Top End's wet season. Such practices include repeated working of the soil, trash harrowing (where all the surface mulch is raked off), burning stubble and mulch, and mounding to discharge water off the land. Mounding is a common practice in forestry operations in southern states to deal with cold, water-logged soils. Mounding in this high rainfall environment can create extensive erosion due to increased concentration, runoff and velocity of water adjacent to the mound. Water should be trapped and stored by the soil or allowed to run off slowly in natural drainage lines or via well designed soil conservation structures to maximise infiltration and minimise soil loss.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PICTURE 43: Intense early season storms can do the greatest damage when plants are small and there is little protective cover.

Mounding soil in this environment increases the concentration and velocity of water flow which can result in massive soil loss.

OTHER PRACTICES AND ACTIVITIES THAT EXACERBATE EROSION INCLUDE:

- running fencelines and farm roads directly up and down slopes without suitable water control structures
- repeatedly grading firebreaks on sloping country
- driving up the slope on freshly cultivated land causing wheel ruts
- repeated hot fires destroying vegetative cover
- neglecting to repair small areas of erosion which become major over time
- interfering with the natural flow of water by leaving obstructions or mounds
- mounding or other practices which disrupt or concentrate the natural flow
- failure to maintain or repair existing soil conservation structures. Damaged structures concentrate water flow increasing land degradation and the costs of repair.

Every effort should be made to reduce overland water flow and water concentration by maximising soil cover and minimising tillage and modification of the natural soil surface.

Early wet season storms invariably occur at the time land is being prepared and cultivated for dryland crop and pasture establishment. This is a high risk period for erosion.

6.5 MEASURES TO COMBAT SOIL EROSION AND LAND DEGRADATION

Soil conservation planning must be an integral part of any agricultural, livestock, forestry, horticultural or property development business. A soil conservation plan is as critical to the overall success of the operation as a business, marketing or labour plan. All of these aspects are usually combined into a property management plan (PMP). A PMP is essentially a business plan for the property which considers the four main aspects of the business:

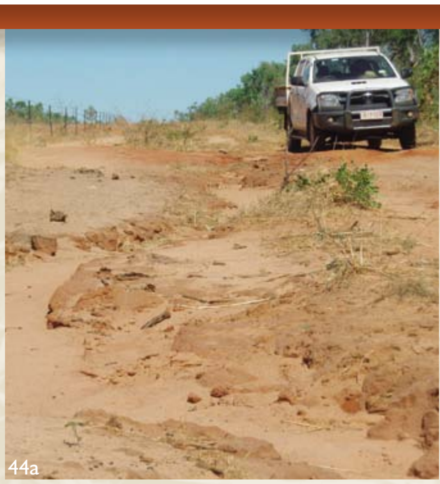
- human resource management
- economic management
- production and marketing
- natural resource management.

The natural resource component of the plan deals with the protection and enhancement of soil, water and vegetation. An erosion and sediment control plan (ESCP) may need to be developed for large land developments that involve changes in vegetation and soil condition. The natural resource agency of the NT Government can advise on what is required.

Farming and grazing systems in the Top End must be designed specifically to deal with the erosive forces of the environment and minimise land degradation. The key to any soil conservation is the maintenance of soil cover and minimisation of soil exposure and disturbance.

Methods to reduce erosion associated with crop and pasture establishment and production include:

- reducing the period of time the soil is exposed due to cultivation



PICTURE 44a+b: Farm tracks, fencelines and firebreaks are commonly eroded due to poor positioning, a lack of maintenance or an absence of control or diversion structures.

- working on the contour leaving vegetated strips between cultivated areas
- minimising or completely avoiding cultivation especially on sloping or fragile soils
- maintaining as much vegetative/ pasture cover as possible
- sowing crops or pastures at the earliest possible time
- using minimum or zero-tillage techniques
- rotating and managing stocking rates to maximise soil cover and optimise weight gain
- installing appropriate soil conservation structures specifically designed for the land use practice the rainfall intensity of the region.

6.6 PHYSICAL STRUCTURES FOR EROSION CONTROL

Physical structures should be combined with appropriate farming practices and land management to manage runoff and erosion. Structures alone are often insufficient to deal with the intensity and volumes of rainfall received in this environment. Soil conservation structures are designed to intercept overland flow (before it reaches a velocity where it begins to scour, rill or gully) and divert it safely to a stable outlet. Expert advice on layout, design and spacing of soil conservation structures may be needed, but all property drainage plans need to follow these basic principles:

- Use stable, naturally occurring flowlines where possible.
- Use designed and well constructed waterways where natural flowlines are unstable or do not exist.
- Ensure exit points are stable and capable of handling flow and volume otherwise the erosion is simply being moved from one location to another.
- Avoid using flowlines or areas with active gully heads.
- Keep flows within their natural catchment.
- Obtain a written agreement from neighbours before altering the point at which water leaves the property.

Biomass flowchart – How better pastures help the soil.

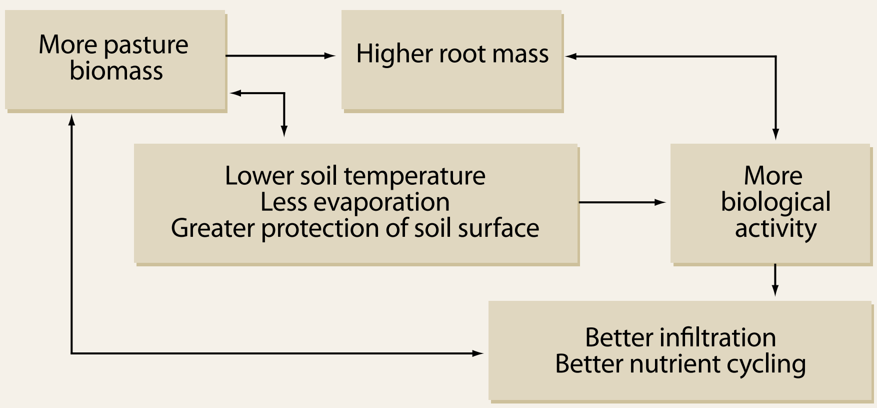


FIGURE 17: The benefits of biomass to soil health and protection. (Source: adapted from Roth 2004)

The shape and type of structure or bank depends on the situation and land use and the need for trafficability by different types of machinery.

Basic principles include:

- Choose the correct type of bank for the job it has to do
- Make the channel created by the bank large enough to carry runoff from heavy rain
- Design the bank outlet so that it discharges water without causing more erosion.

Structures include:

- diversion banks
- contour banks
- graded banks
- grassed waterways
- vegetated strips or hedges.

Diversion banks

Diversion banks are constructed on higher ground to intercept water and convey it to a designated waterway prior to reaching cropping areas. They are usually higher and wider and need to be grassed to carry high speed flows safely. The size and type of structure will be determined by the volume of water to be diverted. Water must be diverted to a "safe" area such as a natural storage or designed water way, otherwise the concentration and velocity of diverted water may cause severe erosion. Diversion banks are used to divert water from roads and fencelines and are often trafficable.

Contour banks

Contour banks are constructed across the slope with little or no grade. They are designed to intercept water and pond it behind the bank to increase infiltration and trap sediment. The banks allow water to travel across the slope at low speeds. Care must be taken to ensure water overflowing the bank can be redirected without causing more erosion. Contour banks should not be constructed in dispersible soils because of the risk of failure through tunnel erosion.

Most banks are constructed to cope with a one in five or one in 10 rainfall event. This could be a 200 mm/hour storm for five to six minutes or a 100 mm/hour storm for 30 minutes in the Douglas Daly area. Spacing between banks decreases as the slope increases. Water is directed into a waterway or safe drainage area.

Studies in the Daly Basin found that by using no-tillage, spacing between contour banks could be increased to twice that required for conventional cultivation while still reducing soil loss. Bank spacing will vary depending on location, seasonal rainfall and intensity. As a guide the following bank spacings are required.

Slope		Bank spacing
%	ratio	metres
0.5	1:200	120-130
1	1:100	90-100
2	1:50	60-70
3	1:33	50-60
4	1:25	45-50
5	1:20	40-45

TABLE 3: Recommended bank spacing according to slope. (Source: NRETAS)

PICTURE 45: Contour banks are important components of conservation farming programs but must be combined with mulch management.

Bank construction is expensive especially if required every 100 metres or less. Maintaining permanent and well vegetated land will reduce the need for and reliance on diversion banks in many instances.

Graded banks

Graded banks are similar to contour banks but run across the slope on a slight grade so that water can drain to a more stable area or watercourse. The grade is designed so that water flows quickly enough to carry sediment with it, but not so quickly that it causes erosion in the channel. The grade is up to 0.3% for bare earth channels or steeper if the channel is well vegetated.

How soil is moved in constructing a graded bank. The dashed line shows the shape of the finished graded bank and channel.

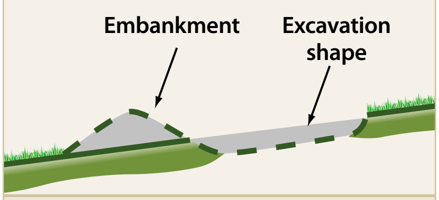


FIGURE 18: How soil is moved in constructing a graded bank. (Source: adapted from Jackson et al 1992)

Grassed waterways

Waterways are bands of permanent, dense, low vegetation, (usually grasses), planted down the slope at right angles to the contour. They are designed to intercept runoff and trap sediment before runoff concentrates or enters a watercourse. Waterways collect water from diversion, contour and graded banks and deliver it safely to natural water courses, dams or storage areas. They must be designed, well constructed and grassed to cope with large volumes of water. A common mistake is the construction of narrow waterways which cannot cope with the volumes of water experienced in this environment. Permanent grass pastures that have prostrate creeping habits such as Sabi, Jarra, Tully or Pangola are all excellent grasses for soil protection. Tufted, clumping grasses such as buffel are less suitable because water will often scour the soil between the plants.

Vegetated strips or hedges

Vegetated strips or hedges are a viable and practical alternative to structures and work extremely well. Such strips are areas that are maintained as natural vegetation or pasture and are spaced at various intervals along the contour. The strips reduce the velocity and volume of water moving down the slope by allowing increased infiltration. Cultivation may be carried out above and below each strip. The width of vegetated strips will be determined by the slope, soil type, land use and expected rainfall intensity. In many instances vegetated strips may be a cheaper and more effective alternative to constructing contour banks.

Hedges are dense rows of vegetation positioned strategically in areas of high flow, to slow water velocity and entrap sediment. Vetiver grass (*Chrysopogon zizanioides*) has been trialled extensively throughout the tropics and the Semi-arid Tropics. The grass is effective in a wide range of soils and rainfalls and has been used in a hedge to slow water flow and reduce gully erosion. When a hedge is established it will slow peak overland water flows by up to 47%. Lighter flows are stopped and slowly filtered through the hedge. This allows more water to infiltrate providing a microclimate near the hedge that is conducive to plant

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PICTURE 46: Physical structures are not always adequate as an erosion control measure and must be combined with surface cover and to be effective.

Experience has shown that soil cover is more effective than earthworks in reducing erosion in this environment.

growth. The hedge traps silt and debris which also improves the immediate environment.

Physical structures, contour farming, strip cultivation and vegetated strips all play an important role in soil conservation. Individually, however they are inadequate as complete erosion control measures. Erosion between contour banks often occurs under intense rainfall and poorly designed or maintained structures will concentrate water and lead to soil erosion. The intensity and amount of rainfall received in the Top End often makes appropriate design difficult and expensive. To be effective, physical structures must be combined with soil surface cover and permanently vegetated areas.

6.7 ASSESSING THE RISKS OF EROSION IN FARMING SYSTEMS

Producers and land developers need to ascertain how their activities and management will impact on the land in terms of erosion and degradation. While nobody sets out to degrade the resource it is often difficult to predict the impacts, especially for those new to the region. Experience tells us much about how different practices impact on the land but gaining this experience can be a very costly exercise in terms of financial loss and environmental degradation. Predictive tools which model erosion rates allow the risks of different land use practices in specific environments to be assessed.

A soil loss prediction formula, known as the Universal Soil Loss Equation was developed in the US in the 1950s. This has been modified in recent times and is now known as the Revised Universal Soil Loss Equation (RUSLE). It calculates soil loss through complex computer models based on:

- rainfall intensity
- soil erodibility
- slope length and gradient
- groundcover
- prevention practices.

While the first two factors are fixed for any particular situation, management practices have a significant impact on the calculation by shortening slope length, establishing groundcover and introducing preventative practices.

Constructing an erosion risk matrix which incorporates slope, the management practice, soil cover and land condition is a crude but helpful way to assess erosion risks. The premise behind the matrix is that there are certain “givens” or conditions which heighten the risks of erosion. At one end of the scale are the most conservative practices and best land condition which minimise the risk, while at the other end of the scale are the conditions which lead to major or catastrophic erosion. There are several scenarios between these two conditions which determine erosion risk. Using a matrix which incorporates land condition, practice and slope will help determine the likelihood and severity of erosion. The conditions at each end of the scale are:

- low slope (< 1%), high mulch cover and conservative grazing/ farming - will minimise erosion risk
- slopes 2% or greater with no cover or soil conservation structures - will maximise erosion risk.

The matrix also allows different scenarios to be compared. By multiplying the likelihood by the severity of erosion (1 = low to 5 =

PICTURE 47: Massive sheet erosion results in the loss of top soil, plant nutrients, carbon and soil biodiversity.

high) the relative risk associated with different management and land conditions can be compared. While these scores are arbitrary, if the process is based on experience it demonstrates the heightened erosion risk under specific land use practices or scenarios. Situations with scores above 15 are those where erosion is almost certain and should ring warning bells. The matrix is simply a starting point for producers and land managers to assess erosion risks, before any development or practice is implemented. Additional professional advice should always be sought prior to development and where erosion and sediment control plans are necessary.

LIKELIHOOD		Severity of erosion and land degradation on sandy red earths.				
		Insignificant	Minor	Moderate	Major	Extreme
	Score	1	2	3	4	5
Almost certain	5			15 Cultivated land > 2% with soil conservation structures	20 Fully cultivated, bare soils, pastures heavily grazed.	25 Fully cultivated or overgrazed land without soil conservation structures > 2% slope
Likely	4			12 Native vegetation or improved pasture heavily grazed	16 Heavily grazed native vegetation > 2% slope	20 Burnt country overgrazed throughout the wet season
Possible	3		6 Native vegetation or improved pasture lightly grazed	9 Cropped using no-tillage on slopes > 2%		
Unlikely	2	2 Farmed using no-tillage or grazed lightly with erosion control structures	4 Cropped using no-tillage and mulch < 2%			
Rare	1					

TABLE 4: Examples of land management scenarios and associated erosion risks. Likelihood and severity scores are multiplied to determine an overall risk score. Scores of one to four represent a low risk, five to 12 a moderate risk and 15 to 25 a high to extreme risk.

PICTURE 48: Land preparation after clearing is a high risk period for erosion; sowing a cover crop or pasture as soon as practicable will reduce the risks.
PICTURE 49: Land management directly influences erosion. Over-grazing permanently degrades soils and pastures.

Slope	Land condition and management	Erosion likelihood		Erosion severity		Total score
Soil < 2% slope	Vegetated with improved perennial pasture and lightly grazed	Possible	3	Minor	2	6
	Vegetated with improved perennial pasture and heavily grazed	Likely	4	Moderate	3	12
	Bare, fully cultivated without vegetation cover	Almost certain	5	Major	4	20
	Cropped using no-till or minimum tillage and mulch cover	Unlikely	2	Minor	2	4
	Uncleared native vegetation, lightly grazed	Possible	3	Minor	2	6
	Uncleared native vegetation, heavily grazed	Likely	4	Moderate	3	12
	Farmed using conservation tillage or grazed lightly with erosion control structures	Rare	1	Minor	2	2
Soil ≥ 2% slope	Vegetated with improved perennial pasture, lightly grazed	Likely	4	Moderate	3	12
	Vegetated with improved perennial pasture, heavily grazed	Almost certain	5	Major	4	20
	Bare, fully cultivated without vegetation cover	Almost certain	5	Extreme	5	25
	Cropped using minimum tillage and mulch cover	Possible	3	Moderate	3	9
	Uncleared native vegetation, lightly grazed	Possible	3	Minor	2	6
	Uncleared native vegetation, heavily grazed	Almost certain	5	Major	4	20
	Farmed using conservation tillage or grazed lightly with erosion control structures	Unlikely	2	Minor	2	4
	Fully cultivated and mounded bare soil	Almost certain	5	Extreme	5	25

When slope, condition and land management are put into a matrix and the likelihood and severity of erosion are scored (1 = low to 5 = high) individually and then multiplied, the risks are clearly evident. Those scenarios which score 15 and above are situations where erosion is almost certain and the severity will be major. The matrix will help ascertain the risks of erosion before practices are implemented.

TABLE 5: Risk assessment for erosion on Kandosols (red earths) as related to slope and land management in the Top End.

PICTURE 50: Sealed and cracked soil devoid of protective cover (photo courtesy NRETAS).

7 Herbicides: part of a more flexible system!

Conservation farming and no-tillage systems rely more heavily on herbicides which is one of the trade-offs in having improved land management and reduced land degradation. Many of the newly developed herbicides have low off-target toxicity and are applied in very low volumes.

Agricultural chemicals are a major component of modern farming and have enabled dramatic increases in farm productivity over the past 50 years. Herbicides are the principal weed control agents in conservation farming. They provide more options for weed management and land preparation, reducing the need for cultivation and can be applied in a fraction of the time it takes to cultivate an equivalent area.

Herbicides such as glyphosate are designed to give total control of weeds prior to sowing and allow crop establishment without weed competition. Herbicide may be applied from several days to immediately prior to sowing depending upon weather and moisture conditions. In many cases, one application of herbicide may be adequate or a follow-up application may be required to achieve better control. Spraying and sowing using no-tillage can often be undertaken on the same day, resulting in significant time, energy and cost savings.

7.1 GETTING THE BEST FROM HERBICIDES

The performance of herbicides in tropical environments can sometimes be erratic. This is particularly true of soil-applied herbicides where high temperatures, intense rainfall and low soil organic matter results in rapid breakdown and loss through leaching. High mulch levels also reduce the effectiveness of many soil applied herbicides. Manipulation of weeds by grazing, slashing or strategic cultivation can reduce the costs and increase the efficiency of herbicides. The older and more mature the weeds, the higher the rate of chemical required for control.

As a result of heavy rain, some herbicides may concentrate in the seed furrow resulting in crop injury. This effect is more pronounced in sandy soils where the absence of clay permits the herbicide to move freely. Herbicides also have the potential to leach into aquifers and contaminate water. Precise calibration and application is required to minimise such impacts.

Herbicide application rates must be adjusted for soil type, weed size and conditions to avoid crop injury and environmental contamination. Experience has shown that many residual herbicides have significantly reduced activity and persistence under tropical conditions compared to temperate climates, due to more rapid breakdown by temperature, moisture and biological processes.

Knockdown and foliar herbicides such as glyphosate are generally more predictable than some soil applied herbicides. The effectiveness of foliar herbicides is influenced by environmental conditions. Windy or hot dry periods should be avoided when applying such herbicides.

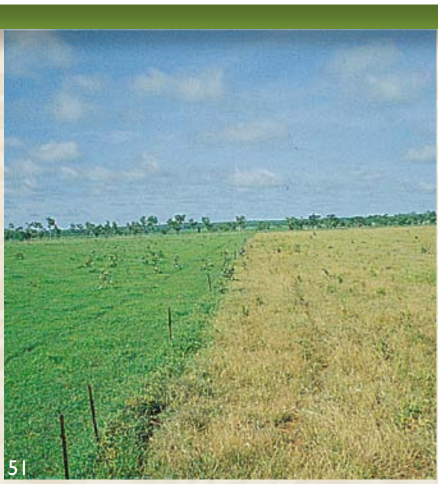
Young, actively growing weeds are more easily controlled. Moisture stressed or dusty plants generally do not take up sufficient herbicide to achieve adequate control.

Foliar herbicide is best applied in the early morning when temperatures are moderate, plants are fresh and there is a 3 to 6 km/hr breeze to assist penetration into the foliage. Recommended rain-fast periods should be observed for various chemicals given the frequency and intensity of tropical storms. Good quality water must be used as hard or dirty water will reduce effectiveness or may cause complete failure. Various wetting agents and surfactants are available and recommended by chemical manufacturers to increase herbicide effectiveness. Certain residual herbicides may be added to glyphosate to give extended control of specific weeds. Recommendations appear on all herbicide labels regarding the use of mixtures, wetting agents and adjuvants.

Boomsprays are the main method by which herbicides are applied but aerial application is becoming more popular in the NT. Poorly maintained spraying equipment is a major cause of chemical waste, spray failure, crop damage and environmental contamination. Boomsprays must be serviced and calibrated regularly. Correct nozzle selection, application rate and operating pressure are the three fundamental aspects for achieving safe and effective chemical application. Advances in spray technology, including nozzle design, have greatly enhanced chemical deposition and weed control as well as providing improved operator and environmental safety. Expert advice should be sought on the best components for specific equipment and applications.

7.2 BIOTECHNOLOGY AND DEVELOPMENTS IN HERBICIDE TECHNOLOGY

Since the introduction of genetically modified (GM) crops in America in 1996, farmers have reduced and, in some cases, completely stopped cultivating. GM crops are now commonly used in the US and herbicide resistant crops such as Roundup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PICTURE 51: Herbicides allow greater flexibility when preparing land for planting and reduce the reliance on cultivation.

Ready® maize and soybeans have outstripped conventional crops in terms of area. This has allowed the strategic use of glyphosate in the crop to kill competing weeds. As a result of GM crops and associated herbicide technology, no-till farming in the US has increased by 35%. World-wide, there is an estimated 60 million hectares of no-tillage crops with the biggest increases in Latin America due to the need to address the catastrophic erosion caused by traditional cultivation. The expansion of no-till has been primarily due to the availability of effective and relatively cheap herbicides (such as glyphosate) and more recently, the introduction of herbicide-resistant GM crops.

Genetically modified crops and conservation farming increase reliance on herbicides, but reduce energy, machinery and labour requirements, provide better weed control and reduce soil degradation. Another development in weed control is the introduction of the CLEARFIELD® Production System. Clearfield Technology is a system of weed management which combines the use of imidazolinone-tolerant crops and commercially formulated herbicides (i.e. Spinnaker® and related herbicides). Mutagenesis, recognised as a traditional breeding technique, is used to develop herbicide-tolerant crop varieties and the system allows imidazolinone herbicides to be used without damage.

This is an important development as the system provides effective and extended control of many difficult-to-control perennial grasses, broadleaves and nutgrass. Lightning® (imazethapyr and imazapyr), is the herbicide specifically registered for use in the Clearfield® system which is suited to conservation tillage systems.

7.3 HERBICIDE RESISTANCE – A THREAT TO WEED AND LAND MANAGEMENT

Herbicide resistance is the inherited ability of a plant to survive and reproduce following the application of herbicide that would normally kill other plants of the same species. Herbicide resistance can occur as a result of mutation but the majority of resistance occurs as a result of selection pressure imposed by the herbicide. A small number of tolerant or resistant weeds (known as biotypes) may exist in any weed population. When herbicide is applied the susceptible weeds are killed leaving the tolerant ones to reproduce until the population is largely composed of resistant weeds.

Herbicide resistance was first detected in the 1970s and since that time hundreds of weeds have become resistant to different groups of herbicide. There is evidence that a number of weeds in the US are now resistant to glyphosate. In Australia, annual ryegrass (*Lolium rigidum*), awnless barnyard grass (*Echinola colona*) and liverseed grass (*Urochloa panicoides*) have developed glyphosate resistance.

Glyphosate is one of the products which has revolutionised agriculture and is heavily relied on for weed control, land management and conservation farming throughout the world. It has been so successful that it has permitted millions of hectares of farm land worldwide to be


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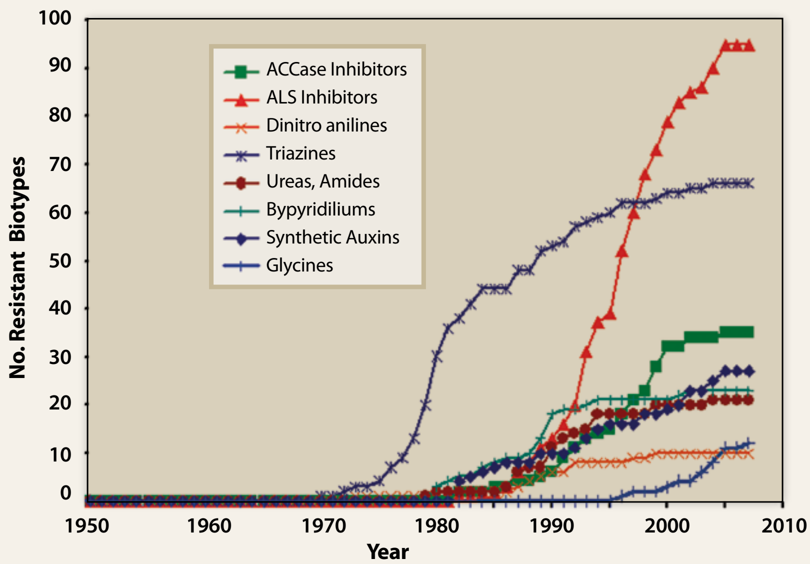
PICTURE 52: Wick-wiper used for applying herbicide to tall weeds.

Herbicide resistance management should be an integral part of overall weed management.



Source: Heap, I. The International Survey of Herbicide Resistant Weeds. Online. Internet. November 20, 2009. www.weedscience.com

FIGURE 19: The development of resistance to each of the major herbicide groups, showing an increase in the number of weeds resistant to glyphosate (glycine group, bottom blue line) since 2002.

no-tilled and in the process reduced erosion and land degradation. Roundup Ready® crops are also causing concern in the US, in relation to resistance in weeds due to the increased reliance on glyphosate. The loss of glyphosate as a weed control agent would seriously compromise farming and land management all over the world.

Specific factors are often present in areas where glyphosate resistance has developed. These include:

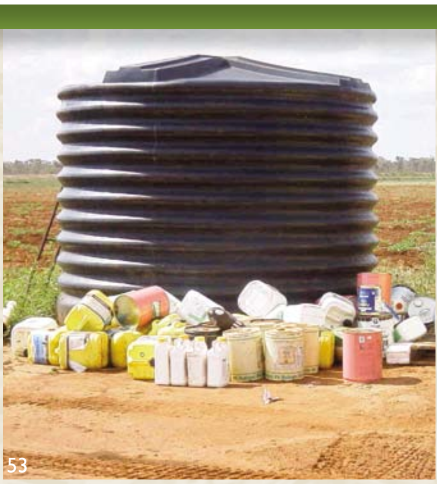
- limited or no crop rotation
- limited or no-tillage practices
- a high dependency on glyphosate alone or a limited use of other herbicides
- reduced rates of glyphosate.

These resistant populations have been found in dryland cropping systems that have relied on continuous glyphosate applications as the only method of weed control.

Herbicide use must be managed as part of an integrated weed control program which involves:

- using crop and pasture rotations
- monitoring weeds before and after herbicide applications for spray failures
- controlling weeds early when they are small
- using the right chemical, rate and timing in relation to weather, weed spectrum and size
- adding or rotating with other herbicide groups to broaden herbicide spectrum and effectiveness
- using strategic cultivation where necessary for hard-to-kill weeds
- controlling weeds and preventing seed set by slashing or physical removal
- using high plant populations, good nutrition and mulch to reduce reliance on herbicides.

Herbicide resistance is a real threat to the viability and sustainability of farming, land management and weed control in the Top End and strategies need to be in place to avoid it.



PICTURE 53: Chemicals should be kept in a lockable storage and empty drums should be triple rinsed and disposed of at an approved landfill or municipal facility.

The number of resistant species is on the increase and the loss of glyphosate as a weed control agent would be disastrous for sustainable farming systems and weed management generally.

7.4 CHEMICAL SAFETY

With agricultural chemicals comes a responsibility to use them wisely and protect the operator and the environment.

Operator safety

Farm chemicals are labelled according to their uses and toxicity. A number of hazardous and toxic herbicides are available, however most herbicides used and recommended in the Top End for conservation farming (i.e. glyphosate) have low toxicities and are safe on both the operator and the environment if used in accordance with label recommendations.

Most poisoning with agricultural chemicals occurs through skin contact but inhalation and accidental oral poisoning have occurred. Full protective clothing in the tropics is often impractical. Gloves, long sleeves, long pants, protective boots, eyewear and a face mask will give adequate protection when handling most herbicides. Clean water and soap should be available to decontaminate splashes or spills. Suction devices on boomsprays eliminate the need to handle the concentrate. Operators have a responsibility to protect others and should store chemicals in original containers in secure areas inaccessible to unauthorised persons or children. Chemical sheds should be locked when not in use. Common sense, respect for the chemical, reading the label and observing safety directions are essential for operator and environmental safety.

Environmental safety

Leaching of chemicals and associated environmental problems have occurred in some intensive farming areas in Australia and other parts of the world. This has resulted in the withdrawal or banning of some products. Atrazine has been taken off the market in the European Union and its use will be limited in the future as further restrictions are imposed on the availability and use of many farm chemicals.

Herbicides are broken down by sunlight and biological and chemical action. Some agricultural chemicals may move off-site in runoff or by leaching. The amount lost is determined by the interaction of rainfall, temperature, soil type, organic matter and herbicide type. Light sandy soils and those low in organic matter are more prone to herbicide leaching. In heavy soils, herbicides are bound to clay particles thereby reducing the amount of chemical leached. Herbicides such as glyphosate are bound strongly to the soil, while others like atrazine, dicamba and hexazinone can leach readily and can damage sensitive crops or plants.

The highest concentration of chemical is found in sediment, but 75 to 99% of chemical losses occur in runoff water. Chemical losses due to leaching may increase in conservation farming systems in some situations, but total losses will be lower due to reduced sediment loss and runoff.

Glyphosate, the main herbicide currently used in conservation farming in the Top End, has a relatively low toxicity. It is broken down by soil microbes to produce plant nutrients such as phosphoric acid, ammonia and carbon dioxide.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PICTURE 54+55: Herbicide damage through spray drift is more likely to occur with aerial spraying in this hot and humid environment.

Glyphosate poses a minimal threat to the environment when used in accordance with recommendations but like any chemical, care in its handling and application is essential.

The environmental impact is minimised by using correctly calibrated and maintained equipment, selecting the least toxic chemicals, using all of the chemical for what it was intended, rinsing and appropriate disposal of containers and minimising spillage or overuse. Better equipment and more environmentally sensitive products such as recyclable drums, dissolvable bags, ultra low rate chemicals and low drift nozzles (i.e. air induction nozzles) should be used where appropriate.

The Australian Pesticides and Veterinary Medicines Authority is the Australian Government's regulator on pesticides and veterinary medicines. The Authority publishes a wide variety of data and information on agricultural chemicals and related information, which is freely available on the web (www.apvma.gov.au).

PICTURE 56: Aerial application of herbicides and fertiliser is becoming more popular in the Top End. Extreme care must be taken to avoid drift and over-spray to protect neighbouring crops and the environment.

8 Crops suitable for the Top End

Grain production in the Top End is a minor industry at present, however a range of crops and pastures are suited to this region. Crop production is limited due the distance from mainstream southern markets, production and transport costs and the lack of local markets. Considerable scope exists for niche cropping enterprises with the development of markets and potential opportunities for fibre and biofuel crops.

Crops suited to the region include coarse grains, grain legumes, oilseeds, forage crops, grass and legume hay crops, pasture seed and high value timber. As with most crops, new improved varieties have been developed but may not yet have been tested in the Top End.

8.1 COARSE GRAINS

Sorghum (*Sorghum bicolor*)

Grain sorghum has been the main grain crop grown in the NT in the past and is used for stockfeed. While it can be grown from Darwin to Daly Waters, the Katherine-Daly region is the preferred growing region due to the prevalence of head moulds in the higher rainfall zones, especially in extended wet seasons. Sorghum is suited to a range of well drained soil types, including gravelly ironstone soils, Blain sands and Tippera clay loams. Average yields range from 2 to 3 t/ha. Paddock yields of over 4 t/ha have been achieved. The best and most reliable sorghum yields have been achieved under conservation tillage, where weed control is good and 80 to 100 kg/ha of N is split applied.

Different cultivars are available for different sowing times and geographical areas. Short-season varieties are recommended for lower rainfall areas south of Katherine and long-season varieties are best suited to the more reliable areas further north. Sorghum is well suited to a rotation with pasture legumes such as Cavalcade and Bundey because it provides excellent mulch for soil protection and the stubble offers valuable dry season grazing.

Maize (*Zea mays*)

Maize is grown for the local stockfeed market and is increasingly being used in a rotation with peanuts under irrigation. Small quantities of maize are grown for the starch, high amylase and pop-corn markets in southern Australia. Processing and popcorn varieties usually have considerably lower yields than feed varieties but are higher value products.

Maize is a high input crop and requires good moisture and nutrition. In dryland situations its establishment and performance is enhanced by no-tillage and mulch cover. Maize has a higher yield potential than sorghum but is less tolerant to moisture or nutrient stress. Dryland maize is not recommended on light soils in the wet season due to high soil temperatures, reduced moisture retention and nutritional problems associated with sandy soils and low nutrient retention. Poor rainfall distribution makes dryland maize a risky option south of Douglas Daly, but is recommended for the higher rainfall areas and heavier soil types (i.e. clay loams) of the Douglas Daly region and further north.

Historically, dryland maize yields in the Douglas Daly have been low with an average 2 t/ha and a high of 5 t/ha. This reflects the use of old varieties and the fact that many crops were grown on light soils and without the benefit of conservation tillage.

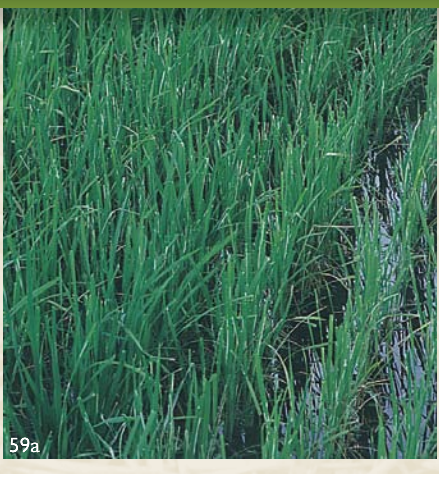
With improved varieties and management dryland maize, should achieve 4 to 6t/ha and irrigated maize should yield 9 to 12 t/ha. Maize produces good levels of mulch and the stubble is a useful stockfeed in the dry season. Maize can be double-cropped with peanuts and is ideally suited to irrigated production, where nutrients and moisture are balanced to achieve high yields. Irrigated maize will require 5 to 7 ML/ha of water depending on cultivar maturity and planting time.

Rice (*Oryza sativa*)

Rice was grown in the 1950s and 60s during the early days of agricultural development under what was originally known as the Humpty Doo Rice project. The project failed due to poor technology, high costs of production, management issues, inferior varieties and an influx of magpie geese. Rice production continued on a small scale on upland areas (over 1200 mm rainfall) and coastal floodplains of the NT, until the late 1990s. It is sometimes grown by individual producers for stockfeed. Two local varieties were developed: NTR 587, for ponded culture; and NTR 426, a shorter variety for upland production. Commercial yields of 2 to 4 t/ha from flooded rice and around 2 t/ha from upland rice were achieved and used as stockfeed. Rice was favoured for its stubble which has about 6 to 7% protein and provides quality dry season grazing. Rice stubble also makes good quality hay.

There has been a renewed interest in the possibility of growing rice in the NT for human consumption as a consequence of drought and diminishing water resources in southern Australia. The outcome of this interest remains to be seen.

PICTURE 57: Grain sorghum is used for stock feed and has good stubble grazing value.
PICTURE 58: Maize is a high yielding crop and ideally suited to irrigated production.



59a

59b

PICTURE 59a+b: Rice is was formerly grown on the northern floodplains of the Top End and is being re-evaluated due to water shortages in southern Australia.

8.2 LEGUME AND OILSEED CROPS

Mungbean (*Vigna radiata*)

Mungbean is a drought tolerant, quick maturing grain legume that is suitable for the Douglas Daly, Katherine and Daly Waters regions. Mungbean is adapted to most well drained soils with moderate phosphorus and zinc levels. Mungbean seed contains 20 to 27% protein and is used for human consumption as either bean sprouts or as dhal (splits) in Asian cooking. High quality beans are required for human consumption and low quality beans are used for stockfeed. Shangtung and Putland were the varieties recommended for the NT in the 1990s. Putland is a tall variety and has better weathering and pod shattering resistance than Shangtung. Average yields of 1 to 2 t/ha can be expected. Mungbean is relatively cheap to grow and is suitable for a rotation with sorghum and sesame. It provides 20 to 40 kg/ha of organic N, is quick to establish and is useful as an opportunity grain, hay or green manure crop.

Soybean (*Glycine max*)

Soybean is a subtropical oilseed legume and one of the world's most valuable crops. Soybean seed has one of the highest nutritive values of any plant. The seed contains between 38 and 45% protein and 20% oil. It was evaluated for biofuel production in the Top End in 2007 but the global recession of 2008-09 and poor biofuel prices stopped the project. Buchannan and Leichhardt were the main varieties grown in the Top End. Leichhardt was a more productive and tropically adapted variety. New varieties are available and need to be assessed in the Top End, as these may yield better than the traditional varieties.

Soybean is generally less drought tolerant and more sensitive to nutrient stress than mungbean and is recommended for the heavier soil types and higher rainfall areas. It is suitable for a rotation with maize, sorghum, sesame or rice and can also be grown under irrigation. Commercial yields of 1 to 3 t/ha under dryland conditions and 3 to 5 t/ha under irrigation are possible. Sowing into mulch greatly enhances soybean establishment and performance. The major agronomic issues are achieving good establishment and controlling pod-sucking insects and legume weeds such as senna.

Sesame (*Sesamum indicum*)

Sesame is a tropical crop well adapted to the Top End and has good domestic and international market prospects. Most of the sesame used in Australia is imported, so market opportunities exist. Despite extensive research over 20 years, it has not been commercially adopted in the NT. Efficient harvesting is still a major issue with sesame. Seed losses are high due to pods opening and shattering at maturity and minimising grain loss is a major challenge. Headers equipped with air-fronts, extended tables and the use of chemical desiccants can help to reduce seed loss considerably.

Sesame seed contains 45 to 55% premium oil and 19 to 25% protein. The seed is used in confectionary, breads, cereals and tahini paste. Two cultivars, Edith and Giles have been developed in the NT. Sesame is drought tolerant and

PICTURE 60: Mungbean is a versatile grain legume which can be grown as a food source, green manure or grazing crop.
PICTURE 61: Soybean is a valuable oilseed which contains up to 20% oil and 45% protein.

suited to free draining soils in the 550 to 1200 mm rainfall areas of the Katherine/Daly Basin. Commercial yields average 300 to 500 kg/ha but the potential could be 800 kg to 1 t/ha with improved harvesting techniques and the availability of varieties which are less prone to shattering. Sesame stubble provides little mulch or useful animal feed. Sesame has good potential as a specialty crop if harvesting, marketing and processing issues can be improved.

Peanut (*Arachis hypogaea*)

Peanut is a high value, high input legume crop grown for human consumption as confectionary and oil. Peanuts are suited to the free-draining sandy loams of the Daly Basin. They are also successfully grown on the heavier clay loams at Katherine under irrigation where soil moisture content is regulated for efficient digging.

Dryland peanut production is possible in areas with over 1000 mm of seasonal rainfall but yields can be variable depending on rainfall distribution. Short season varieties are recommended for dryland production and produce yields of 2.0 to 3.5 t/ha. Supplementary irrigation is recommended south of Douglas Daly, which is a more reliable dryland production area than the Katherine region. Fully irrigated crops produce 4.0 to 5.5 t/ha - close to double that of dryland crops.

Peanuts can contribute up to 100 to 200 kg/ha of N to the system depending on growth and biomass production. They are ideally suited to a rotation with maize, sorghum or sesame. Timely digging and threshing is critical to ensure high quality, low aflotoxin levels and high kernel recovery. Peanut stubble is a good source of animal feed, which can be grazed or baled.

Hay yields vary from about 2.0 to 4.5 t/ha depending on harvesting time, moisture content and variety. While peanut hay is a valuable livestock feed and contributes to overall profitability, hay can remove 50 to 100 kg/ha of N from the system and leaves the soil exposed and prone to erosion. Peanut stubble should ideally be left on the soil for a more sustainable farming system.


Peanuts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PICTURE 62: Sesame is a tropical crop with good market and production potential; however efficient harvesting still remains the greatest challenge.
PICTURE 63: A high yielding peanut crop which has been dug and is ready for harvest.

Forage sorghum at the head stage.

Several peanut cultivars are now produced in the NT with different maturities, disease tolerance, growth characteristics and yield potential. Short season lines like Walter will mature up to four weeks earlier than varieties such as Holt or Sutherland, which may take up to 20 weeks to mature. The major agronomic issues in peanut production include leaf disease, leaf and flower eating caterpillars (i.e. *Heliothis* and *Spodoptera* species) and vining weeds which interfere with digging operations.

8.3 FORAGE CROPS

The demand for fodder in the NT is closely tied to the live cattle trade to South East Asia. As cattle exports increase so does the demand for fodder. Fodder quality is also becoming increasingly important as the market becomes more discerning. Good quality hay is required for the processing of pellets which are used prior to and during shipping of cattle.

Hybrid forage sorghum (*Sorghum x Sorghum*)

Forage sorghum hybrids are perennial, high yielding fodder crops suited to wet season or irrigated dry season production. Several hybrid forage sorghums are available which are suitable for either grazing or haymaking. Digestibility and protein content decrease significantly with maturity, therefore early harvesting, or grazing is necessary to maintain forage quality. Forage sorghums can produce cyanogenic glucosides under certain conditions and levels may become toxic if the crop is heavily fertilised with N or is suddenly water stressed. The compounds are converted to hydrogen cyanide (commonly called prussic acid) when eaten and stock losses may occur. Prussic acid poisoning is a real but relatively minor occurrence if good grazing management is observed and stock and crop conditions are carefully monitored. Hungry animals should not be put on excessively lush forage sorghum or crops which are suddenly stressed. Making hay may reduce prussic acid levels but will not completely eliminate it.

Forage sorghum can yield anything from 5 to 12 t/ha over the wet season depending on cultivar, time

PICTURE 64: Round bale fodder is popular with smaller livestock operations and horse owners.
PICTURE 65: Forage sorghum at the ideal cutting stage.

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of planting, level of nutrition and harvest maturity. Under irrigation it usually yields 4 to 6 t/ha per harvest and may be cut four to five times during the season. Forage sorghum stands and yields decline with repeated harvests. Forage sorghum is suited to a rotation with legume pastures as a means of utilising accumulated soil N and as a break crop for controlling weeds and insect pests. It is also an ideal initial crop to sow when developing new country due to its rapid establishment and can be undersown with perennial pasture to ensure rapid ground cover.

Pearl millet (*Pennisetum typhoides*)

Pearl millet is an annual, open pollinated forage and grain crop. It produces yields of up to 14 t/ha but forage quality deteriorates on maturity. It is deep rooted, drought tolerant and has been used as a horticultural green manure crop to recover leached nutrients and build soil organic matter. The grain is used for stockfeed and bird seed.

Cultivars Ingrid Pearl, Katherine Pearl and Siromill are available but hybrids have not performed as well as the local cultivars under NT conditions. Ingrid flowers one to two weeks earlier and produces higher seed yields than Katherine Pearl. Millet is an alternative to forage sorghum, does not produce prussic acid and is relatively inexpensive to grow. Pearl millet is suitable for rotation with legume pastures, will utilise accumulated soil N and assist in weed control. It is ideal for sowing on newly developed country where rapid ground cover is required.

Lablab (*Lablab purpureus*)

Lablab is a vigorous, twining, annual legume which is grown for seed, forage or as a green manure crop. Lablab has a longer growing season, higher seed yield and better tolerance to root and stem rots than cowpea. It matures up to 60 days after cowpea depending on variety. Lablab is drought tolerant but has poor tolerance to waterlogging.

Varieties recommended are Rongai (a white flowered, late maturing variety) and Highworth, (blue or purple flowered), which matures approximately a month earlier.

Pearl millet is a useful forage and excellent green manure and cover crop.

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PICTURE 66: Pearl millet is a useful forage and excellent green manure and cover crop.
PICTURE 67: Lablab in flower and setting seed.

Rongai is suited to the higher rainfall areas of the Top End and Highworth to Katherine and further south. Seed inoculation is recommended when sowing lablab. Forage yields range from 4 to 6 t/ha and crude protein ranges from 10 to 22%. Lablab can be grown in conjunction with forage sorghum to improve forage quality.

Cowpea (*Vigna unguiculata*)

Cowpea is an annual twining legume suitable as a green manure, fodder or seed crop. Meringa and Palmyra are grown in the NT. Cowpea is drought hardy, suited to a wide range of well drained soils and will tolerate short periods of waterlogging. Existing cowpea varieties flower and mature earlier than lablab. They require moderate phosphorus levels and must be inoculated when grown in new areas.

Cowpea produces dry matter yields of 3 to 6 t/ha with a crude protein of 10 to 20%, depending upon time of harvest. It may be grown with forage sorghum to improve fodder quality. Seed yields range from 200 to 1000 kg/ha.

Irrigated maize at establishment.

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PICTURE 68: Lablab is an ideal companion legume with forage sorghum.
PICTURE 69: Cowpea is an alternative legume seed or green manure crop.

9 Pastures in farming systems

Farming and grazing systems in the Top End rely on both native and improved pastures. The sustainability of agriculture is dependant upon the health, grazing management and productivity of pastures. Permanent pasture will play an increasing role in carbon sequestration, improving the productivity, fertility and biodiversity of soils and moderating the effects of climate change.

9.1 NATIVE PASTURES

Native pastures carry most of the livestock in the NT and will remain the mainstay of extensive livestock production in drier areas. They support animal production in areas where the soil has relatively poor natural fertility or where rainfall is low or unreliable. Native pastures are also an integral part of the farming system on many mixed farming properties in the higher rainfall zones of the Top End.

Native pastures have a number of limitations including low production levels and carrying capacities. They have short productive periods during the wet season, after which feed quality rapidly deteriorates. When mature, native pastures are low in minerals and digestible energy and are unable to support live weight gain (LWG).

Native pastures generally do not respond well to fertiliser, are intolerant of heavy grazing and are easily degraded.

Many producers run their breeder herds on native pastures and use their improved pastures and crop stubbles for growing weaned animals. Native pastures can be improved by introducing exotic legumes such as stylos or Wynn cassia and applying phosphorus and sulphur fertiliser to improve legume productivity. However, in most cases it is more efficient to supply phosphorus directly to animals as a mineral supplement rather than applying it over vast areas of native pasture.

PASTURE COMPOSITION (% DRY MATTER)					
	End of wet (April)		End of dry (September)		Maintenance* level required
	Native pasture	Improved pasture	Native pasture	Improved pasture	
Crude protein (%)	3-6	8-10	1-3	4-10	7
Phosphorus (%)	0.03-0.05	0.09-0.14	0.02	0.04	0.12-0.18
Digestibility(%)	30-54	41-65	30-43	38-57	approx 50

*Maintenance refers to the feed intake which is required to maintain an animal's weight.

TABLE 6: Average nutrient content of native and improved pasture in the Top End.

9.2 IMPROVED PASTURES

Improved pastures are becoming more important due to the demand for more productive grazing and the increasing fodder requirements of the live cattle trade. Approximately 50 000 to 70 000 tonnes of hay are produced annually in the Top End largely from improved pastures; a further 40 000 to 50 000 tonnes of processed cubes and pellets are imported annually from southern states to meet export cattle requirements.

Improved pastures play a major role in enhancing soil fertility and structure and improving animal nutrition and reproduction. The performance, persistence and profitability of any pasture will depend upon soil type, moisture, fertility and management.

Pastures also have a positive environmental role in fixing carbon, reducing erosion, improving the quality of ground water and reducing the activity of many chemical residues.

Introduced pasture grasses

Sabi grass (*Urochloa mosambicensis*) cv Nixon

Nixon Sabi grass is a trailing perennial grass with short rhizomes and erect flowering stems growing to 80 cm. It is suited to a range of soil types in areas with an annual rainfall of 500 to 1200 mm. It is a popular, productive and drought tolerant pasture suited to the Katherine-Daly Basin. Sabi responds well to early wet season storms but does not tolerate waterlogging.

Sabi grass is palatable, tolerates close grazing, is suitable for mixed pastures and makes good quality hay. Hay yields of 4 to 8 t/ha with a crude protein of up 10% can be expected. Sabi grass provides excellent mulch and is ideal for conservation tillage systems. It is easily controlled with glyphosate and crops can be sown into Sabi grass pastures using no-tillage. Sabi will re-establish from residual seed after a one to two year cropping phase.

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PICTURE 70: Native pastures in the Top End have relatively low productivity and need to be lightly stocked to remain sustainable.
PICTURE 71: Irrigated fodder production is becoming more popular as a crop option.

Jarra grass hay crop ready for baling.

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72b

PICTURE 72a+b: Sabi grass is a valuable pasture and excellent ground cover for conservation tillage systems.

Pangola is suited to all forms of livestock grazing but must be planted vegetatively (photo courtesy DoR).

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Gamba grass (*Andropogan gayanus*)

Gamba grass is now a declared weed and can no longer be sown as a pasture in the NT. It must now be managed through grazing or spraying to prevent its spread in the northern Top End and must be eradicated in national parks and areas south of Katherine.

Gamba is a tall perennial, tussocky grass which forms dense clumps. It will support high stocking rates (four to five beasts per hectare) during the wet season, if well fertilised. Gamba grows to over four metres and forms an impenetrable stand if neglected. Mature stands consist of low quality indigestible dry matter and have high fuel loads which pose a serious fire risk in the dry season. Gamba seeds prolifically and spreads rapidly into disturbed areas with the potential to invade conservation areas, roadsides and cropping and pasture land.

Indian bluegrass (*Bothriochloa pertusa*)

Indian bluegrass is a creeping, moderate yielding perennial grass. It produces stolons or horizontal stems which root at the nodes. Foliage grows to 30 cm with erect flowering stems to 65 cm. Crushed leaves and stems have a characteristic scent. It is suited to the Katherine district and further south and will grow on a range of soil types in areas receiving over 500 mm of annual rainfall. Bowen is the main line grown in the NT. Growth and spread of Indian bluegrass is enhanced by continuous grazing or frequent mowing. Due to its creeping habit, it is a good species for soil conservation in holding paddocks and laneways. It prefers clay soils but will grow on several soil types in the Top End.

Signal grass (*Urochloa decumbens*) cv Basilisk

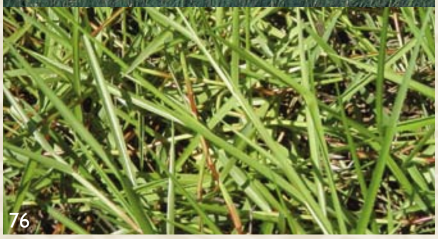
Signal grass is a vigorous, clumping, perennial grass which branches and roots at the lower nodes. Leaf blades are hairy, up to 20 cm long and 10 to 15 mm wide. Leaves are commonly dark green during the wet season and yellow-green during the dry season. Foliage grows to 70 cm with erect flowering stems to 85 cm.

Signal grass is suited to a range of well drained soils in areas receiving over 1000 mm of rain but will not tolerate prolonged flooding or waterlogging. It stays green in the dry season longer than most other species. Signal grass is palatable to cattle and buffalo, but most horses reject it if an alternative is available. Signal grass can produce yields of 6 to 12 t/ha but the hay is usually coarse and of inferior quality. Most horses reject signal grass and it is not recommended as a pasture for horse paddocks.

Tully grass (*Urochloa humidicola*)

Tully is a vigorous, creeping perennial grass which roots from lower nodes and forms a dense low growing sward. Leaf blades are 11 to 15 cm long, smooth and taper to an acute point. Tully is suited to a range of soil types in areas receiving over 1000 mm annual rainfall and tolerates waterlogging and shallow flooding.

It may be slow to establish in the first season and is generally less palatable as a grazing pasture than other grass species. Stock may accept it better when it is short and well fertilised. Tully produces reasonable quality, course but palatable hay and yields of 6 to 14 t/ha can be expected depending on growing conditions and nutrition.



PICTURE 73: Gamba grass (Pangola in foreground) is now a declared weed and must be eradicated or managed to prevent its spread in the NT.
PICTURE 74: Indian bluegrass is a hardy species and assists in soil stabilisation.
PICTURE 75: Signal grass is a tough hardy species but horses find it unpalatable.
PICTURE 76: Humidicola or Tully grass is a tough, adaptable species which grows well on seasonally wet areas in the Top End.

Tully is a useful species for soil stabilisation on earth banks, slopes and areas prone to erosion.

Buffel grass (*Cenchrus ciliaris*) cvs American, Gayndah, Biloela, Nunbank

Buffel grass is a tussocky, clumping, drought resistant pasture which grows to about 90 cm. It is leafy when young but becomes coarse when mature. Buffel is suited to a range of free draining soils in areas with 300 to 1200 mm rainfall but will not tolerate waterlogging. Buffel is well accepted by stock. When horses are restricted to a diet of buffel grass they may develop swelling of the facial bones ("big head") which is caused by a calcium deficiency induced by high oxalate levels in the grass.

Buffel grass pastures are not generally used for hay production due to the strong tussocky growth habit which can make the ground too rough for machinery operation. Maintaining a legume in buffel pastures has proved difficult but Wynn cassia persists due to cattle preferentially grazing the buffel grass. Blue pea and other legumes may persist if rotationally grazed to enhance legume growth.

Buffel grass does not spread as readily in the Top End as it does in Central Australia and is not considered an aggressive invader species in the area. Producers in the Douglas Daly rate buffel grass as one of the most productive and palatable pastures and it is now extensively used in cell grazing systems in the region.

Birdwood grass (*Cenchrus setiger*)

Birdwood grass is a short, drought tolerant, perennial tussocky grass; it is similar to buffel grass but less vigorous. It has a purple seed head with short, stiff spines. Birdwood is suited to the drier areas and well drained soils in the 600 to 750 mm rainfall zone. It flowers earlier than buffel and tolerates periods of heavy grazing. It is a minor pasture in the Top End and rarely sown.

Pangola grass (*Digitaria eriantha*)

Pangola grass is a low, creeping, perennial pasture which roots at the nodes and forms a dense sward. Pangola has been a popular and productive pasture in the Darwin rural area for over 30 years. It is a fine stemmed grass, suited to a range of soils in regions receiving over 1100 mm of annual rainfall. Pangola grass tolerates waterlogging but will not persist under continuous flooding and performs better if the soil is free draining.

Pangola grass does not produce viable seed and must be planted vegetatively. It is best used as permanent pasture and once established will persist indefinitely if well managed. It is palatable and makes good quality hay if harvested early and is an ideal pasture for horses and young weaners. Hay yields from wet season growth are in the order of 8 to 14 t/ha with crude protein levels of 3 to 5%. High yields and quality will only be obtained from well fertilised swards.

Finger grass (*Digitaria milanjiana*) cvs Jarra, Strickland

Finger grass is a vigorous species with a growth habit similar to Pangola. Jarra has broader, hairier leaves, and is lighter in colour than Pangola. Strickland has a leaf shape similar to Pangola but is also blue-green in appearance. Both cultivars produce viable seed. Jarra also roots at the nodes and can creep several metres in a season. Jarra is suited

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to a range of soils in areas receiving over 1000 mm of rainfall and grows well around the Katherine region. Strickland may be a better species for drier environments south of Katherine.

Finger grass can withstand waterlogging but not prolonged flooding. It is palatable as green or standing dry feed or hay. Both Jarra and Strickland produce similar yields and quality to that of Pangola (8 to 14 t/ha), but Jarra hay is generally coarser and the leaf hairs make the hay dusty and causes an itchy reaction in some people. Jarra is one of the most popular pastures of recent times due to its productivity, palatability, ease of establishment and hay yields. Douglas Daly producers rate Jarra second to buffel grass in terms of cattle productivity but more palatable than buffel grass.

Finger grass (*Digitaria swynnertonii*) cv Arnhem

Arnhem finger grass was released in the NT in 1997. It differs from Jarra and Strickland in being smooth and hairless. It does not produce creeping stems or stolons but has a tussocky more erect growth habit. Arnhem is a strong, free seeding grass which tolerates continuous grazing and grows on a range of soils. It is suited to the wetter areas and seasonally saturated soils of the Adelaide River and northern Top End.

Dry matter yields of up to 17 t/ha have been recorded under experimental conditions near Darwin. Arnhem may tolerate higher stocking rates for longer periods than many other grasses if adequately fertilised, resulting in higher total live weight gains per hectare. Arnhem may prove to be a viable alternative to gamba grass in pasture improvement programs.

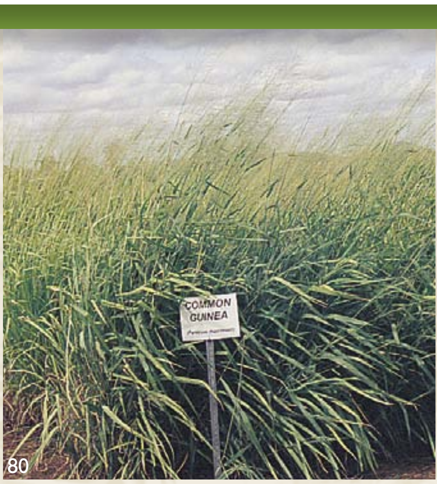
Guinea grass (*Panicum maximum*) cvs Common, Hamil

Guinea grass is a tall, perennial tussocky grass with long, flat, broad leaves. Flowering stalks can reach four metres. Cultivars Common and Hamil are adapted to 1100 mm and higher rainfall areas on deep well drained soils of medium to high fertility.

Guinea grass is palatable and moderately drought hardy. It tolerates short periods of heavy grazing but prolonged heavy grazing pressure may permanently deplete the stand. Guinea grass is suitable as a permanent pasture and good quality hay can be made from well fertilised swards. It is not widely used in the Top End.

Rhodes grass (*Chloris gayana*)

Rhodes grass has not been used extensively in the NT due to its lack of persistence under dryland conditions. However it is a productive grass for dry season irrigated hay production on some properties in the Top End. Fine-cut Rhodes is one of the few tropical grasses to respond to irrigation in the dry season. It produces yields of between 20 to 30 t/ha over four to six harvests under irrigation. Rhodes grass hay is good quality if made prior to seed set and has protein and energy levels averaging 10% and 9 MJ/kg of energy, respectively. Rhodes is not as palatable as some other grasses and stock may require a period to get used to it. Feed processors have also reported that Rhodes grass is hard to process into pellets or cubes due to the additional energy required for milling; this detracts somewhat from its marketability. Despite this



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PICTURE 77: Buffel grass is a highly productive grass and well suited to cell grazing.
PICTURE 78: Pangola grass is a highly productive and palatable pasture and is also a popular hay crop.
PICTURE 79: Jarra grass is one of the most widely sown grass pastures in the Top End and is also used for hay production.
PICTURE 80: Guinea grass is a productive grass but rarely sown in the Top End.
PICTURE 81: Fine-cut Rhodes grass is one of the few tropical grasses to respond to irrigation in the dry season.

it is one of the most productive grasses for dry season irrigation in the Top End.

Setaria (*Setaria sphacelata*) cv Kazungula

Kazungula setaria is a robust, tussocky, perennial grass which spreads by short underground stems or rhizomes. It grows to two metres and has light, bluish-green leaves. Kazungula is adapted to a range of soils in areas receiving over 1100 mm rainfall. It performs best on waterlogged soils or shallow floodplains in the northern Top End, which stay moist during the dry season. It is palatable and can withstand periods of heavy grazing once established. Kazungula contains oxalates, (like buffel grass) and may be toxic to horses and lactating or hungry cows. It is not recommended as a pasture for horses.

Perennial sorghums (*Sorghum* spp) cvs Silk, Jaffa

Silk and Jaffa are open-pollinated, short lived perennial sorghums used for grazing and forage production. They grow to over three metres and are suited to deep, well drained soils in areas receiving between 900 and 1300 mm of rainfall. They are suitable for grazing and may be combined with pasture legumes or grown as a hay crop. Open-pollinated varieties are a cheaper alternative to commercial hybrid forage sorghums and generally produce less dry matter but have less stringent nutrient requirements. Perennial sorghums may contain prussic acid if suddenly water stressed and appropriate grazing management is necessary. They are ideal as an inexpensive cover or initial crop on newly developed country.

Napier or elephant grass (*Pennisetum purpureum*)

Napier grass is a large robust perennial grass native to Africa. It is a valuable component of cut-and-carry fodder systems in developing countries and has now been introduced into most tropical countries. It is suited to deep fertile soils where it will produce yields of 10 to 30 t/ha and up to 80 t/ha under high nutritional inputs. Young growth is nutritious and palatable and can provide crude protein levels approaching 19% and digestibility levels of 65%.

Napier grass has potential as a specialist fodder crop for small niche operations in the Top End where a high quality, productive fodder is required in an intensive livestock system. Napier grass produces very little viable seed in this environment and is propagated vegetatively. Basal cuttings which have two to three nodes are placed into moist soil and covered. Irrigation will enhance establishment. Napier grass is unlikely to become a weed due to its low seed viability and its requirement for vegetative propagation.

Introduced pasture legumes:

American jointvetch (*Aeschynomene americana*) cvs Glenn, Lee

Jointvetches are vigorous, annual or perennial shrub legumes growing to two metres. Glenn has green stems and mauve flowers whereas Lee has reddish stems and bright orange flowers. Glenn flowers in mid- April while Lee flowers in early-to mid-June and both cultivars generally behave as annuals in the Top End.

Jointvetch will grow in wet or waterlogged soils where rainfall

PICTURE 82: Kazungula setaria is adapted to the wetter soils of the high rainfall areas of the Top End.
PICTURE 83: Silk sorghum is often used as a pioneer cover and grazing crop on newly developed country.

Riverine buffalo grazing elephant grass.
Photo courtesy of Geoffrey Arthur.

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PICTURE 84: Napier or elephant grass is an option for small holdings under intensive management; it has to be vegetatively planted.
PICTURE 85: Jointvetch is a legume adapted to the higher rainfall areas and floodplains of the Top End.

exceeds 1100 mm and is best suited to waterlogged soils and the floodplains of the Top End. Plants become woody at maturity so early grazing is preferable. Where grazing is deferred due to flooding, Lee is the preferred cultivar as it maintains its leaf and nutritional quality for longer into the dry season.

Roundleaf cassia (*Chamaecrista rotundifolia*) cv Wynn

Wynn is a semi-erect, short lived, perennial legume which grows to 70 cm. It is adapted to a range of conditions but prefers sandy surfaced soils. Wynn is grown from Darwin to Daly Waters, is a prolific seeder and spreads rapidly.

Wynn has low palatability and stock tend to selectively graze companion grasses resulting in Wynn dominant pastures; especially under set-stocking. Wynn dominance can be managed through intensive rotational grazing systems. Experience has shown that some cattle reject Wynn even when it is the principal feed source, resulting in reduced feed intake and low (0.17 to 0.73 kg/head/day) live weight gain over the wet season. Producers using cell grazing report improved utilisation and management of Wynn.

Wynn is a valuable contribution to a mixed pasture if kept in balance and contributes N to the system. Phosphorus application may improve its palatability and help stimulate grasses in the sward if phosphorus levels are low. Hay and feed pellets containing up to 50% Wynn have been well accepted by cattle and some livestock enterprises use Wynn hay as part of a ration. Pure Wynn cassia hay is generally considered unpalatable. Wynn spreads rapidly and is difficult to control in legume crops and is not recommended for horse paddocks due to its low palatability.

Producers in the Douglas Daly described Wynn as: "An easy-to-establish, highly persistent, dominating legume of low palatability and low grazing value in fertile soils [in the Douglas Daly]. It may have a role in soil conservation and may also have potential for hay and pellet production." Grazing strategies, such as cell grazing and spelling have resulted in better balanced pastures, higher animal performance and reduced Wynn dominance.

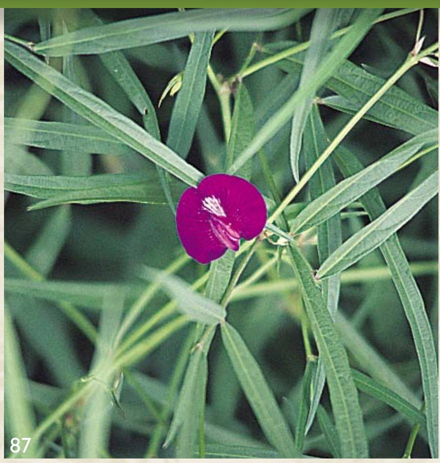
Centurion (*Centrosema pascuorum*) cvs Bundey, Cavalcade

Cavalcade and Bundey are annual tropical legumes which have a prostrate, twining growth habit with large showy crimson flowers. Cavalcade flowers in mid-March while Bundey flowers a month later. Bundey is recommended for areas with an extended wet season such as sub-coastal areas and the Darwin and Daly regions. Cavalcade is recommended for the Katherine area, however both species grow on a range of soil types and will tolerate periods of waterlogging and temporary seasonal flooding. Both tolerate short seasonal droughts when established.

Bundey and Cavalcade are highly productive species and make up over 90% of the legume hay produced in the Top End. Fodder yields average 5 to 7 t/ha but commercial crops of 9 t/ha have been grown in favourable seasons. Hay is palatable, deep green and has crude protein levels of 8 to

PICTURE 86: Wynn cassia can form a dense monoculture if not managed through rotational grazing.

Oolloo centro is a valuable companion legume for many grass pastures.



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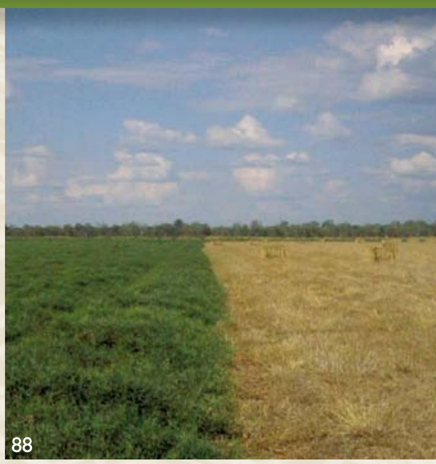

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PICTURE 87+88: Cavalcade and Bundey are the most important fodder legumes in the Top End. They produce high quality, palatable hay which is keenly sought by the market.

12% depending on the growth and time of harvest. Both species are suitable for processing as cubes or pellets. In a feeding trial at Berrimah Farm Cavalcade cubes produced equivalent animal weight gain (1.1 kg/head/day) to that of lucerne pellets.

Bundey and Cavalcade pastures can contribute 50 to 200 kg N/ha/year to the soil, are suitable for rotation with cereal crops and provide ideal mulch for no-tillage systems. The main agronomic issues associated with centro pastures and hay crops include: the cost and difficulty of controlling weeds especially legumes like senna, buffalo clover, Wynn cassia and other broadleaf weeds; establishing good plant populations; and efficient mowing of high yielding crops. Centro should be planted in the cleanest paddocks and in areas without senna and a minimum of other broadleaf weeds.

Centro (*Centrosema brasilianum*) cv Oolloo

Oolloo is a short lived, perennial centrosema cultivar. Leaflets are oval in shape and three to four centimetres long. Flowers are large, showy and purple in colour.

Oolloo is a climbing, twining cultivar which produces roots from its stems when conditions are favourable. It forms a prostrate sward when grown alone but climbs vigorously with tall companion grasses. It is suited to a range of soil types and conditions and will grow in most locations in the Top End. It has the ability to persist under heavy grazing when given the opportunity to set seed and produces dry matter yields of 3 to 4 t/ha. Due to its prostrate growing habit it is not used as a hay crop.

Blue pea (*Clitoria ternatea*) cv Milgarra

Milgarra blue pea is a perennial legume which has been widely sown throughout the Top End. It has an erect woody base and fine twining stems. The attractive flowers are large and blue or occasionally white. It is suited to a range of soils including well fertilised sandy soils and heavy clays where rainfall exceeds 600 mm.

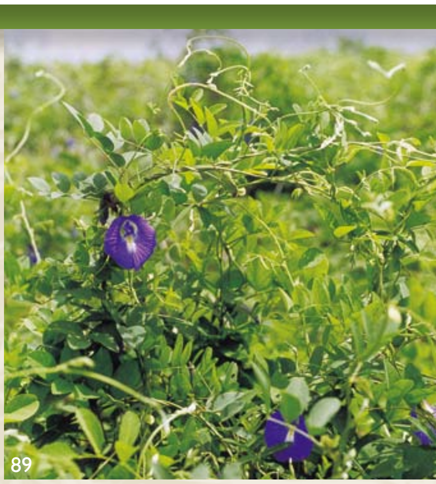
Milgarra is very palatable and produces good quality hay with up to 19% crude protein. However it drops its lower leaves as it matures which reduces yield and quality. Blue pea is vigorous when established but (due to its palatability) does not tolerate heavy wet season grazing pressure. Its persistence under continuous set-stocking is generally poor but it may perform better in a cell or rotational grazing system. Blue pea is the only tropical legume to respond to dry season irrigation in trials at Douglas Daly Research Farm (DDRF). It produced yields of around 2.0 t/ha per harvest, however its total seasonal production was only about half that of lucerne grown under the same conditions.

Blue pea is a valuable legume and its N contribution makes it an ideal candidate for a ley farming system or a companion legume in grass pastures. It can contribute 50 to 200 kg/ha of N to the system depending on its management and its proportion and time in the sward.

Llanos macro (*Macroptilium gracile*) cv Maldonado

Maldonado is a twining, short lived, perennial legume. Leaves are trifoliate and flowers are grey-orange

PICTURE 89: Blue pea, a productive perennial legume adapted to a range of soil types throughout the Top End.
PICTURE 90: Maldonado is a vining legume.
PICTURE 91: Verano stylo, a legume suitable for intensive pasture improvement or oversowing into native pastures.
PICTURE 92: Seca stylo, ideally suited to extensive pasture improvement programs.
PICTURE 93: Forage peanut is a perennial legume with potential as a pasture or ground cover on small blocks.



in colour. It is suited to a range of soil types in areas receiving over 1100 mm of rainfall and tolerates waterlogging and seasonal flooding. It is well accepted by stock and re-establishes from seed set in the previous season. The lack of commercial seed has limited its adoption in the Top End.

Carribbean stylo (*Stylosanthes hamata*) cvs Verano, Amiga

Verano and Amiga stylos are similar in appearance and both are annual or short lived perennial herbaceous legumes. They have a branched, semi-erect habit and grow to 75 cm with small yellow flowers. Stylos are drought hardy and are suitable for a range of soil types in regions receiving over 600 mm of rainfall. Stock will generally accept stylos well and palatability can be enhanced by applying phosphorus fertiliser.

When grown under adequate nutrition, stylos can fix about 130 kg/ha/year of N for use by subsequent crops. Verano and Amiga make good quality hay and yields of around 3 to 5 t/ha are possible.

Shrubby stylos (*Stylosanthes scabra*) Seca, Siran

Shrubby stylos are vigorous, erect, perennial shrub legumes which can grow to two metres, but rarely grow that tall in the Top End. The stems and leaves are sticky and have a distinct aromatic odour when crushed. Flowering commences in late April and continues into the dry season.

Seca and Siran are suited to a range of soil types in areas receiving over 500 mm of rainfall. They tolerate burning, drought stress and limited waterlogging. Shrubby stylos are used in mixed pastures or for oversowing into native pastures. They are a valuable component to both native and improved pastures and provide stock with high protein pick throughout the season. They are generally unsuitable for hay production because of their stalky and woody nature.

Calopo (*Calopogonium mucunoides*)

Calopo is a naturalised and vigorous, free seeding, annual legume which was widely sown in the 1970s and 1980s. It is a sprawling, vining species forming dense swards. It climbs trees and fences and may become a weed on small blocks, in horticultural situations and reserves. It is therefore no longer recommended. Calopo is unpalatable when young but stock will graze it when hayed off in the dry season. Once established it is difficult to eradicate as it is a prolific seeder.

Forage peanut (*Arachis glabrata*)

Forage peanut is a species for free draining soils in tropical Australia. It has potential as a ground cover or a speciality pasture for horses or cattle on small blocks. It produces little or no seed and is propagated vegetatively, which limits its adoption and use on a broad scale. It is a perennial legume, makes excellent hay and will persist indefinitely when established. Forage peanut has considerable potential for small blocks but requires more development to become a commercial reality.

Leucaena (*Leucaena leucocephala*) Cunningham, Peru, Tarramba

Leucaena is a perennial, deep rooted, shrub or tree legume which produces high quality fodder. It can grow to 10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metres but is maintained as a shrub for grazing purposes. Leucaena is suited to well drained soils in areas receiving over 750 mm of annual rainfall. Leucaena likes clay soils or those with higher moisture holding capacities that permit it to grow during the dry season.

Irrigated leucaena has given live weight gains of over 1.0 kg/head/day or over 1000 kg/ha/year in the Ord River area. New shoots are 75% digestible and contain 20 to 25% crude protein. Leucaena-grass mix pastures at Douglas Daly Research Farm have consistently provided higher live weight gains than the other grass and grass-legume pastures, producing over 200 kg LWG/head/year at a stocking rate 1.5 head/ha.

Leucaena contains mimosine, a toxic amino acid. Animals require specific rumen bacteria to detoxify mimosine which can be acquired from contact with other stock or by inoculation. Leucaena has proved difficult to establish under dryland situations in the Top End. Protection from wallabies is essential in young plantations. Supplementary irrigation may be required initially to assist in establishing leucaena, which should then remain productive without irrigation for many years. Leucaena has the potential to become a weed due to its prolific seed production, hard seed and ability to invade conservation, wetlands and coastal areas. The Leucaena Network (www.leucaena.net) has developed a management code of practice which will help reduce the potential environmental consequences of growing leucaena.

Lucerne (*Medicago sativa*)

Lucerne is one of the world's most important fodder crops. It is a plant of desert origin and commonly grown in southern Australia, but is not well adapted to the environment of the Top End. However, lucerne shows promise as a short-term, irrigated crop if intensively managed and can produce 10 to 20 t/ha per season. Its persistence in the Top End is determined by nutrition and the level of insect, disease and weed pressure. Lucerne may persist for only two to three seasons but could be a valuable rotation or niche crop for specific cropping systems. Lucerne hay commands a good price, however the local market is limited. The issues associated with lucerne production are its susceptibility to "littleleaf" virus, (transmitted by leafhoppers), weed competition and the absence of a dormant or cold period, preventing the build-up of carbohydrate reserves in its crown and root system. Varieties with better insect and disease resistance and tropical adaptation are required.

9.3 MAINTAINING PASTURE PRODUCTIVITY

Grass pastures

Maintaining pasture productivity is a major challenge as nutrients run down, weeds invade and plants lose vigour. Nitrogen (N) is the most important nutrient in grass production. Animal productivity is largely determined by feed intake and digestibility. When soil N declines or is tied up in organic matter and becomes unavailable, grass growth, digestibility and feed intake is dramatically reduced. A 50% reduction in available soil N will generally result in a corresponding 50% decline in pasture growth. Nitrogen

PICTURE 94: Leucaena produces the highest quality feed of any tropical legume.

Cattle in leucaena at Douglas Daly.
(photo courtesy DoR)

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PICTURE 95: Irrigated lucerne is an option as a short term intensively managed rotation crop.

availability is required to stimulate new pasture growth and will increase live weight gains or carrying capacity. There are three main ways N is supplied to the system: as organic N in animal waste (urine and dung); by legumes through N fixation; or as synthetic fertiliser.

Tropical grasses are high in indigestible fibre and this proportion increases with age and declining N levels. Young grasses with a digestibility of 70 to 80% can fall below 30% on maturity. Stock must have continual access to new growth to benefit from grazing tropical grasses.

In the Top End the application of 100 to 200 kg N/ha of N based fertiliser on various grass pastures allowed wet season stocking rates to be increased from 2 to 4 head/ha without a reduction in live weight gain. Similarly, 75 to 150 kg N/ha applied to Pangola grass late in the wet season gave a three to four fold increase in dry matter production compared to unfertilised pasture. High inputs of N fertiliser applied to grasses will result in increased pasture and animal production but requires a significant financial investment. Application of N fertiliser is not necessarily the most economically or ecologically sustainable option; it is expensive and energy intensive and may result in the release of nitrous oxide (N_2O), a greenhouse gas which is 300 times more potent than CO_2.

Pasture and animal performance may be improved by better synchronising grazing pressure with pasture growth periods and utilising pasture legumes to bolster N levels and pasture quality. Cell grazing or rotational grazing systems are alternatives to traditional set-stocking, and can result in better animal productivity, pasture persistence and quality if well managed.

Mixed and legume pastures

Legumes play a vital role in improving pasture quality and soil and animal productivity. Legumes are higher in protein, more digestible than grasses and require no N fertiliser. At low to moderate stocking rates the productivity from legume based pastures should be similar to that of grass pastures fertilised with N but is achieved at a lower cost. Pastures containing compatible legumes and grasses are often more productive and ecologically stable than either pure grass or pure legume pastures.

Pure legume pastures are difficult to maintain and as N accumulates, pastures succumb to weed invasion within two to three years. Standover legume forage also deteriorates sharply in nutritive value and acceptability with the onset of rain. This results in lower intake and animal weight loss until new growth is available. Perennial grasses grown with legumes will provide more rapid growth, assist in maintaining pasture quality and reduce the period of weight loss.

Maintaining legumes in mixed pastures, however, can be difficult as many are intolerant of heavy grazing and are generally less competitive than perennial grasses. Some legumes may persist for only two to three years when sown with vigorous grasses such as buffel, Tully or Pangola. Declining legume content significantly reduces fodder quality and studies have shown that live weight gain decreased by up to 64% when legumes were


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lost from the pasture. This would equate to a production loss of up to 96 kg/head/year in situations where stock gained 150 kg/head/year with access to legumes. Clearly, losses like these reflect a serious decline in productivity, possibly due to a number of factors.

Legume persistence can be extended by strategic grazing, spelling pastures, fertilising and weed control. Reducing grazing pressure at the start and end of the wet season is critical to legume persistence. This allows re-establishment after the dry season and allows seed set at the end of the wet season. Phosphorus and sulphur are necessary to promote growth, root development and nodulation of legumes. Phosphorus application of 15 to 20 kg/ha at establishment and 10 kg/ha annually should provide optimum dry matter production in most legume based pastures in the higher rainfall areas. This equates to an initial application of 190 to 250 kg/ha single superphosphate plus 125 kg/ha annually.

Fertiliser rates may need to be varied depending on grazing enterprise and market considerations. Maintenance fertiliser of 5 to 10 kg/ha/year of phosphorus may be appropriate to achieve optimum economic return in many grazing situations. Potassium and trace elements such as zinc and molybdenum are required for highly productive legumes such as Cavalcade and Bundey and where hay is being produced.

Pasture productivity may, in the future, be determined by the ability to manage soil acidification. Leaching of calcium, magnesium, potassium and the mineralisation of organic N from legume pastures may result in soils becoming progressively more acid. Management of pastures and crops may involve the application of lime to maintain an acceptable soil pH.

When pastures become rundown and unproductive, a combination of spelling, cultivation, re-seeding and herbicide and fertiliser application may be necessary depending on the particular situation. A cropping phase can reduce the weed burden, use accumulated N and improve soil conditions for subsequent pastures. Strategically spelling pastures at the start of the wet season, to allow the plants to develop a strong base and root system will be one of the most effective and cheapest options for maintaining healthy pastures.

9.4 SUSTAINABLE GRAZING FOR PASTURE AND ANIMAL PRODUCTIVITY

Stocking rate (SR) and grazing duration are the most important management factors in grazing systems because they determine the health and persistence of pastures and animal productivity. The stocking rate must allow for a continuous supply of good quality feed and the maintenance of pasture health. This is achieved by adjusting stocking rates to suit seasonal and pasture conditions, resting pastures at strategic times, applying fertiliser and if necessary supplementing feed. There is a vast difference between wet season and dry season SR due to the total absence of pasture growth during the dry.

The choice and management of the grazing system will

PICTURE 96: Lucerne and Rhodes grass under irrigation at Douglas Daly.
PICTURE 97: Cattle grazing mixed pastures (Wynn cassia/Kazungula setaria) at Coastal Plains Research Station.
PICTURE 98: Mixed grass and legume pastures provide the best liveweight gain but require careful management to maintain the balance.

Stocking rate, grazing duration and the timing of rest periods are the most important management factors. These decisions determine soil and pasture health, animal productivity and profitability.

ultimately determine productivity, sustainability and economic viability. Soil health drives pasture health which in turn drives livestock productivity. Pastures and soil health are highly inter-dependant. Grazing animals require healthy pastures to thrive and in turn pasture health is determined by grazing management. Overgrazing will result in a decline in top growth, root mass and pasture energy reserves.

Animals are attracted to soft young growth because it is more nutritious (i.e. has higher energy and protein), is more digestible and easier to eat. With high set-stocking rates, animals will continually graze the same plants as soon as they produce new growth. Therefore plants never get a chance to accumulate energy or reserves, resulting in the continual decline of pasture productivity.

If pastures are in poor condition due to overgrazing, then it is almost guaranteed that the root systems are also unhealthy. In this condition pastures cannot convert the sun's energy and carbon dioxide into leaf growth and root systems are less able to derive nutrients and moisture from the soil. Overgrazing acts as a double-edged sword against productivity by making plants less responsive to good growing conditions and unable to withstand tough conditions. Overgrazing also results in weed dominance and soil degradation.

While under-grazing is more the exception and better from a soil protection perspective, it results in poor feed utilisation, reduced feed intake and low overall productivity due to the rank indigestible nature of old plants. At a low SR the performance per animal will be high because animals select the most nutritious feed, however, overall productivity and pasture utilisation will be low.

Increasing SR will increase production per hectare despite decreases in individual animal

LIVE WEIGHT GAIN PER ANIMAL AND PER HECTARE ON SABI GRASS PASTURE AT DDRF

Animals/ha	kg/animal	kg/ha
1.0	100	100.0
1.5	75	112.5
2.0	60	120.0
2.5	40	100.0
3.0	25	75.0

NOTE: In this example two head/ha provides the maximum per hectare weight gain but incurs a 20% and 40% reduction in individual animal performance compared to 1.5 and 1.0 head/ha respectively. Stocking at 1.0 to 1.5 head/ha is a more sustainable option as individual and total live weight gain is maintained and pastures are less likely to be degraded. (Trials were carried out on un-supplemented animals with initial weights of between 180 and 200 kg.)

TABLE 7: The effect of set-stocking on productivity per animal and per hectare on a Sabi grass pasture at Douglas Daly Research Farm (DDRF).

PICTURE 99: Conservative stocking levels during the dry season are critical for animal welfare, soil protection and pasture persistence.

performance. Optimum SR is usually somewhere between the point of maximum production per animal and maximum production per hectare.

Estimating optimum SR can be difficult because of all the variables, however if the soil and pastures are in good condition, animal productivity will follow. The challenge is to provide stock with a continuity of fresh growth or dry feed without damaging pastures and ensuring viable productivity.

There are two basic grazing systems: continuous grazing (or set-stocking) and rotational grazing. Several variations of both systems are practised and some producers use a combination. Terminology related to these systems gets confusing as interpretations are sometimes different.

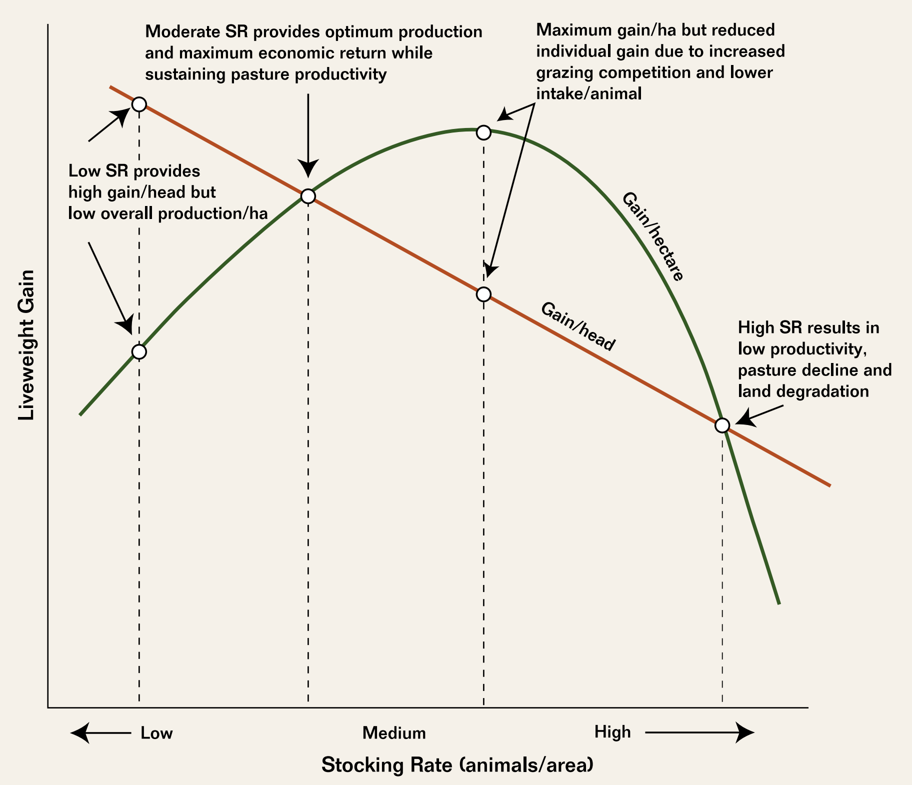


FIGURE 20: The relationship between liveweight gain per head and per hectare as influenced by stocking rate. SR will determine the productivity and the profitability of grazing enterprises.

Continuous grazing

Continuous grazing or set-stocking has been the standard practice in most extensive livestock industries. Stock generally remain in a pasture for extended periods or indefinitely until sold. Stocking rate adjustments are made when warranted by livestock numbers or changes in seasonal or pasture conditions. It is the simplest and most widely practised system due to the ease of management and relatively low requirement for fencing, water and labour.

Continuous grazing can result in selective grazing pressure and loss of desirable species, lower than optimum feed quality, gradual weed invasion, compaction and erosion. The system works well at conservative stocking rates but at high numbers or during extended dry spells, land condition, soil

PICTURE 100: Brahman cows on native pasture at Kidman Springs, in the Victoria River region.
PICTURE 101: Cell grazing is an intensive management system that achieves high productivity and maintains good pasture health.

health, pasture and animal productivity can decline rapidly.

Rotational grazing

Rotational grazing has many variations but is basically a system where livestock are moved from one patch of pasture to another after specific periods. Grazing duration can range from a few days to several weeks. Rotational grazing requires more paddocks, labour and infrastructure. It is designed to provide feed of the highest nutritive value to maximise intake and animal productivity. Rotational grazing (often referred to as strip grazing) has been practised in the dairy industry for many years and is now being adopted in more extensive grazing enterprises. If well managed it allows for higher stock numbers while maintaining pasture quality and animal productivity. It also solves many of the problems associated with continuous grazing. It gives pastures a chance to recover and accumulate energy reserves, improves the quantity and quality of pasture and increases livestock weight gain per hectare. While the biological and animal productivity benefits may be higher, the cost of implementing and managing a rotational system needs to be considered. Cell grazing is a highly intensive form of rotational grazing where high stocking numbers are continually moved through a series of paddocks or “cells”. The grazing time in any one cell may be one or two days. The infrastructure and labour costs associated with cell grazing are high but well managed systems can result in high productivity. Cell grazing has been adopted by several producers in the Top End with good results. Commercial cell grazing in the Douglas Daly allowed one producer to carry 3000 animals sustainably on 1500 ha of improved pasture without fertiliser. Cells stocked at 40 to 50 animals/ha for one to two days on a 30 day rotation provided an average live weight gain of 0.8 kg/head and up to 1.1 kg/head over the grazing period December to March. The producer suggested this level of productivity would not be possible under a set-stocking regime but also stated the system was a seven-day-a-week operation. Systems are being constantly refined as producers learn and gain more experience in this environment.

Carbon grazing

Carbon grazing is a relatively new term given to a principle of pasture management that involves strategic spelling or resting of pastures to maximise carbon capture and bolster the plants’ energy reserves. Carbon grazing simply considers the carbon cycle in the management of pastures for optimum pasture quality and performance. It involves strategically spelling paddocks for several weeks at the onset of growth cycles (i.e. at the start of the wet and other significant periods) to allow plants to accumulate carbon and photosynthesise efficiently. The critical aspect of this principle is the timing of the spell to coincide with maximum carbon flow and growth.

Carbon grazing is a principle that is intrinsic to well managed rotational grazing systems. To fully appreciate the principle, an understanding of the carbon cycle and its relationship to soils, plants and animals, is required.

The principle is extensively covered in a publication called *Carbon grazing* by Alan Lauder (2008).

9.5 CALCULATING FEED REQUIREMENTS

Feed budgeting is an essential part of running a sustainable grazing enterprise. Estimating how much feed is on offer at different times of the year and understanding animal requirements can make the difference between losing money and degrading the resource and running a sustainable enterprise. Feed availability will vary widely from wet season to dry season and on the type of pasture and its management. Feed quality (protein, digestibility and energy) is also a major consideration when estimating feed requirements. The question pastoralists must answer is: "How much feed is on offer, how many animals can it feed and for how long, before degrading the resource?"

A rule-of-thumb estimate for young growing stock is that animals require between 2 and 3% of their body weight in dry matter (DM) intake each day. Using an example of 200 kg steers at a stocking rate of 2 head/ha, the daily feed required for both animals would be:

- *Daily feed required/animal = Animal live weight (LW) multiplied by 2.5%*
- *Daily feed required for 2 animals = Animal LW x 2.5% x 2*
- *Total daily feed required = 200 x 0.025 x 2 = 10 kg dry matter/day*

Knowing that the combined DM intake must be approximately 10 kg, animals would need to consume 28 kg of pasture/day to satisfy their requirements. This is because the pasture contains 60 to 65% moisture which is not contributing to their overall nutrition. In reality, significantly more feed needs to be available to allow for pasture growth and maintenance, trampling losses and spoilage.

In any grazing situation pastures are not totally utilised. Utilisation rates (grazed or trampled etc.) will vary but in most cases only between 20 and 50% of the available pasture dry matter should be used, depending on pasture type and time of year. Utilisation rates of native pastures should be lower (i.e. 20 to 30%) due to their lower biomass and sensitivity to grazing pressure. The remainder should be maintained for soil protection and to ensure continual regrowth and persistence.

Monitoring is essential for assessing pasture condition and the amount of feed and soil cover remaining.

Assuming a paddock of 5 to 6 t/ha of sorghum stubble and legume understorey is available for grazing in the dry season and the aim is to have a 50% utilisation rate. Stock can therefore utilise 2.5 to 3.0 t/ha of the feed on offer before being removed.

Using the above example of two animals/ha consuming 28 kg/ha/day, there would be less than 90 days grazing available before the desired utilisation rate is exceeded. Extending the grazing beyond this period would result in loss of soil cover and reduced animal performance due to increasing competition and reduced feed quality.

PICTURE 102: Cattle on improved pastures.

Paddock	Species	Average LWG per head (kg)	Years of recording	Average LWG per hectare (kg)
All		175	12	
39	Gayndah buffel and leucaena	222	2	277.5
39	Gayndah buffel and leucaena @ 2.5 h/ha	163	2	407.5
40	Nunbank buffel	154	5	204.3
41	Tully grass	128	5	168.3
42	Wynn cassia	128	2	160.0
42	Wynn and Jarra	173	4	236.9
43	Silk sorghum/legume	185	3	184.7
	P. atratum (Higane) + twining legumes	180	3	209.3
43	Mix legumes Oolloo/Milgara/Cavalcade	198	2	247.5
43	Forage sorghum/legumes	138	1	206.4
43	Signal grass planted December 2007	167	1	208.7
44	Pangola/leucaena	197	5	197.2
	Pangola	186	6	245.3
45	Pangola + urea	167	5	166.8
	Pangola/half rows of leucaena	197	3	234.2
	Pangola/leucaena	196	3	287.9
46	Sabi grass	150	8	181.6
	Sabi + urea	158	4	176.6
47	Jarra	168	11	213.3
48	Sabi/Kaz/Wynn	190	1	190.0
	Sabi/Wynn/leucaena (leucaena in half the paddock @ 10 m row spacing)	189	5	226.6
48	Sabi/Wynn/leucaena	191	3	267.8
49	Buffel/blue pea	178	5	190.0
	Buffel/blue pea @ 2.5 head/ha	147	7	367.3
50	Buffel/legumes	186	8	236.6
51	Wynn/stylo	173	2	173.0
	Strickland/Wynn/stylo	184	10	241.7
52	Arnhem/Oolloo	162	12	188.8
531	Buffel grass	180	12	211.3
532**	Buffel grass	171	12	179.1
533	Buffel/Wynn	179	12	211.5
534	Buffel/leucaena (leucaena in half the paddock @ 8 m row spacing)	195	9	215.8
	Buffel/leucaena	187	3	261.8
535	Buffel/Oolloo	182	4	247.2

TABLE 8: Live weight gain (LWG) in kg on different pastures at DDRF.

NOTES:
** Trials of applied urea, different lick block and no lick.

Stocking rates:	Pre-June 2001		1.0 head/ha
	July 2001 to June 2006		1.25 head/ha
	June 2006 to June 2008		1.5 head/ha
Exceptions:	Paddock 39	June 2006 onwards	2.5 head/ha
	Paddock 49	June 2001 onwards	2.5 head/ha

10

Ley farming and farm forestry

Ley farming is a system of rotating crops with legume or grass pastures to improve soil structure and fertility and disrupt pest and disease lifecycles. It has been practised in many parts of the world for centuries. The concept has considerable application in the Top End.

THE BENEFITS OF LEY FARMING ARE:

- improved soil fertility and structure
- reduced erosion and land degradation
- more efficient use of natural resources
- improved weed, insect and disease control
- more reliable crop and animal production
- increased options and flexibility.

Legume ley farming systems are particularly important in the Top End due to the N provided by legume pastures. Legumes supply varying amounts of N depending on existing soil N levels, growth of the legume, seasonal conditions and effectiveness of nodulation.

Contributions up to 200 kg N/ha/year have been measured in legume swards. Experiments have shown that the N requirement of a sorghum crop can be supplied by a two-year ungrazed Cavalcade pasture. In commercial practice, Cavalcade can supply up to 25 to 40 kg of N/ha or 30 to 50% of a dryland grain crop's N requirement. One and two year grazed stylo pastures have contributed 25 to 45 and 35 to 75 kg N/ha respectively, to sorghum crops. In other studies at Katherine it is estimated that one

ATTRIBUTES OF IMPROVED PASTURES

Perennial grass pastures

- persistent and productive under good fertility
- effective competitors with weeds
- tolerate periods of high stocking pressure
- build organic matter and soil structure
- regenerate quickly at the start of the wet season
- tolerant to many herbicides (i.e. more weed control options)
- require N fertiliser in absence of legumes
- can become unproductive or "run down" and tie up N

Legume pastures

- productive, palatable and highly nutritious
- less competitive and subject to weed invasion, less tolerant to high grazing pressure, less persistent than most grasses
- build N fertility and soil structure
- annual legumes slow to regenerate at the start of the wet season
- susceptible to many herbicides, fewer weed control options
- do not require N fertiliser
- require renovation and re-seeding to remain productive
- may promote soil acidity due to N build-up and leaching

and three year stylo ley pastures increased the uptake of N in cereal crops by 30 and 50 kg N/ha respectively.

Grass pastures increase organic matter, improve soil structure and are effective in suppressing many broadleaf weeds. Buffel, Pangola, Jarra and Tully are best used as permanent pastures, but have been rotated with Cavalcade hay crops and may need to be re-established after the cropping phase. Sabi grass is compatible with many legumes and is ideal as a rotation in a cropping program. It is easy to drill into and regenerates after a one or two year cropping phase.

10.1 LIVESTOCK INTEGRATION IN FARMING SYSTEMS

The major challenge in animal production systems in the Top End is providing a continuity of good feed and minimising weight loss during the dry season. Weight loss occurs during the transition period from the late dry to the early wet season on both native and improved pastures. Native pastures can provide live weight gains of 50 to 120 kg/head/year at low stocking rates (one head per 16 to 40 hectares) depending on seasonal conditions, location and pasture species. Larger gains are only achieved with mineral supplementation. However, weight loss occurs on native pastures throughout much of the dry season with losses of 0.25 kg/head/day recorded in the Katherine district.

Stock generally maintain or gain weight through most of the dry season on improved pastures and crop stubbles until the dry feed deteriorates with the onset of rain. In trials at Katherine, Douglas Daly and the Coastal Plains Research Station (CPRS), live weight gains of 120 to 200 kg/head/year were

PICTURE 103: A highly productive Cavalcade pasture requires good management and weed control.
PICTURE 104: Cavalcade undersown to grain sorghum makes excellent grazing after harvesting.

Stocking rate decisions must be based on the feed required per animal, anticipated grazing duration and growth and protection of pastures.

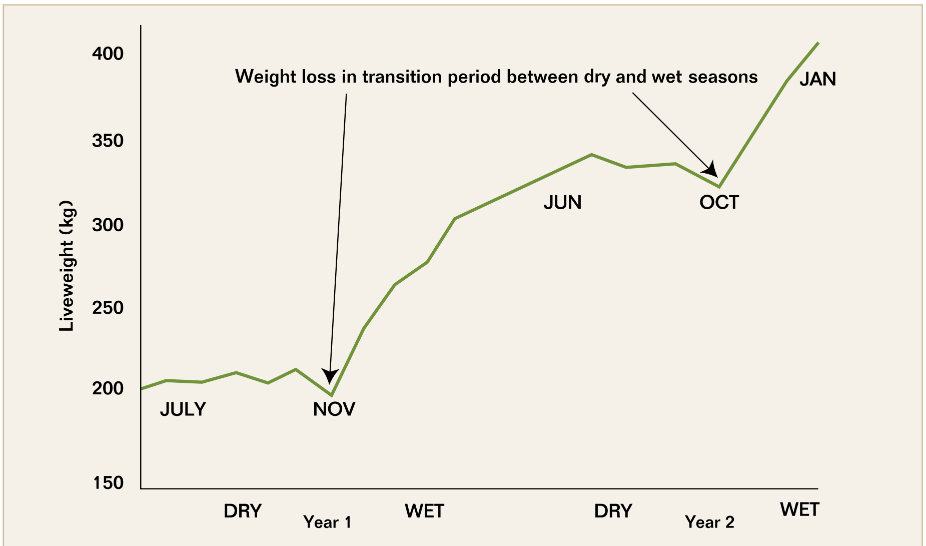


FIGURE 21: Seasonal weight loss in cattle during the transition period between the dry and wet season as feed deteriorates in quantity and nutritive quality. Stocking rate decisions must account for this period to minimise losses.

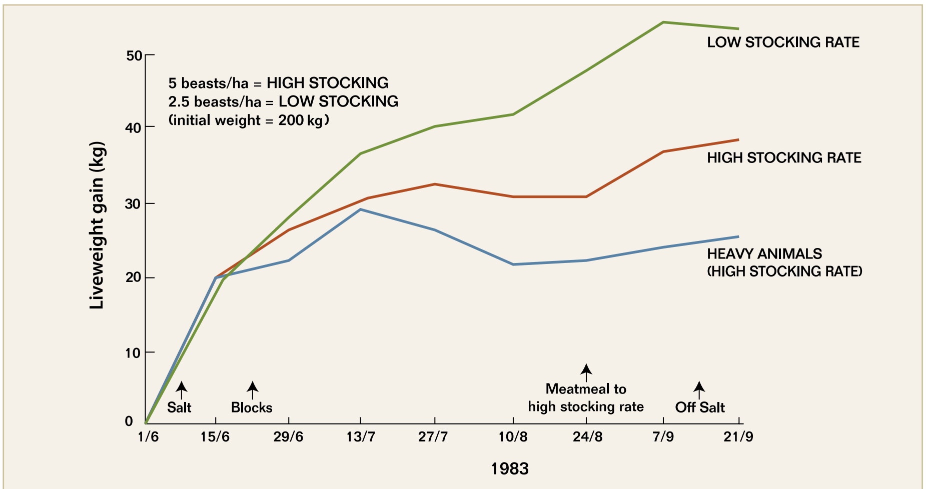


FIGURE 22: The effect of different stocking rates and supplementation on liveweight gain of steers grazing rice stubble at Tortilla Flats Research Station in 1983. The low SR produced almost 70% (20 kg) more liveweight per animal, while the high SR with supplementation produced a 40% (50 kg extra/ha) increase in per hectare liveweight gain.

obtained at stocking rates of one head per hectare. Rice and sorghum stubbles have provided weight gains of 0.5 to 0.7 kg/head/day at one to two beasts per hectare, during the early- to mid-dry season.

At Katherine, three head per hectare (average weight 200 kg/head) on sorghum stubble and legume understorey gained an average of 0.46 kg/day for 99 days in the main part of the dry season. In another study, similar weight steers at two head per hectare which were supplemented and implanted with a synthetic growth promotant, gained an average of 0.6 kg/head/day from mid-April to mid-July while grazing a combination of sorghum stubble, Cavalcade and Maldonado pastures.

At Douglas Daly, un-supplemented steers at 1.5 head/ha gained up to 60 kg/head over three months (July to September) on sorghum stubble. In some experiments cattle weight gain was higher on crop stubbles (i.e. maize, sorghum and rice) than on improved pastures during the latter part of the dry season, illustrating the benefit of integrating cattle and crop production.

PICTURE 105: Blue pea and buffel are a productive combination in a well managed pasture.
PICTURE 106: High stocking densities damage pastures which then take longer to recover once the rain arrives.

Grazing situation	Stocking rate (head/ha)	Grazing period duration (days)	Weight range gain/loss (kg/head/day)	Weight range gain/ loss for grazing period (kg/head)	Weight range gain/loss for grazing period (kg/ha)
Native pastures[1] (un-supplemented)	1.0 per 16 to 40 ha	Wet season 140 Main dry 163	+ 0.30 to + 0.50 – 0.24 to – 0.39	+ 40 to + 70 – 40 to – 64	+ 1.0 to + 4.4 – 2.5 to – 4.0
Native pastures[1] (supplemented*)	1.0 per 16 to 40 ha	Wet season 140 Main dry 163	+ 0.42 to + 0.86 – 0.24 to – 0.39	+60 to + 120 – 40 to – 64	+ 1.5 to + 7.5 – 4.0 to – 2.5
Improved mixed pastures[1,2,4] (supplemented*)	1.0 per ha 1.0 per ha 0.75 per ha 1.0 per ha 1.0 per ha 1.0 per ha	Wet season 134 Main dry 163 Full season 365 Early dry 84 Late dry 84 Full season 365	+ 0.75 to + 0.88 – 0.10 to + 0.25 + 0.34 to + 0.46 + 0.40 to + 0.83 – 0.21 to + 0.1 + 0.34 to + 0.54	+ 100 to +118 – 16 to +40 + 127 to +170 + 34 to +70 – 18 to +9 + 125 to +200	+ 100 to + 118 – 16 to + 40 + 95 to + 125 + 34 to + 70 – 18 to + 9 + 125 to + 200
Sorghum stubble[2]	1.5 to 2.0 per ha	Main dry 84	+ 0.15 to + 0.72	+12.7 to +60	+18.7 to + 120
Sorghum stubble and Cavalcade understorey[1]	2.0 per ha	Main dry 120	+ 0.10	+12	+24
Rice stubble[3]	2.5 per ha 5.0 per ha	Main dry 56 Main dry 113	+ 0.5 + 0.22	+28 +24	+70 +120

Figures from various grazing trials conducted since 1985 at: 1. Katherine; 2. Douglas Daly; 3. Tortilla Flats; and 4. Coastal Plains.
* Animals provided with mineral supplementation (i.e. non protein nitrogen in dry season, phosphorus in wet season)

TABLE 9: Live weight gains and losses under different grazing systems.

Combining native and improved pastures with crop stubble allows more flexible management, greater animal productivity and more rapid turn-off. Table 9 shows the performance of steers under various grazing systems in the Top End. Animal production varies considerably depending on location, season, pasture type, age of animal, stocking rate and grazing duration.

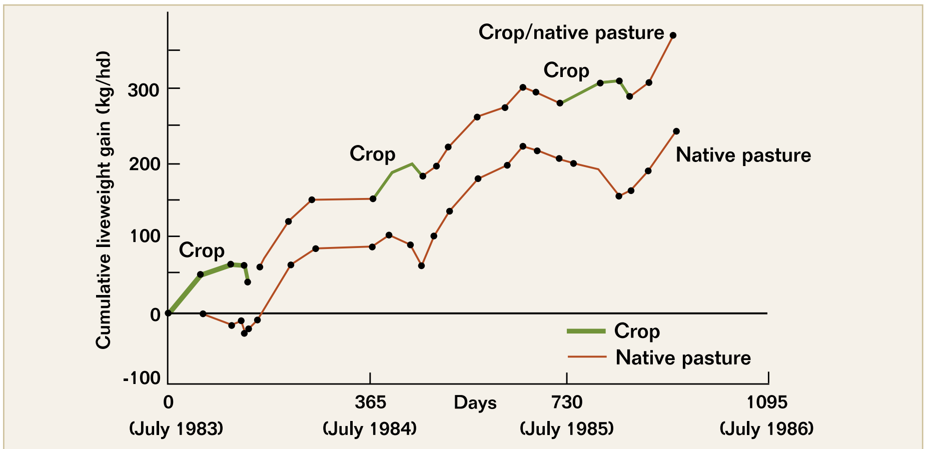
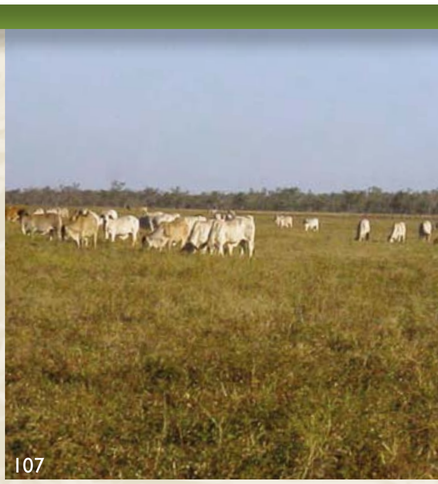


FIGURE 23: Animal liveweight gain achieved on: a combination of crop stubbles in the dry and native pastures in the wet; versus cattle grazing on native pastures only.



PICTURE 107: Stock grazing a well managed pasture in the dry season.
PICTURE 108: Weaners in top quality pasture.

10.2 FORESTRY IN THE TOP END

Forestry is now a major form of land use in the Top End with over 50 000 hectares purchased for plantation establishment in the Douglas Daly region alone. Several forestry companies are involved in the establishment of African mahogany (*Khaya senegalensis*) plantations. Some have invested heavily in land acquisition while other companies lease land, limiting their exposure to risk. Tree species such as sandalwood, rosewood and teak have also been evaluated in the Top End, but African mahogany appears to have the best economic prospects at this stage.

Government tax concessions, managed investment schemes and the potential to sequester and trade in carbon credits have contributed to the rapid establishment of forestry plantations in recent years. Along with the demand for intensive grazing and irrigable land this has contributed to a shortage of cleared freehold properties, resulting in significant increases in land values in the Top End over the past five to 10 years.

Regardless of investment philosophy and the difficulties experienced by some companies, forestry is likely to be a permanent feature of the Top End. Forestry will continue to expand as good markets exist worldwide for high quality hardwood for furniture and carpentry. Forestry is likely to become a more popular investment option as carbon credits and emissions trading schemes become a feature of primary industry.

In the Top End forestry offers good potential from an environmental, financial and social perspective, if establishment, agronomy, marketing and financial risks are well managed. It offers landholders the opportunity to diversify into high value timber production, providing additional income, shade for stock and reduced surface runoff and erosion from sloping or more fragile country. Some forestry companies will consider plantations as small as 50 hectares if located near larger plantation areas, which makes leasing land for plantations or establishing private plantations an attractive option.

Forestry could ideally be integrated into existing farms, where plantation timber is used to complement other agricultural activities. Integration could be achieved by designing plantation rows and tree densities that would allow grazing and farming to be undertaken amongst the trees. While land is limited for forestry and maximum wood production per hectare is desirable, integration may allow more land to be planted while minimising direct competition with agriculture. Whole farm planning and economic models should be used to determine the best mix of agriculture, grazing and forestry on any parcel of land.

Plantation forestry in the Top End requires deep soils with low slopes. The preferred soils are Kandasols (red sandy loams to red clay loams). These deep soils act as a moisture bank after the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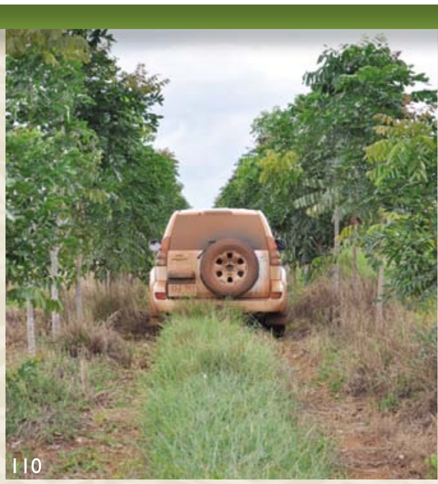
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PICTURE 109: A young African mahogany trial plot in the Top End.
PICTURE 110: A commercial forestry plantation with good grass cover in the interrow.

wet season and allow the trees to continue growing well into the dry season. As management systems and the selection and establishment of ground cover are refined, plantation forestry may be sustainably undertaken on sloping land and on shallower or poorer soils.

Forestry is still a new enterprise in the Top End and the agronomy, establishment and management of forestry plantations require ongoing research and development. Like all agricultural activities, forestry must adopt practices which are specifically developed in and suited to this environment to prevent land degradation and achieve optimum productivity.

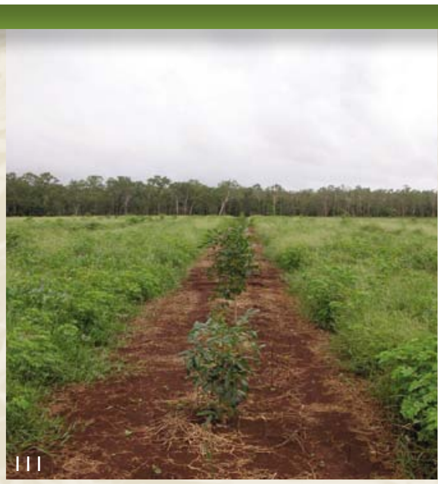
Some forestry practices which have been adopted from southern Australia or other temperate areas may not be suitable in this environment; mounding with conventional tillage, for example, should be avoided. Runoff, soil disturbance and ground cover need to be carefully managed at establishment when the potential for runoff and erosion is high. Grasses are strong competitors with trees for N and water and must be managed to prevent direct competition. However the maintenance of grass cover is essential for erosion control and maintaining soil health.

Forestry is still a new enterprise in the Top End. The agronomy, establishment and management of forestry plantations require ongoing research and development.

Defects such as wavy stems or heavy branching reduce the value of timber trees. Experience has shown that the incidence of such defects is normally reduced in populations as high as 1200 trees per hectare. However in the Douglas Daly indications are that tree quality remains the same at populations of 700 and 550 trees per hectare. This lower population would allow sufficient pasture growth and cattle integration. However the impact of cattle in young African mahogany plantations needs to be fully assessed, as damage to the bark and tree shape can significantly reduce timber quality.

In central Africa foliage is lopped from mahogany trees to provide palatable and nutritious fodder for cattle during the dry and there is potential for this to occur in the Top End when trees are pruned and thinned. This would reduce the fuel load and accelerate trash breakdown and nutrient cycling.

Plantation forestry requires ongoing research, development and economic modelling to refine the best establishment, production and integration strategies for local conditions.



PICTURE 111: Young African mahogany trees protected from weed competition but with good soil protection between the rows.
PICTURE 112: Seedlings planted without mounds under full cultivation; minimum or strip tillage is a preferable option in this environment.

11 Crop and pasture nutrition

Sixteen elements are essential for good plant growth. Carbon, oxygen and hydrogen are obtained from water and the atmosphere. Nitrogen (N) is also fixed by legumes from the atmosphere. Other elements are supplied in fertiliser and are obtained from the release and recycling of nutrients in soil and organic matter. Plant nutrients are divided into two groups: major nutrients and trace elements. Major nutrients such as N, phosphorus (P) and potassium (K) are required in the largest quantities. Trace elements such as zinc (Zn), copper (Cu) and iron (Fe) are equally important but are required in much smaller amounts.

ESSENTIAL PLANT NUTRIENTS		
	Symbol	Role and function in the plant
Major nutrients		
Nitrogen	N	The most important element for plant growth and is usually taken up in the largest quantities. N is the key building block of protein and is required for vigorous growth, yield and quality.
Phosphorus	P	The second most important element and essential for photosynthesis. Required for early root growth, cell division and seed and grain formation.
Potassium	K	Often taken up in a similar quantity to that of N. Required for cell division, the formation of sugars and control of water within the plant. Promotes plant health and disease resistance.
Sulphur	S	Essential part of plant proteins and is taken up in a similar quantity to that of P.
Calcium	Ca	Required for cell wall formation and cell growth and promotes the uptake of other nutrients.
Magnesium	Mg	A component of chlorophyll and needed for efficient photosynthesis.
Trace elements		
Zinc	Zn	Trace elements are used by plants in minute quantities and are essential for many functions in the plant. They are activators in many enzyme systems and are essential for vigorous growth, which is in turn, required for viable production and animal health. Fe and Zn are often the most deficient trace elements in plants in the Top End. Fe is required for efficient photosynthesis. Zn promotes stem elongation. Mo is required by the bacteria (*Rhizobium* spp.) essential for efficient nodulation and legume nutrition.
Copper	Cu	
Molybdenum	Mo	
Iron	Fe	
Magnesium	Mg	
Manganese	Mn	
Boron	B	
Chlorine (Cl), cobalt (Co), sodium (Na) and silicon (Si) are required and taken up in minute quantities by some plants, however their exact role in plant nutrition is not yet fully understood. Cobalt, sodium and other elements have a significant role in animal nutrition.		

TABLE 10: Essential plant nutrients.

Crop	Yield t/ha	N	P	K	S	Cu	Zn
		kg/ha				g/ha	
Maize (grain)	9.5	150	27	37	11	66	170
Maize (stubble)	11.0	110	19	135	16	55	300
Soybean (grain)	3.4	210	22	60	9	140	193
Peanut	3.4	220	45	120	25	17	30
Grain sorghum (total)	4.5	130	20	110	19	13	162
Rice (grain)	2.8	184	20	18	18	-	42
Grass pastures (hay)	10.0	100	10	100	10	60	250
Legume pastures (hay)	6.0	120	9	90	9	36	150

TABLE 11: Nutrients removed in crop and pasture production

The law of the limiting nutrient

The law of the limiting nutrient states that plant growth can be no greater than that allowed by the most limiting plant nutrient. If any one element is unavailable or absent, production cannot be increased until the specific deficiency is corrected. Once a specific nutrient deficiency is remedied, another deficiency may be induced if other nutrients are in short supply. Optimum plant growth depends on balanced nutrition and the availability of all nutrients in sufficient quantities. Tissue and soil tests are used to estimate nutrient requirements and when calculating fertiliser inputs.

Grain crops (particularly hay) remove large amounts of nutrients which must be replaced to maintain production. Under grazing many nutrients are recycled and remain in the system for longer periods.

Soil fertility in the Top End

Top End soils have low levels of natural fertility but are also subject to high rates of nutrient leaching (e.g. N, K, S, Ca and Mg). Nitrogen is also lost to the atmosphere from waterlogged soils.

Plant nutrition is determined by the complex interaction of natural fertility, soil texture and structure, pH, organic matter levels, climatic conditions and management practices.

Crops are generally more sensitive to nutrient deficiencies than pastures and even short term deficiencies can significantly reduce grain yields. Perennial pastures have a longer period in which to grow, are more efficient in extracting nutrients and are generally more tolerant than crops to lower levels of nutrition.

Many nutrient deficiencies can be eliminated by banding fertiliser close to the seed at sowing time.

Aspect	Comment
Natural fertility	Top End soils are inherently low in fertility. All major and most trace elements are deficient for intensive production. Sandy surfaced soils are less efficient in maintaining nutrients and frequently have greater nutritional problems than heavier soils. Many crops have specific nutritional requirements.
Soil texture and structure	Determines how well moisture and nutrients are retained. Well structured soils composed of appropriate proportions of sand, silt and clay are generally more easily managed and provide a good store for plant nutrients. Top End soils are poorly structured and easily compacted by cultivation. Conservation tillage and rotations will improve soil structure.
Soil pH	A measure of soil acidity or alkalinity. A pH of 7.0 is neutral, lower values are progressively more acid and values above 7.0 more alkaline. Many nutrients are "tied up" if soil is either very acid (pH 4-5) or very alkaline (pH 8-9). Most plant nutrients are available in the range pH 6.5 to 7.5. Fertiliser and irrigation practices may change soil pH. Soil acidification may occur under intensive management and legume pastures. Lime application may be required to reduce acidification and to maintain productivity.
Organic matter	Organic matter levels in Top End soils are inherently low and often less than 1%. Cultivation and heavy grazing rapidly accelerates the break down of organic matter, which is already high under tropical conditions. Organic matter: helps bind soil particles; improves structure, aeration and drainage; enhances moisture holding capacity; and acts as a reservoir for nutrients such as N, P and S. Conservation farming, pasture rotation and green manuring will help increase organic matter levels.
Environmental conditions	Dictate moisture availability, release and loss of nutrients, soil temperature and the degree of erosion. Heavy rain and high temperatures break down organic matter, leach nutrients and may lead to acidification. Environmental conditions cannot be changed but the adverse effects can be reduced by using conservation farming and associated practices.
Management practices	Management practices will dictate soil fertility and structure, pH, organic matter levels, and productivity. Conservation farming, mulch retention, rotations and good agronomic and grazing practices will improve soil health and conditions for plant growth. Overgrazing and continuous cultivation reduce fertility, organic matter levels and productivity, which ultimately lead to land degradation.

TABLE 12: Aspects of plant nutrition and soil fertility.

Conservation farming, especially no-till systems may result in an increase in organic matter in the top layer of the soil. This rich source of organic nutrients is not immediately available to plants and can immobilise or "tie-up" N, resulting in poor initial crop growth. The degree of N immobilisation depends on climatic conditions and the quantity and type of mulch. Grass mulches or crop stubbles will immobilise N for a longer period than legume mulches. Cultivation prior to planting will assist in breaking down organic matter and releasing some of the N. Banding fertiliser beneath or beside (rather than touching) crop seed will ensure crops have access to N and P to stimulate early growth and vigour.

Practices such as maintaining mulch, fertilising to meet crop requirements and rotations which include pasture phases will assist in managing soil fertility. Selecting crops and pastures for specific soil types will also enhance crop nutrition and performance.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PICTURE 113: Severe N deficiency in sorghum.
PICTURE 114: Zinc deficiency is a common occurrence on light sandy soils especially in maize and legume crops.
PICTURE 115: Phosphorus deficiency in maize. Many nutrient deficiencies can be avoided by banding fertiliser close to the seed at sowing time.
PICTURE 116: Soil sampling in pastures can help identify and correct any major nutrient deficiencies.
PICTURE 117: Plants on the right are suffering from a nitrogen deficiency which results in reduced growth, delayed maturity and low yields.

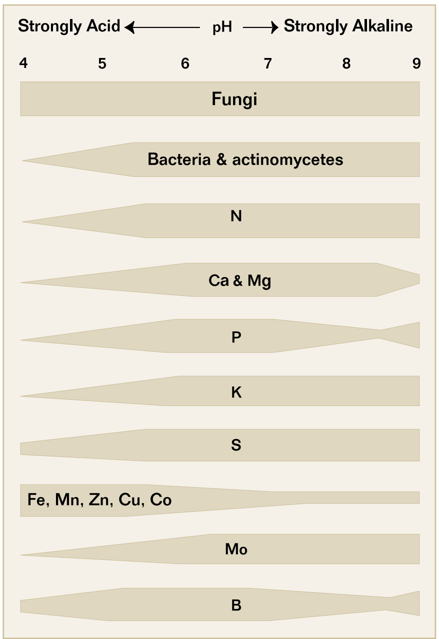

FIGURE 24: The effect of soil pH on the availability of plant nutrients and activity of soil microbes. Most nutrients are available at pH 6.5 to 7.5.

A healthy maize plant, the result of balanced nutrition.

Conservation and ley farming practices are the most effective way of building carbon, improving soil structure and fertility and maintaining crop and pasture yields.

PICTURE 118: Soil samples should be taken from intensively cropped areas every year to determine nutrient levels and fertiliser requirements.
PICTURE 119: Iron chlorosis and zinc deficiency in soybean, a disorder common in many crops on light textured soils, especially under irrigation.
PICTURE 120: Effective nodulation of legumes is essential for nitrogen fixation.

12 Field crop irrigation in the Top End

Irrigation of field crops in the Top End is a developing industry that is likely to grow in the light of declining water reserves in southern Australia. Many believe in the popular myth of unlimited water for agricultural development in the north. However given the climatic conditions, semi-arid environment, seven to eight months of dry season and absence of any major water storages, water resources in the north are not as bountiful as many imagine.

Irrigation and agricultural development will be tightly constrained by water allocation planning, the availability of suitable soil types and equitable distribution of the consumptive pool between agriculture, industry, the community and environmental needs.

12.1 IRRIGATION DEVELOPMENT AND SUSTAINABLE WATER USE

Agricultural irrigation can no longer be viewed in isolation but must be viewed in the context of the environmental, social, cultural, economic and indigenous fabric of the NT. Balancing these issues and ensuring sustainable agricultural development is the major challenge facing planners, policy makers and agriculturalists. While good water resources exist, agriculture is just one user and component within the system.

There are three principal aquifer formations within the Katherine Daly Basin which provide water to the region. The Tindall Limestone formation is the major aquifer in the Katherine region and supplements the town's water supplies. The aquifer is 150 to 200 m thick producing generally high yields of good quality, but relatively hard water.

The Jinduckin Formation overlies the Tindall Limestone and has probably the most variable quantity and quality of water. The Oolloo Limestone is the youngest of the three formations and overlies the Jinduckin Formation. It has a maximum thickness of 150 to 200 m of dolomite and dolomitic limestone and is usually reliable and high yielding. Numerous springs fed from the three main aquifers occur along river channels within the Daly Basin and contribute to river baseflows (minimum dry season river flows).

Irrigation is one of the best ways to maximise yields and returns but one of the quickest ways to lose money and degrade natural resources if not well planned and implemented.

Water from these aquifers is often high in calcium and magnesium carbonates, which has implications for crop growth related to nutrient availability.

There is a close interaction between ground and surface water systems in the Daly River catchment. During the wet season, runoff occurs and aquifers are recharged. However in the seven to eight months of the dry season, ground and surface water systems decline and are not replenished until the following wet.

This seasonal decline is due to evapotranspiration and the natural discharge of ground water to rivers, creeks and billabongs. As the dry season progresses, the surface flow in rivers and creeks recede and billabongs dry up. By the end of the dry season, smaller tributaries cease to flow. Dry season groundwater discharge maintains river baseflow and keeps them alive.

From May to December the baseflow in larger rivers and creeks is attributed mainly to groundwater discharge. This discharge is critical to the health and sustainability of permanent Top End rivers and their dependant ecosystems. Over extraction of water from aquifers will have a direct impact on river health and ecology.

The question is how much can be extracted sustainably. Estimating underground water resources is an inexact science. Resource surveys are continually undertaken and hydrological models have been developed to gauge recharge, discharge and sustainable extraction rates over short and long term time frames.

Unlike the Ord Irrigation Area in north-western Australia which has an abundance of gravity fed water, irrigation in the Top End currently relies on water from individual bores or rivers fed from these aquifers. Bore capacities of 80 to 100 L/s are possible but flow rates vary depending on aquifer depth and the size of the bore. Many irrigation bores yield only 10 to 50 L/s and in certain regions of the Top End water cannot be sourced due to inadequate subsurface water availability. Strategic water harvesting and conservation of wet season river flows hold considerable potential but have not yet been undertaken. On-farm storage of water may be possible in specific cases but is impractical in many situations due to high evaporation rates and the porosity of many soils.

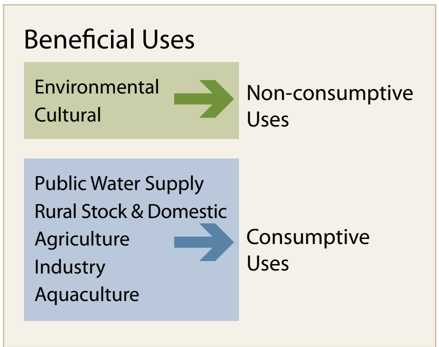

FIGURE 25: Water has to meet the needs of many consumptive and non-consumptive uses. (Source: NRETAS)

There is potential to produce a wide range of crops under irrigation but it is a continuing challenge to find crops which offer good returns. The distance from mainstream markets and the cost of imported inputs make the production of many crops unviable in the Top End at present. Territory producers require crops which have a marketing and production

PICTURE 121: Fresh water; the world's most important resource.
PICTURE 122: Winter wheat is currently being evaluated for irrigated production in the Top End.

advantage, such as out-of-season produce or niche products. The search for such crops is ongoing.

FIELD CROPS PRESENTLY PRODUCED UNDER IRRIGATION IN THE TOP END INCLUDE:

- peanuts for processing and confectionary
- maize grain or silage for local stockfeed and industrial uses
- irrigated hay (i.e. forage sorghum), Rhodes grass and lucerne for local stockfeed and the live cattle trade.

Other potential crops include:

- lucerne for local and interstate/overseas markets
- sesame for confectionary
- oil seeds or bio-fuel crops
- potatoes
- fibre crops
- pharmaceutical crops
- winter cereals i.e. wheat and oats for grain or fodder
- pasture seed for local or export markets.

12.2 IRRIGATION CONCEPTS AND MANAGEMENT

Efficient water management is essential in achieving sustainable and viable crop production. Yields and returns are increasingly measured in tonnes or dollars per megalitre (ML) of water used.

The red earth soils of the NT are only suited to sprinkler or drip irrigation. Flood irrigation is not an option on these soils due to high infiltration and percolation rates. Flood irrigation on such soil types results in massive water loss and inefficiencies. Well designed flood or furrow irrigation may be possible on the black and grey clay soils of the Adelaide and Keep River flood plains but these areas remain largely undeveloped at present.

Field crops such as maize, peanuts and sorghum require between 4.5 and 7.0 ML/ha depending upon time of planting, cultivar, soil type and seasonal conditions. This equates to 450 to 700 mm of water applied through the growing season. Total water required can be reduced significantly by sowing immediately after the wet season, using conservation tillage, accurate moisture monitoring and irrigation scheduling. Forage crops repeatedly harvested through the dry season may require up to 12 ML/ha.

Crops sown in the late wet or early dry season may require two to three ML less water than crops grown later in the dry. This is due to a lower evaporative demand earlier in the dry season and avoidance of the hottest period. Time of sowing has a big influence on total water consumption, costs of production and returns. Supplementary irrigation is also an option where crops are grown through the wet season and finished off with irrigation to ensure maximum yield.

Irrigated crops have a high requirement for nutrients and any deficiencies are often amplified under irrigation. Due to the poor buffering capacity of many soils, alkaline water often increases soil pH, resulting in a “tie-up” of nutrients and subsequent zinc, copper and iron deficiencies. Increased insect and disease pressure can occur under

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PICTURE 123: Forage oats are currently being evaluated for irrigated production in the Top End.

irrigation due to the availability of a continuous moisture and food supply, allowing pests to breed throughout the year. Sorghum midge, leafhoppers, heliothis (now known as *Helicoverpa* spp.), armyworm and pod-sucking pests may require management. Leaf diseases such as cercospora leaf spot in peanuts and other plant diseases thrive in irrigated environments. As a result, irrigated crops require more intensive management.

The dry season offers ideal growing conditions for many temperate crops. However, the lower temperatures, particularly inland, can restrict the growth and production of many tropical and sub-tropical crops. Cavalcade and tropical grass pastures do not respond to irrigation or have reduced growth rates due to lower than optimum temperatures especially between May and July. Reduced growth rates may have significant production and economic implications for specific crops. Figure 26 shows the response of irrigated Rhodes grass to reduced dry season temperatures at Douglas Daly Research Farm.

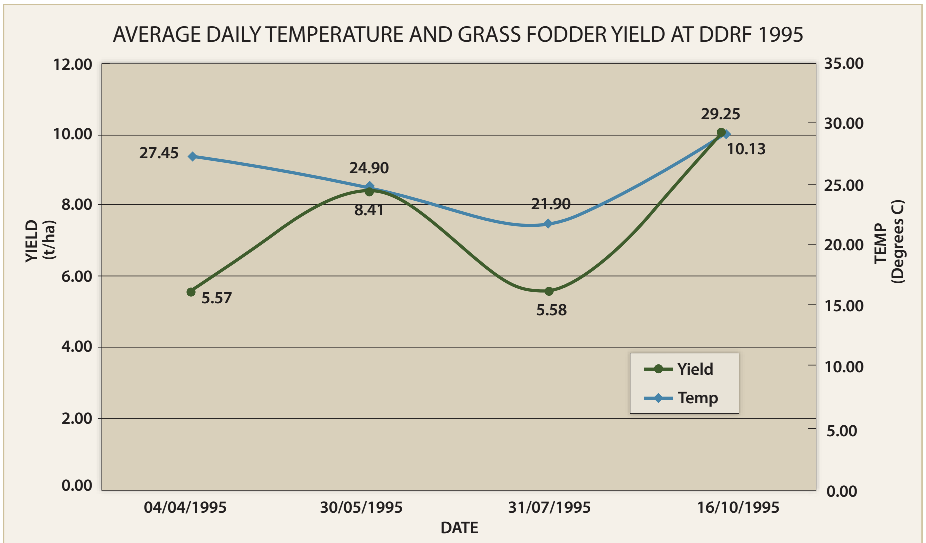


FIGURE 26: Irrigated Rhodes grass yields decline with seasonal reductions in temperature at DDRF.

Water is lost from a cropping system in a number of ways: direct evaporation; transpiration; deep percolation and runoff.

Evaporation

Evaporation is the direct loss of water as vapour from vegetation, soils and water bodies. In irrigation, evaporation from unprotected and exposed soil surfaces is a major source of water loss, especially in young crops where overhead irrigation is used. This needs to be considered when calculating crop water requirements. When a crop is small and the soil is exposed, most of the water is lost as evaporation from the soil surface.

Average daily evaporation is moderate through the early dry season with rates of 5 to 7 mm/day, creeping up to 8 mm/day during August, September and October. However, maximum evaporation can spike at 10 to 11 mm/day for several days in September to November in the Katherine Daly Basin.

One of the major considerations for irrigated cropping is the total

PICTURE 124: Maize is one of the most productive and versatile irrigated grain crops.

Month	Average daily pan evaporation (mm)	Average daily maximum temperature (°C)	Average monthly evaporation (mm)
January	5.7	33.8	186
February	5.4	32.9	167
March	5.5	33.7	170
April	5.9	34.5	177
May	6.4	33.0	198
June	5.9	31.5	177
July	6.3	31.7	195
August	7.1	33.6	220
September	7.7	36.5	231
October	7.4	36.6	242
November	6.7	36.7	210
December	6.0	34.7	192

TABLE 13: Average monthly evaporation at Douglas Daly Research Farm weather station.

wind speed. The accuracy of pan evaporation measurements is determined by the maintenance and position of the pan in the landscape. Specific conditions must be maintained to ensure accuracy so pan evaporation is normally measured at selected Bureau of Meteorology stations or agricultural facilities. Automated weather stations are also now available and can be installed on site to provide site specific information. Daily pan evaporation figures are a key indicator of plant water requirement and may be the only information some producers can access.

number of days over 35°C later in the dry season. From September to November, an average of 23 days per month will be 35°C or higher, meaning higher water requirements and irrigation costs. Crops finishing off in this period may require 60 to 70 mm/week at peak water use.

Pan evaporation

Pan evaporation is measured in millimetres of evaporation/day using a specifically designed US Class A evaporative pan. It is determined by temperature, humidity and

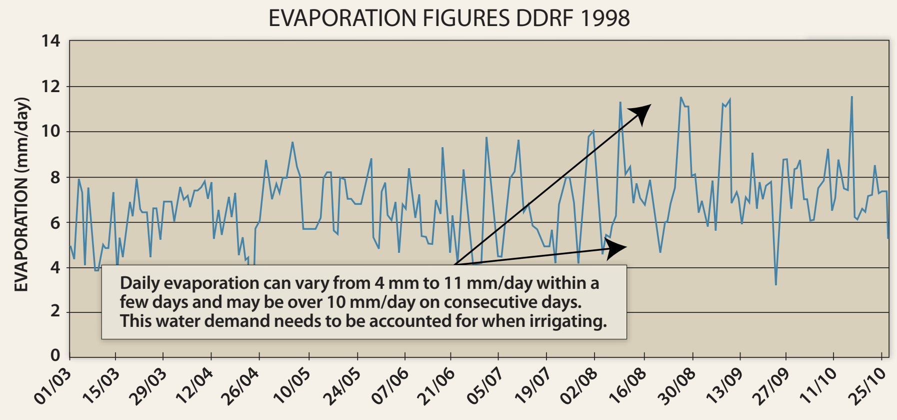


FIGURE 27: Daily evaporation rates from March to October 1998 for DDRF showing large variations over short periods.

PICTURE 125: Assessing and describing soils is essential prior to irrigation development to ensure the best soils are selected.
PICTURE 126: Evaporation pan

Transpiration

Transpiration is the loss of water as vapour from plant leaf surfaces. It is an essential physiological process which allows the plant to take up carbon dioxide for photosynthesis and nutrients and water for growth and reproduction. The process cools plants and is a necessary "cost" associated with producing crops. As a crop matures and shades the soil, evaporation decreases and transpiration becomes the major pathway for water loss. Practically all the water taken up is lost through transpiration and only a fraction is used within the plant for chemical and physiological processes.

Evapotranspiration

Evapotranspiration is the combined loss of water from the soil (evaporation) and the plant (transpiration) and represents the amount of water that needs to be replaced to satisfy productive crop growth. When working out irrigation schedules it is the daily evapotranspiration which is calculated to determine how much water is required.

Percolation

Percolation refers to the movement of water (deep drainage) through

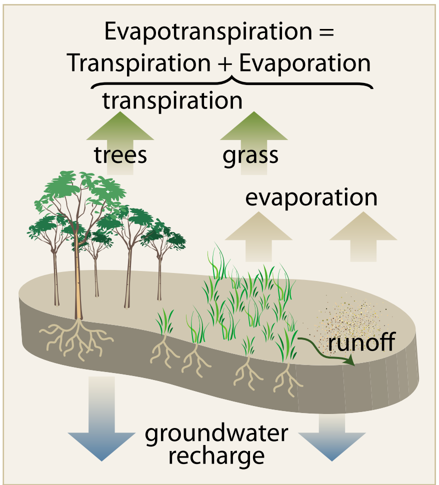


FIGURE 28: The various pathways by which water is lost from the environment.

the soil profile, which can account for considerable water loss in inefficient irrigation and poor irrigation practice. Avoiding deep percolation is essential in irrigation management. Top End soils, especially the red earths, have high percolation rates and are therefore unsuited to flood irrigation systems.

Irrigation runoff

Irrigation runoff is an excess of applied water associated with inefficient and wasteful irrigation. Badly designed systems and poor scheduling practice will often result in runoff, which represents a gross waste of water and can lead to agronomic and environmental damage. Runoff can also be a result of poor soil structure and crusting or hard pans which restrict water infiltration into the soil.

In well designed and managed sprinkler systems, runoff should be negligible.

The following terms describe concepts used in managing irrigation.

Soil-water holding capacity

Soil-water holding capacity is the amount of water a soil can physically hold or store in the root zone for plant growth. Soil moisture holding capacities are determined through tests and field measurements and have been tabulated for differently textured soils. Soil-water storage will depend on the soil type; its texture, structure and depth. Most agricultural soils in the Top End have very low to moderate water storage capacities. Irrigation rates must be matched to the soil's water holding capacity, crop type and growth stage.

PICTURE 127: Incorrect operating pressures and sprinkler selection will result in huge evaporation losses and low irrigation efficiency.

Application rate

The application rate is the amount of water applied in millimetres per hectare. It can be measured directly at the sprinkler head or as a total volume pumped divided by the area. In sprinkler systems such as pivots and lateral moves, irrigation output can be measured at the sprinkler outlet or by means of catch-cans beneath the sprinkler. Accurately measuring the water applied in mm/day is essential if crop water needs are to be met.

Using a water budget approach is an essential first step in developing an initial estimate of weekly and seasonal crop water requirements. Daily pan evaporation is the key indicator of plant water requirement. Irrigation scheduling and accuracy is further enhanced by using soil moisture sensors which accurately determine soil water content and depth.

WEEKLY WATER USE ESTIMATIONS	
Crop water use (mm) = Pan evaporation (mm) x Crop factor	
Example 1 (excluding system inefficiencies)	
Pan evaporation per day	= 6.0 mm
Pan evaporation per week	= 42 mm
Crop factor for a partially grown forage crop	= 0.7
Water required per day	= 6.0 mm/day x 0.7 = 4.2 mm/day
Water required per week	= 4.2 mm/day x 7days = 29.4 mm/week
When system inefficiencies, such as leaks and evaporation from sprinkler heads are factored in, slightly more water may need to be applied. No system is 100% efficient and most operate at between 80 and 90%. By factoring in system inefficiency the calculation would look like:	
Crop water use (mm) = Pan evaporation (mm) x Crop factor x inefficiency	
Example 2 (including system inefficiencies)	
Pan evaporation per day	= 6.0 mm
Pan evaporation per week	= 42 mm
Crop factor for a partially grown forage crop	= 0.7
System efficiency	= 85%
Water required per day	= (6.0 mm/day x 0.7) ÷ 0.85 = 4.94 mm/day
Water required per week	= 4.94 mm/day x 7days = 34.6 mm/week
When inefficiencies are considered, 5.2 mm more water is required per week at this particular growth stage which could equate to an extra 0.5 to 1.0 ML per hectare depending on growing season.	

TABLE 14: Weekly water use can be estimated excluding and including system inefficiencies.

Crop factors (Cf) are used in conjunction with pan evaporation to calculate crop water requirements at a particular growth stage. Crop water use is determined by leaf area and how much ground the crop covers and is estimated as a proportion of pan evaporation (0.1 to 1.0). Young crops with small leaves use only a small proportion of daily pan evaporation and therefore have a small Cf. As the leaf area and canopy expand, water consumption approaches that of daily pan evaporation and therefore will have a Cf of about 0.85 to 0.9. In excessively hot, dry and windy conditions (as experienced late in the dry season) a crop factor of 0.9 to 1.0 may be used (see Table 15.)

PICTURE 128: Over application of irrigation water results in a gross waste of water and nutrients.

An estimate of crop water requirements can be derived using pan evaporation and a crop factor based on the crop's growth stage. This estimate will need to be refined with moisture monitoring and crop and soil observations.

Canopy cover	Crop factor
Bare ground	0.3
1/4 canopy	0.4
1/2 canopy	0.6
3/4 canopy	0.7
Full canopy	0.85
Maturing crop	0.65

TABLE 15: Crop factors related to the proportion of ground cover.

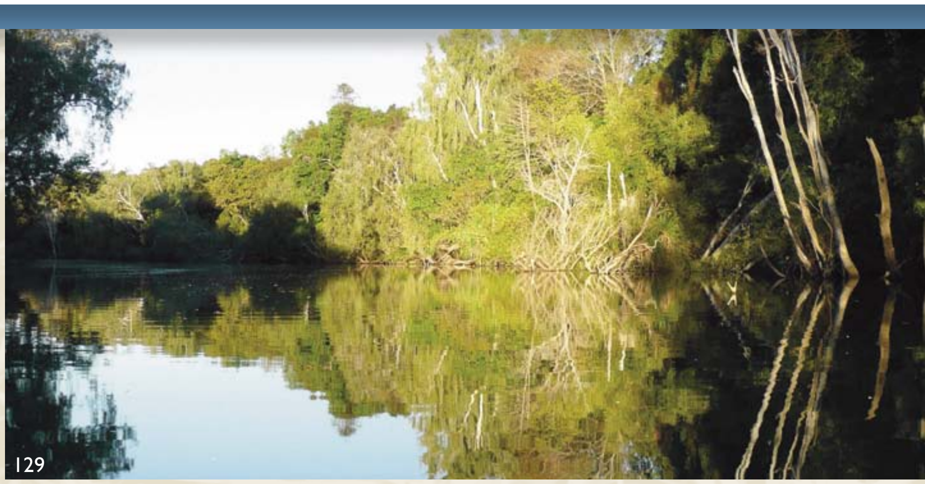
Using pan evaporation rates in conjunction with a Cf allows an estimate of crop water use to be made. This equation should also take into account system inefficiencies and losses.

Crop coefficients

Crop coefficients are used in conjunction with evapotranspiration rates calculated from temperature, solar radiation, wind speed and humidity data using the Penman-Monteith equation. This method calculates the equivalent evapotranspiration from a reference crop, considered to be a well watered, full-canopy grass sward. Crop coefficients have been developed for many crops and are available in the literature. Estimating actual crop water use from measured environmental parameters and using crop coefficients is a more precise method than using pan evaporation and crop factors. However the

Days from planting	Average crop factor	Physiology of crop	Comment
5 to 15	0.3	Early seedling growth, small leaves	Low moisture requirement
16 to 25	0.4	Increasing leaf and root extension	Increasing water demand and growth
26 to 40	0.6	Initiation of tassel and rapid leaf expansion Determination of grain numbers	Rapid leaf and root growth and increased water demand
41 to 60	0.85	Formation of ear and tasselling	Full canopy cover and approaching maximum water use
61 to 95	0.85	Silking, fertilisation and early grain fill.	Peak water demand and maximum shoot and root development. Stress at this time will have more impact on yield than at any other time in the crop's life
96 to 110	0.75 to 0.85	Grain filling and maturation	High water demand to fill grain
111 to 120	0.5 to 0.65	Late grain fill	Water requirement declining as grain reaches maximum dry matter

TABLE 16: Crop factors for an irrigated maize crop.



PICTURE 129: Tropical rivers are a critically important environmental, cultural, social, recreational and economic resource in the Top End.

terms '"crop coefficient" and '"crop factor" are often confused and used interchangeably. In reality crop coefficient values can be up to 30% higher than crop factors, because direct pan evaporation rates are higher than evapotranspiration rates from a reference crop.

Some automated and regional weather stations provide evapotranspiration rates based on local environmental data. However NT producers generally rely on pan evaporation and crop factors as evapotranspiration calculations are not widely available.

12.3 IRRIGATION DESIGN, SCHEDULING AND WATER BALANCE

Irrigation design, scheduling and water balance are critical and interdependent aspects of any irrigated cropping system and will determine profitability and long term sustainability.

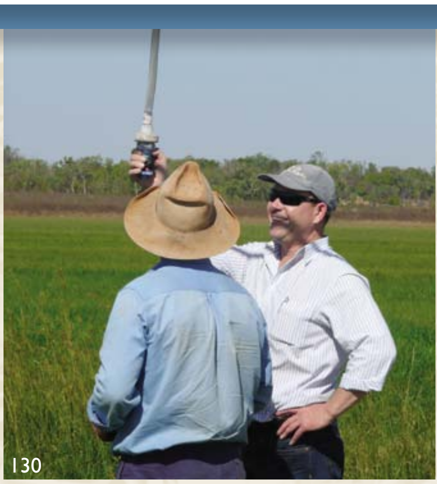
Irrigation systems must be well planned and designed. Sufficient volume and delivery capacity needs to be available to meet peak crop water demand at any growth stage. The most common mistakes in irrigation are under-design, lack of capacity and the inability to provide total crop water demand at the hottest time of the year. For example, using a system that delivers a maximum of 8 mm/day to crops which require 10 to 11 mm/day for multiple days (in October and November) will result in severe crop stress and a loss in yield, quality and income.

Irrigation scheduling is the process of calculating the timing and volume of irrigation required to meet crop yield and quality objectives. Accurate water scheduling and budgeting is essential. Over-estimating water demand will result in nutrient leaching, water logging, plant disease, resource wastage, higher costs and ultimately environmental degradation. Under-estimating crop water demand results in crop stress, yield reduction and poor returns.

Water balance is imperative for optimising crop performance, minimising costs of production and avoiding environmental issues.

Water balance is determined by crop water use, soil type and irrigation scheduling (i.e. timing, frequency and amount), and is ultimately driven by the design and efficiency of the irrigation system. A fault or deficiency in any one of these components will compromise the entire operation. A good understanding of the following factors is essential:

- The amount of moisture held by the soil in the root zone. The depth of the root zone is dependent on the crop and soil type (i.e. rooting depth of crop or soil profile to 1000 mm).
- The amount of water which can be applied by the irrigation system (as determined by physical capacity, flow rate and design of the system).
- The amount of water required by the crop on a daily basis (taking into account evapotranspiration, crop type, growth stage and physical environment).
- The amount of irrigation the soil can accept at one time (as determined by soil type and condition, infiltration rate and slope).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PICTURE 130+131: Matching pump capacity with water availability and irrigation system is an essential part of irrigation planning and design.

Accurate irrigation planning and design cannot be overstressed. The inability to apply sufficient water to meet peak crop requirements will continuously compromise yield, quality and farm profitability.

Approximate water holding capacities of different soil types in the Top End have been estimated and appear in Table 18. These figures should be used as a guide to determine how much water can be applied before the soil is full and runoff or deep percolation occurs. A detailed soil survey should be undertaken to determine specific soil properties and water holding capacities for any significant irrigation development.

Using long term average evaporation figures to design irrigation systems can result in gross under-estimations of water demand at the most critical time of the year. Peak evaporation rates should be used in design. The irrigation system will largely influence the profitability and efficiency of a cropping operation. Irrigation design is a specialist field and must incorporate all physical and environmental factors (soil, crops and climatic conditions) as well as the engineering and capacity components.

Water balance is determined by the water lost through evapotranspiration, runoff or percolation and gains made through irrigation, rainfall and contributions from the water table or lateral water movement. Water balance can be calculated using a cheque book approach (i.e. with debits and credits). A water balance looks at the following losses and gains.

Total soil water available = (TWy + Irr + rain) – (ET + Perc + runoff) + WT

where

TWy = yesterday's available soil water

Irr = irrigation water applied

Rain = water received through rain

Et = water lost as evapotranspiration

Perc = water lost as deep percolation beyond the root zone

Runoff = water lost as runoff due excess irrigation or poor soil conditions

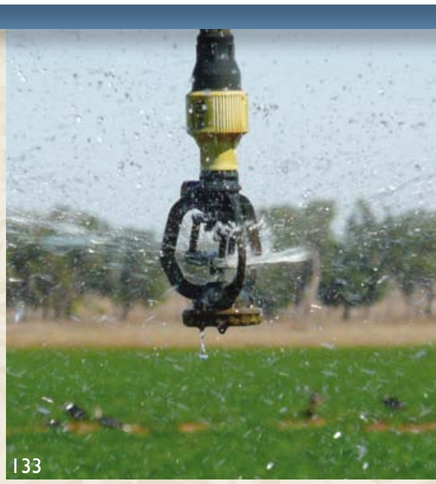
WT = water contributions from water table or lateral flow

In the Top End dry season, rainfall is negligible and water lost through runoff and deep percolation should be minimal under efficient sprinkler irrigation, but high if over-irrigation occurs. The contribution through high water tables will also be negligible. A simplified water balance for Top End conditions could be represented by:

Total water available = (Soil water + irrigation) – crop water use (evapotranspiration)

Weekly crop water requirements can be estimated using pan evaporation figures and crop factors (discussed previously), with amounts and frequencies determined by soil water holding capacities. Irrigation rates need to be aligned to the soil's ability to hold on to moisture. Applying more water than the soil can hold will cause runoff and leaching of nutrients below the root zone.

The final aspect in scheduling is determining how much water the soil can accept at any one irrigation. This will be determined by soil type, physical structure and condition. To avoid excessive ponding, runoff and loss through direct evaporation, irrigation should not exceed the infiltration rate.



PICTURE 132+133: The correct sprinkler package and operating pressure is essential for high application efficiencies and uniform water distribution.

Putting on more water than the soil can physically hold is like putting 20 litres of water into a 10 litre bucket. It doesn't work and results in huge water and nutrient losses.

Soil type	Plant available water (mm/m)
Coarse sand	35 to 60
Sand	60 to 75
Loamy sand	75 to 100
Sandy loam	100 to 160
Loam	150 to 220
Clay loams and silty clay loam	170 to 220
Silty clay and clay	150 to 200

TABLE 17: Plant available water according to soil type (Source: adapted from QDPI Note 2004, Irrigation: water balance scheduling).

On deep sandy loams, for example, 30 to 40 mm of irrigation may be applied in one pass without ponding or runoff. Particular care must be taken on very light soils to not over irrigate and cause losses through deep drainage. Heavier clay loams have lower infiltration rates and 25 to 30 mm of irrigation may cause ponding and runoff, depending on soil structure and surface conditions. Balancing the needs of the crop without causing excessive ponding or drainage beyond the root zone is a major challenge in irrigation.

Irrigation management requires experience and a thorough knowledge of the crop, soil and irrigation system. There is considerable potential for irrigated field crops. However more knowledge on crop selection, water use, nutrition, pest management, temperature requirements and economics is required before significant expansion takes place.

Irrigation and moisture sensors are now available to assist with the fine tuning of irrigation management. These are covered in the next section.

Soil type	Plant available water-moisture holding capacity/ meter *	Allowable deficit (allowable depletion before irrigation)	Readily available water per meter (50% of total available water)
Blain (sandy loam)	40 to 75 mm	40 to 50%	20 to 35 mm
Oolloo	60 to 80 mm	40 to 50%	30 to 40 mm
Tippera (clay loam)	75 to 140 mm	40 to 50%	37 to 70 mm

*This relates to the quantity of moisture that a plant can freely take up before the onset of stress (Source: adapted from Dilshad et al. 1996).

TABLE 18: Estimated soil moisture holding capacities for agricultural soils in the Top End.

PICTURE 134: Good water management is critical to the success and viability of irrigation.

12.4 SOIL MOISTURE SENSORS

Soil moisture sensors provide an accurate picture of the moisture status of the soil and allow informed irrigation decisions. Moisture sensors can be combined with other instruments which measure salinity, temperature, pH and electrical conductivity, to provide a more complete picture of soil conditions. Sensors help in managing optimum moisture levels and avoid over- or under-watering. When used and interpreted correctly they allow more accurate scheduling and can achieve very high irrigation efficiencies.

Better irrigation practice results in higher yields and water use efficiency as well as preventing loss of nutrients and potential ground water contamination. Soil moisture sensors show what is happening within the profile, where the water is being used, and how deep it is moving through the soil. Many systems produce computer graphs and scheduling programs that show water infiltration, movement and depth.

There is a wide range of sensors available that directly or indirectly measure soil moisture and other soil parameters. Prices vary from a few hundred dollars (for tensiometers and gypsum blocks, for example) to thousands of dollars for highly sophisticated electronic sensors (such as capacitance probes). The latter offer water, nutrient and pH monitoring and web downloads from remote sites.

In most cases sensors are purchased primarily on price and are often discarded shortly afterwards. This may be because they are too labour intensive, too complex or have not been maintained properly. Choosing the right equipment that works for your particular situation is essential so that it effectively improves irrigation efficiency. Seek professional advice and ask the following questions:

- What information will it give and how is it presented?
- How complex is it to install and read?
- Is a computer required to read the information?
- How durable is it and how much maintenance does it need?
- How labour intensive is it?
- Does the device suit my soil, crop and location?
- How much does it cost?
- Is there backup advice and service?

Tensiometers are porous ceramic-tipped tubes with a vacuum gauge that measure the tension with which moisture is held in the soil. They are the simplest and least expensive tool for indicating soil moisture status. Higher gauge readings reflect drier soils and the greater tension with which moisture is held. When the tension reaches a predetermined level it indicates that irrigation is required. When irrigation is applied, moisture re-enters the tensiometer, reducing the vacuum and indicating sufficient moisture. Tensiometers come in different lengths, are easy to install and provide a good guide to soil moisture status.

Electronic soil moisture equipment such as capacitance sensors (such as Enviroscan® and C-Probe® etc.) measure volumetric moisture at predetermined depths throughout

PICTURE 135: Installing an Enviroscan® soil moisture monitor.
PICTURE 136: A solar panel which provides energy for the data logger on the Enviroscan®.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Irrigation requires a high level of planning and design and agronomic,financial and marketing management to be viable and environmentally sustainable.

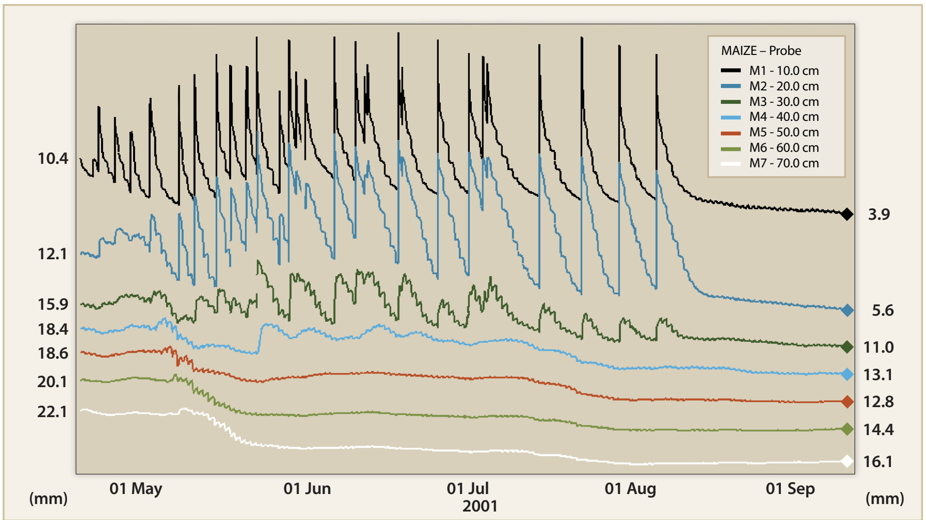

FIGURE 29: An Enviroscan® chart showing moisture extraction at various depths.

the profile. Once calibrated, this equipment will continuously measure and log moisture levels at the depth at which sensors are placed. Graphs visually illustrate moisture at various depths (Figure 29). Such systems can be set up to automatically turn irrigation systems on and off when moisture levels reach predetermined settings. Telemetry can now be used to remotely manage irrigation systems.

Gypsum blocks are increasingly being used as they are an economical alternative for smaller enterprises. They are simple and less expensive than most capacitance probes and can measure soil moisture at sufficient accuracy for most irrigation situations.

12.5 IRRIGATION CAPACITY AND WATER ALLOCATION

The capacity of an irrigation system is determined by its design and the availability of water. Once the water quantity and supply is determined the infrastructure can be designed to match the resource. Most field

Fresh water is the world's most important resource.

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PICTURE 137: G Bug® is gypsum block moisture sensor which mimics the soil moisture and records it electronically on a digital readout.
PICTURE 138: Tensiometers are the simplest soil moisture monitors; they consist of a hollow tube and vacuum gauge which measures the tension with which water is held in the soil.

crop irrigation systems in the NT are based on centre pivots supplied by underground aquifers. Irrigation bore capacities may be as high as 100 L/sec, but the majority range from 30 to 70 L/sec. The sustainable yield of a bore should be determined through a pump test before the irrigation system is designed or installed. A pump test is the only way to accurately establish the draw-down and recharge rates, sustainable yield and the capacity of the bore. Many irrigation systems are installed without sufficient planning or consideration of the physical environment, peak evaporation rates or available resources.

Bores subjected to long periods of continuous pumping at maximum rates are likely to fail. Over-pumping may result in sand being sucked into the system causing premature pump wear and possible collapse of the bore. Bores require time to recharge and each will vary in draw-down and recharge rate. The NT Government and private contractors can advise on bore construction, testing and maintenance.

Due to the increasing demand on resources, water allocation plans are being implemented by the NT Government to ensure the sustainable and equitable distribution of the resource. Commercial irrigators require an extraction licence and allocation from the Government for specified agricultural and horticultural uses.

Determining total water availability and maximum crop water demand is essential when calculating irrigable areas, pumping schedules and operational costs.

Once water allocation plans are implemented in the different regions, irrigators will have to apply for an allocation. Bores will be metered to determine water use and total ground water extraction rates. Producers will have to budget to determine how much crop area can be grown and to ensure there is enough water in their allocation to satisfy crop needs.

Water trading (the buying and selling of water from other irrigators) is likely to become a feature of irrigation in the Top End as it is elsewhere in Australia.

For example, if a producer is allocated 1000 ML for 100 hectares of forage and budgets on 10.0 ML/ha but finds there is insufficient water for the last irrigation, a number of options may have to be considered. The grower may:

1. Irrigate the entire area at a reduced rate and incur a yield reduction over the whole crop.
2. Irrigate a smaller portion of crop and redistribute the remaining allocation to maintain yield potential over a reduced area.
3. Purchase additional water to finish the original 100 ha of forage with full irrigation.

These are some of the decisions that will need to be made when irrigating in the NT once allocations have been finalised. Managing water is the key to profitability and sustainable resource use.

PICTURE 139: Water meters determine flow rate and water usage.
PICTURE 140: Accurate pump testing is essential to determine sustainable yield and for appropriate irrigation design.


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13 Weeds – a major threat to agricultural systems

Weed infestation is a major form of land degradation and productivity loss in the Top End. Weeds cost Australian farmers over $3 billion dollars per year in weed control activities, herbicide, labour costs and lost production. They reduce productivity, increase production costs, degrade and devalue land, poison stock and threaten Australia's biodiversity and native plant communities.

Throughout Australia, weeds are spreading faster than they can be controlled. Nationally the impact of invasive plants continues to increase, with exotic species accounting for about 15% of all flora. This figure is increasing by about 10 species per year. Producers in the Daly have repeatedly stated that weeds are one of their major and most costly production issues.

Agricultural weeds are defined as... "Plants that are competitive, persistent and damaging and interfere with human activities, agricultural and natural processes and as a result are undesirable".

Weeds directly affect production through competition for nutrients, light and moisture. The degree of competition depends upon weed type, time of emergence and many

WEEDS HAVE THE POTENTIAL TO:

- contaminate and reduce the quality and quantity of produce
- restrict the production of certain crops
- compete for moisture and nutrients
- interfere with and damage harvesting equipment
- increase fire risk
- interfere with mustering and stock movements
- act as hosts for insect pests and diseases
- cause animal and human health problems through toxic properties
- contaminate and obstruct waterways and aquatic resources
- reduce aesthetic and property values
- damage and interfere with natural ecosystems.

The real cost of weeds to the economy and the environment is greater than the combined value of all our agricultural industries.

other factors. The effect of weed competition is greatest when the crop or pasture is young. Weed competition can reduce crop yields to below economic levels and may render pastures virtually unproductive. Weeds reduce the quality of hay, grain or pasture and in certain cases can prevent the produce being sold or moved off property. Contamination of sesame or mungbean, either by plants or weed seed, can reduce the price or cause rejection of the crop.

13.1 INTEGRATED WEED MANAGEMENT

Unfortunately, weeds are a fact of life and integrated control is the only effective management strategy. This involves a combination of preventative, cultural, chemical and biological control methods. Good farm hygiene, strategic cultivation, herbicides, crop rotation and grazing management are all required to minimise the spread of weeds.

Preventative weed management

Prevention is the first control measure. Any implement, animal, product or vehicle entering the farm from another area is a potential source of weeds. Isolated weeds can rapidly become heavy infestations. Stands of senna (*Senna obtusifolia*) can produce over 10 000 seeds/m^2 which can remain viable for over 10 years.

Don't buy weeds!

Hay and pasture seed contaminated with weed seed is a major cause of weed introduction and spread. In the NT, the Government may issue a notice restraining a person from selling hay or animal fodder containing noxious weeds or seeds. Failure to comply can result in a fine under the *Weeds Management Act 2001*.

Seed should always be analysed for purity, germination and weed seed content before purchase. A seed analysis report should be available with all seed sold. Certified seed is the best option, but the quality of any seed should be confirmed by a seed analysis prior to purchase. Buying "cheap" seed of unknown quality may result in poor establishment and a lifetime of costly weed control.

Most hay contains some weeds but the level of contamination can vary from less than 1% to over 50%. Buyers should insist on the cleanest hay possible and be aware of its origin and content prior to purchase. Inspecting the paddock from which the hay is about to be harvested allows any weeds to be identified before purchase. Demanding clean hay, buying from reputable producers and using hay in confined areas can help to minimise weed spread.

Contaminated pasture seed and hay are major sources of weed introduction. Insist on clean hay and demand a seed analysis before purchasing.

Beware of stock and farm machinery!

Introducing stock or machinery from other areas almost always carries the risk of introducing weeds. Livestock distribute weed seeds in their dung and spined seeds such as Noogoora burr (*Xanthium occidentale*) stick to their tails and hides. Hard seeds such as senna can pass through the digestive system undamaged. To minimise the spread of weeds, stock introduced from other areas should be inspected or


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PICTURE 141: Heavy infestation of hyptis.
PICTURE 142: Weed growth is prolific and control is one of the major costs of production in Top End agriculture.

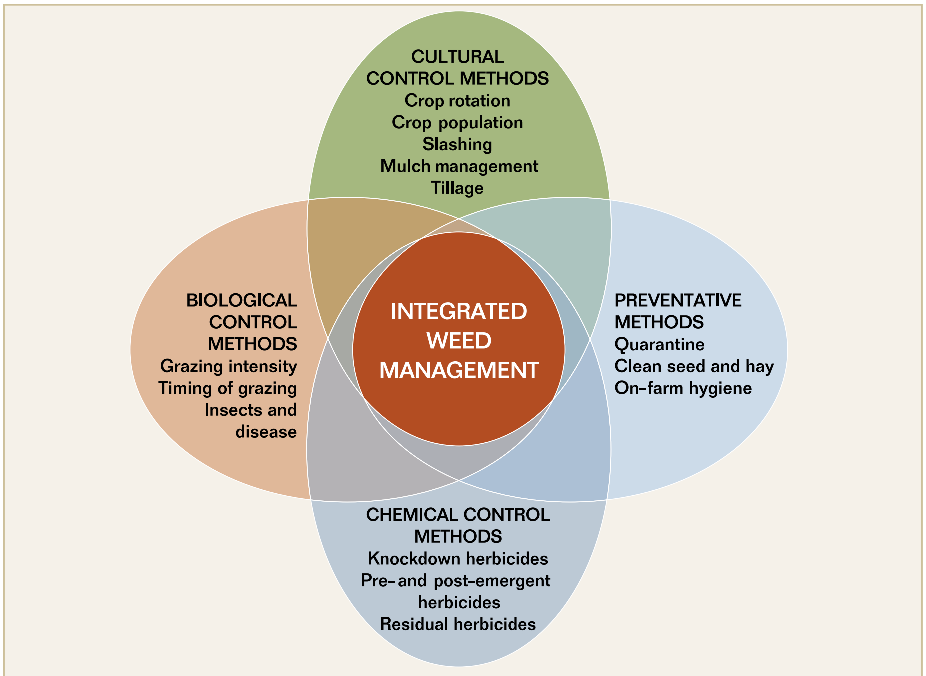


FIGURE 30: Integrated weed management involves bringing all the elements of weed control together into a combined management program to reduce the spread and impact of weeds.

confined and fed in a small area until all foreign feeds have passed through the digestive system. This will help limit the initial spread of weed seeds.

Vehicles, farm machinery and earth moving equipment can introduce and spread weeds. Washing down machinery prior to entry into new country will minimise the risks of introduction. Spined weeds like caltrop (*Tribulus terrestris*) pierce tyres, while sida (*Sida acuta*), hyptis (*Hyptis sauveolens*), senna (*Senna obtusifolia*) and *Pennisetum* spp. are easily transported and distributed by vehicles and machinery. Farm quarantine and restricting vehicle access will help reduce the introduction and spread of weeds.

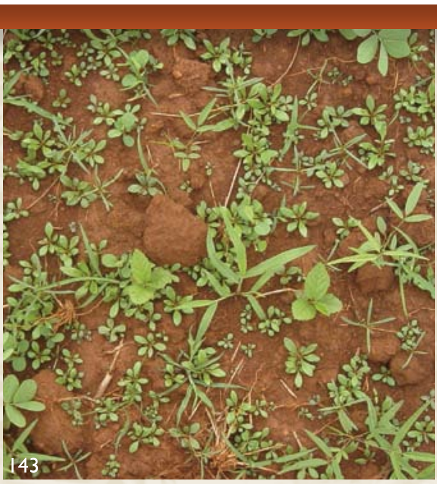
Cultural weed management: Tillage

Tillage is an effective form of weed control and can be used when conditions are unsuitable for herbicides. Tillage can be used to control hard-to-kill perennial and woody weeds, to clean up heavy or dense weed infestations and at times when herbicides may be less effective. Deep ploughing inverts soil, buries seed and reduces emergence of some weeds. Shallow cultivation brings weed seeds close to the surface and stimulates germination, allowing control with subsequent tillage or herbicides. Tillage has limited application for weed control if constant rain is being received as it simply transplants weeds. Herbicides, in conjunction with light tillage, offer the best option for weed control in such situations.

Slashing

Repeated slashing of weeds will reduce seed production and plant vigour, but in most cases, will not eradicate weeds completely. Seed produced after slashing late in the season often has lower viability and less vigour which helps in reducing weed populations.

Slashing along boundaries and fencelines minimises seed set and is



PICTURE 143: Weed germination is stimulated by cultivation. Once weeds emerge herbicides can then be used as a management tool.
PICTURE 144: Mulch has the added advantage of suppressing the emergence of weeds. The thicker the mulch the better the control.

an effective means of manipulating vegetation prior to herbicide application. A combination of slashing and herbicide will be more effective in most situations than relying on a single method.

Good pasture and crop management

A healthy, vigorous crop or pasture is an effective competitor for weeds. Narrow rows result in earlier canopy closure and more effective suppression of weeds and will also reduce the need for post emergent herbicides. Research on narrow row corn and soybean has shown significant improvement in weed control, moisture efficiency and crop yields.

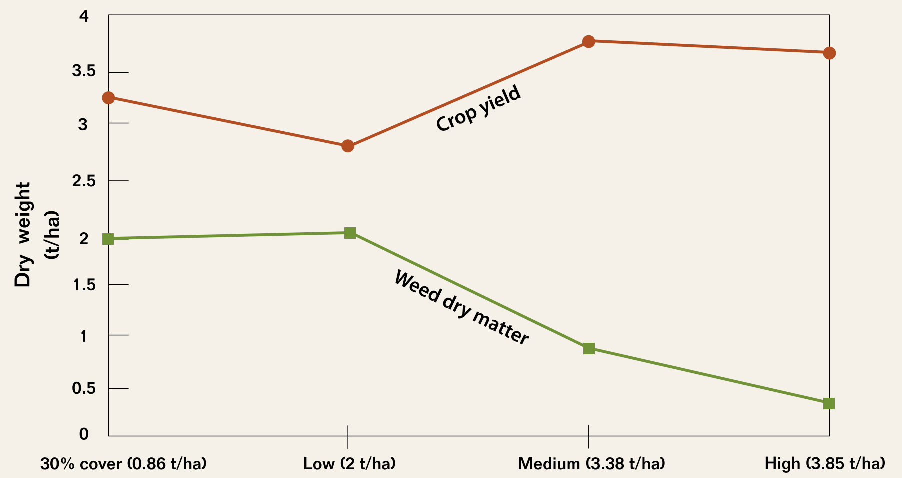


FIGURE 32: The effect of mulch quantity at sowing time on sorghum yield and weed biomass at harvest. High mulch levels at planting resulted in reduced weed competition and better crop performance, indicating the potential of mulch.

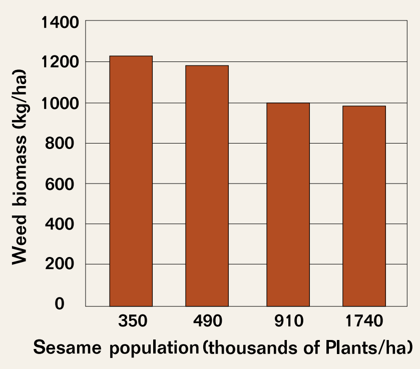


FIGURE 31: Relationship between sesame population and weed density.

Grazing management largely determines how quickly weeds spread. Continuous heavy grazing creates opportunities for weed invasion. Maintaining adequate ground cover conserves moisture allowing pastures to re-establish rapidly and compete more effectively with weeds. The most effective weed control is healthy competitive pasture.

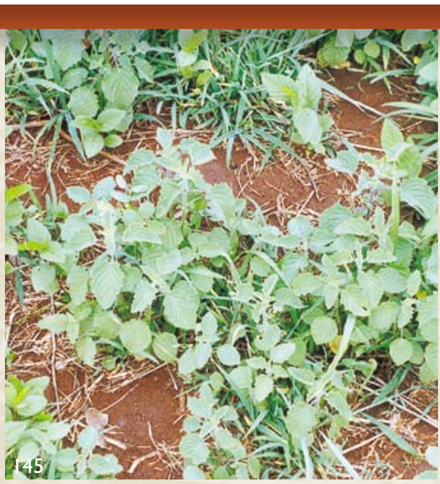
Mulch cover also suppresses early weed emergence by changing the light, temperature and moisture conditions at the soil surface. If weed infestation is significantly impacting on pasture performance, complete rejuvenation and re-seeding may be necessary to restore productivity levels.

Chemical weed control

Herbicides allow greater flexibility and offer a range of management options for weed control. Herbicides are grouped into categories according to active ingredient, mode of action, type of formulation, and application method and timing.

Weed control prior to planting is the best management strategy as it enables crops and pastures to establish without competition. In conservation farming, a single application of glyphosate will

PICTURE 145: Three major broadleaf weeds are senna, hyptis and sida. Control at an early stage with herbicides is more efficient and cheaper than when more mature.
PICTURE 146: Sida seedling. Sida is an invasive perennial weed which is difficult to control with selective herbicides once mature.
PICTURE 147: Senna seedling. Senna is the most damaging weed in legume pastures and crops.
PICTURE 148: Hyptis seedling. Hyptis is an invasive weed but is susceptible to many selective herbicides.
PICTURE 149: Herbicide rollers allow tall weeds to be controlled in pastures.



BROAD HERBICIDE GROUPS USED IN NT FARMING SYSTEMS	
Herbicide type	**Activity**
Non-selective/non-residual knockdown	Controls most vegetation. Used as an initial knockdown prior to planting or total vegetation control. No residual effect. Various glyphosate formulations and other herbicides such as diquat and paraquat.
Selective and residual	Controls certain weeds in specific crops and pastures for extended periods. Applied pre- or post-planting. Residual effects for weeks or months. Examples include atrazine, metsulfuron-methyl, trifluralin, diuron, imazethapyr and S-metolachlor.
Selective non-residual	Controls certain weeds in established crops and pastures, such as grass weeds in legumes or broadleaf weeds in grasses. Little or no residual activity. Examples include 2,4-D, fluazifop, fluroxypyr, sethoxydim and haloxyfop.
Non-selective and residual	Used in spot applications for difficult weeds and for non-crop purposes such as along fencelines. Long term residual action. An example is hexazinone.

NOTE: Active ingredients are mentioned as examples only. Consult herbicide labels for specific uses and conditions.

TABLE 19: Broad groups used in farming systems in the NT.

adequately control most weeds prior to planting. If weed growth is prolific, two separate herbicide applications, one to two weeks apart, may be necessary for adequate control. The addition of selective and residual (soil acting) herbicides may be added to glyphosate to provide improved and longer control over specific weeds.

Controlling weeds after crop or pasture establishment is often costly and in some situations may be impossible. Selective post-emergent herbicides are available but are expensive and must be applied to small weeds to be effective. These include herbicides for broadleaf weeds in grass crops, broadleaf weeds in legumes, grass weeds in legume crops and grass weeds in crops such as maize and sorghum. Weed control is more easily achieved when herbicides are applied to young, actively growing weeds.

Herbicide rollers and rope-wick applicators

Herbicide rollers and rope-wick applicators are designed to apply herbicide to weeds growing above the crop or pasture canopy. Herbicide rollers consist of a rotating, ground driven drum covered with a chemically impregnated material. Rope-wick applicators work on the same principle but use a rope-wick to carry the herbicide. Herbicide is physically “wiped” or “rolled” onto the stems and leaves of the weeds and is an ideal method for targeting weeds that are taller than the crop. In many instances a systemic herbicide such as glyphosate is used.

Biological control

Biological weed control involves the use of insects or disease organisms to reduce the spread of weeds. Biological control is a slow process requiring several years of research to identify suitable agents. Bio-control of weeds is not an option in most agricultural or cropping situations due to the slow nature of the control agents, but is valuable in long term control of some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important environmental weeds. A number of bio-control agents have been released in the NT including the insects *Cyrtobagous salviniae* and *Calligrapha pantherina* that are assisting in the control of salvinia (*Salvinia molesta*) and spinyhead sida (*Sida acuta*) respectively. A number of bio-control agents are currently being evaluated for mimosa control, including the carmenta stem boring moth and two disease organisms.

13.2 NOXIOUS WEEDS – A CAUSE FOR CONCERN

The major noxious weeds in the Top End include mimosa (*Mimosa pigra*), salvinia, hyptis, senna, Noogoora burr, bellyache bush (*Jatropha gossypifolia*), and parkinsonia (*Parkinsonia aculeata*). Others such as Siam weed (*Chromolaena odorata*) and rubbervine (*Cryptostegia grandiflora*) pose a serious threat if introduced to the NT. Gamba grass (*Andropogon gayanus*), a commonly used pasture in the Top End, is a declared weed and must now be managed, controlled or eradicated depending on the region. It is no longer to be sown as a pasture.

Weed problem or source of contamination	Options for control and management
Introduction into new country or new crops and pastures	• Inspect and clean all machinery prior to use. • Purchase certified/clean seed. • Hand pull or spot spray small outbreaks to minimise spread.
Introduction through purchased hay/fodder	• Purchase clean fodder. • Isolate areas where fodder is used. • Control weeds as they emerge. • Grow own fodder.
Introduction through livestock	• Hold cattle in "quarantine" area on farm until digestive tract is emptied. • Control weeds in quarantine area. • Avoid stock from known noxious weed areas.
Introduction from surrounding areas	• Isolate and treat initial outbreak. • Slash and spray borders and fencelines. • Plant competitive pasture around perimeter of property. • Cooperate with neighbours in controlling boundary weeds. • Fence property to prevent entry by wildlife which carry weeds. (An option for small blocks only.)
Build-up of weeds in pastures or crops	• Employ good grazing management. • Apply selective and or residual herbicides. • Apply non-selective herbicides with herbicide roller or rope wick. • Spot spray and hand pull isolated areas. • Slash or cultivate where desirable. • Renovate pasture (i.e. re-seed, fertilise and apply selective and or residual herbicides). • Rotate with alternative crops or pastures.

TABLE 20: Weed control strategies for different situations.

Noxious weeds are found on pastoral and farming properties, small rural blocks, national parks, Aboriginal and Crown lands. Landholders are responsible for the control of noxious weeds within their boundaries but cooperation between landholders, the community, councils and government agencies is required to effectively manage


PICTURE 150: Weeds in pasture controlled by a herbicide roller.
PICTURE 151: Gamba grass can still be used as a pasture in the upper Top End but can no longer be planted and must be managed to avoid further spread.

Gamba grass can still be used as a pasture in the upper Top End but can no longer be planted and must be managed to avoid further spread.

PICTURE 152: Mimosa, a major weed of the Top End floodplains, is a target for biological control.

weeds. *The Northern Territory Weeds Management Act 2001* is aimed at preventing the introduction and spread of noxious weeds. An outline of the Act and a list of noxious weeds appear in the appendix. More information on weeds is available from the NT Government web site www.nt.gov.au/weeds, or the Federal Government's weed web site www.weeds.gov.au.

13.3 MAJOR WEEDS IN TOP END FARMING AND PASTURE SYSTEMS

There are a number of major weed issues which cause significant economic damage and in some cases restrict the production of certain crops or pastures.

Legume and broadleaf weeds in Cavalcade hay crops

Legume and broadleaf weeds seriously reduce the productivity and quality of Cavalcade crops and if weed densities are high, will preclude the growing of Cavalcade on some land. Senna is almost impossible to control in Cavalcade and crops can become totally overrun, making the hay un-saleable. Other broadleaf weeds such as Berrimah weed (*Ludwigia* spp.), sida and pasture legumes like Wynn cassia and buffalo clover (*Alysicarpus vaginalis*), are difficult to control in Cavalcade crops.

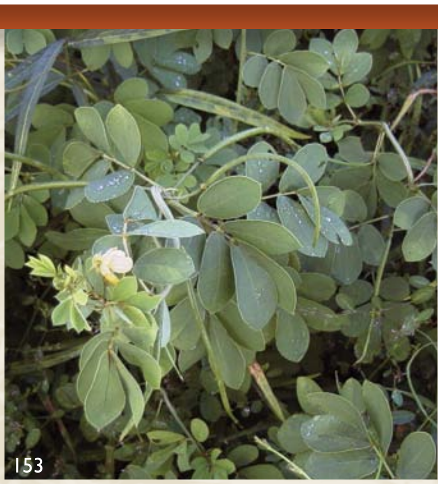
Cavalcade should be planted in clean paddocks after a grass rotation, where broadleaves have been controlled. Using zero-tillage and applying one or two knock-down glyphosate applications followed by a registered selective herbicide provide good control in most instances. However there are no selective herbicides which will control legume weeds in Cavalcade at this stage. Applying glyphosate through a rope-wick applicator or carpet roller is the only option once some of these weeds become established and tall enough to contact. Paddocks heavily infested with senna should be avoided.

Legume and broadleaf weeds in legume crops

Similar problems are caused by legume weeds in crops such as mungbean, soybean, lucerne and peanut crops. Senna, phasey bean (*Macroptilium lathyroides*), buffalo clover and Wynn cassia can be particularly hard to control. In row crops such as peanuts there is the opportunity to use some selective herbicides or do inter-row spraying with shielded sprayers, but there are few options for senna in soybean and mungbean crops. Senna is possibly the biggest economic threat to legume production in the Top End and its seed remains dormant in the soil for several years.

Broadleaves such as paddy melons (*Cucumis myriocarpus*), caltrop and sesbania (*Sesbania* spp.) can all cause problems in peanut crops and interfere with harvest operations. Plants become entangled in machinery causing downtime and loss of produce through reduced harvest efficiency. Early control of these weeds is essential to prevent problems at harvest.

Nut grass (*Cyperus rotundus*) is a sedge and considered one of the world's worst cropping weeds. It is very competitive and almost impossible to eradicate. It is prevalent on many irrigation areas and is difficult and expensive to



PICTURE 153: Senna is the most economically important weed of legume crops and pastures in the Top End.
PICTURE 154: Senna seedlings establishing in a soybean crop.

control once established in a crop. Every effort should be made to prevent the entry or establishment of nut grass through quarantine and farm hygiene.

Weeds in pastures and hay crops

There are several species that progressively dominate and reduce the quality and production of pastures and hay crops. Major grass weeds include annual and perennial species of *Pennisetum* (including mission grass), grader grass (*Themeda quadrivalvis*), Mossman River grass (*Cenchrus echinatus*), gamba grass and various weedy summer grasses. Such species spread readily by seed and can dominate an area within a few seasons.

Some selective herbicides can assist in suppressing annual grass weeds in grass pastures. However, established grassy weeds in grass pastures or hay crops are difficult and costly to control. Spot spraying, wick-wiping or pasture rejuvenation are the main options. Early identification and control is essential before weeds mature and set seed.

Sida, hyptis, flannel weed (*Sida cordifolia*), goat's head burr (*Acanthospermum hispidum*), caltrop, paddy melon and nut grass are serious weeds which cause economic impacts in pastures, hay and irrigated crops. Most of these weeds can be adequately controlled by selective herbicides in grass crops but costs will vary depending on weed density, maturity and herbicide type and rate required.

Woody weeds and sucker regrowth

Woody weeds and sucker regrowth are a major issue especially in areas that were cleared at the wrong time of year (i.e. in the middle of the dry season) and have had minimal management or cultivation thereafter. The density of suckers will vary depending on the clearing operation and timing, post-clearing management and previous vegetation type. In some instances multiple suckers regrow from root fragments or lignotubers and the resultant vegetation is thicker than the original. Along with native regrowth there is a range of introduced woody weeds of economic importance, including rubber bush (*Calotropis* spp.), mimosa, parkinsonia and other species.

Senna seed pods.

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PICTURE 155: Nutgrass, a serious weed of irrigation areas, grows from underground tubers or nuts. Cultivation spreads the nuts and once established is impossible to eradicate.
PICTURE 156: There are a number of species of pennisetum all of which are invasive, free seeding grasses. Young plants may be grazed but older plants are avoided by animals.

Woody weeds reduce the capacity of good agricultural land and interfere with agricultural and mustering operations. Some species, including zamia palm (*Cycas armstrongii*) and ironwood (*Erythrophleum chlorostachys*), are toxic to livestock and contaminate hay and may result in stock deaths.

If regrowth density is low, light cultivation or spot spraying with herbicides may be effective. Where growth is advanced and at high densities, re-chaining combined with heavy cultivation using dozers and blade ploughs may be necessary.

Good clearing practice followed by strategic cultivation, cutter-barring or blade-ploughing will minimise subsequent regrowth problems. One or two seasons of cultivation and cropping (incorporating chemical control) after the initial clearing may be required to sufficiently reduce regrowth. A clearing permit is required to control regrowth if a permit for that area has not been previously issued. Native vegetation clearing guidelines and advice are available from the NT Government.

Grader grass is an unpalatable and invasive grass species that is spread through slashing, grading and movement of hay.

PICTURE 157: Caltrop is a major weed of irrigation areas and its seeds are dispersed widely on machinery tyres.

14 Insect pest and disease management

Conservation farming promotes a diversity of insect life, influences pest populations and also favours many beneficial insects. The beneficial insects which act as natural control agents help to create a more stable agricultural system.

Reducing cultivation and maintaining mulch provides a more favourable habitat for certain soil dwelling insect pests and disease organisms. A range of pests including caterpillars, beetles, grasshoppers, foliage feeders and sap-sucking insects occur in all crops and pastures and will require control from time to time.

14.1 INTEGRATED PEST MANAGEMENT – THE LONG TERM SOLUTION

Pest management will be achieved only by a long term commitment to integrated control practices. Integrated pest management (IPM) involves the strategic use of rotations, resistant varieties, beneficial insects, cultural measures and selective pesticides. IPM requires an understanding of the interaction between pests, plants and the environment and will ensure that chemical use and pest control is optimised, environmental contamination is minimised and productivity is maintained.

INTEGRATED PEST MANAGEMENT INVOLVES:

- rotating crops and pastures to disrupt pest lifecycles
- selecting varieties resistant to pests and disease
- using strategic cultivation to disrupt the development of pests
- eradicating plants which harbour insect pests or disease
- monitoring crops to determine pest and beneficial insect activity
- encouraging and protecting beneficial insects
- applying pesticides only when pests approach economic injury level
- using selective or "soft" pesticides which target pests only
- using systemic seed dressings which offer protection from pests and diseases.

Identifying pests and their damage and knowing when they are likely to attack the crop is essential for effective insect management.

14.2 COMMON INSECT PROBLEMS

Insect pests and crop establishment

Soil dwelling pests such as earwigs, scarab beetles, false wireworms, wingless cockroaches and cutworms are active in or on the soil particularly under high mulch levels. They feed on the roots and shoots of emerging seedlings. Insect numbers and damage levels will vary from year to year according to seasonal conditions.

False wireworm (*Gonocephalum elderi* and *Adelium brevicorne*) are the most common and damaging insect pests of crops and pastures at establishment. Damage is caused by the larval or immature stage feeding on germinating seeds, but adults may also feed on seedlings.

Some soil dwelling insects can be detected prior to planting by placing baits of pre-soaked sorghum grain at several sites throughout the field. Baits are dug up and inspected after the seedlings emerge. The number of insects found gives an indication of expected populations. One or more insects per bait usually indicates control is necessary.

Control of soil borne pests involves seed treatment with an appropriate insecticide or an in-furrow insecticidal spray or granule at planting. Commercial bait is available for the control of surface insect pests. The application of systemic fungicidal and insecticidal seed dressings is one of the most effective ways of managing soil borne pests and associated diseases. A number of commercial products are available that protect the seed from a range of soil dwelling and above ground insect pests. Pre-treated crop and pasture seed can be purchased which avoids the need to handle the seed dressing.

Presswheels or seed firming wheels will allow more rapid germination and may help to restrict the movement of insects through the soil.

Grasshoppers, yellow-winged locusts (*Gastrimargus musicus*) and various caterpillars occasionally damage sorghum and maize crops at establishment. Problems may arise in no-tillage areas where immature hoppers move from the dying mulch to emerging crop seedlings. Damage at this stage is swift and monitoring is essential to identify the problem. Armyworm caterpillars (*Mythimna separata*) can also cause sporadic damage to young crops.

Foliage feeders, sap suckers, pod and grain pests

Grasshoppers, beetles, caterpillars, flies, aphids, plant hoppers and pod-sucking bugs attack the foliage, flowers, pods and seed of crops and pastures. Some insects are specific and feed on only one type of plant while others attack a wide range of crops. *Helicoverpa* spp. caterpillars (formerly *Heliothis* spp.) attack several crops, including sorghum, maize, peanut, sesame and most grain and pasture legumes. Sorghum midge (*Contarinia sorghicola*) is a specific pest of grain sorghum.

The most common insect pests are caterpillars (*Helicoverpa,*

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armyworm and *Spodoptera* spp.) and pod-sucking bugs such as the green vegetable bug (*Viridula nezara*), redbanded shield bug (*Piezodorus hybneri*) and *Riptortus* species. Pod-sucking bugs are particularly damaging to legumes such as mungbean, soybean and Cavalcade and Bundey seed crops.

Leafhoppers are a serious economic pest in the Top End, particularly in irrigated cropping. They are vectors of many important diseases. Irrigated maize is very susceptible to infestation by leafhoppers (*Cicadulina bimaculata*) which transmit "wallaby ear" virus and render the crop unviable. Lucerne is severely damaged by a number of leafhopper species. These transmit "littleleaf" disease which stunts and eventually debilitates a stand.

Leafhoppers in maize are effectively controlled by using systemic insecticidal seed dressing and such protection is recommended on all maize crops. However leafhopper control in perennial crops like lucerne is more difficult due to the rapid reinfestation and continuous supply of young succulent growth. Leafhoppers are one of the major limitations to the longevity of lucerne stands in the Top End.

Monitoring pests and deciding on control

Crops vary in their tolerance to insect attack depending on the type of damage and stage of growth. Seedlings have little tolerance to insect attack and relatively small numbers can cause economic damage. Most crops can withstand considerable insect pressure in the vegetative stage but considerably less damage at critical growth stages such as establishment, flowering, grain fill and pod maturity. Monitoring and management during these high risk periods is essential to minimise economic loss.

The first step in managing pests is to establish which insects, and how many, are present. Monitoring involves regular inspection of crops. Insect pests are usually present but in most instances are in numbers too low to cause economic damage or warrant control. Monitoring avoids unnecessary use of pesticides and allows informed decisions to be made based on actual pest numbers and damage levels, rather than guesswork. Monitoring involves counting insect numbers in a given area (for example, five metres of crop row) at several sites throughout the field. Guidelines regarding insect tolerance levels have been established for most crops.

Beneficial insects such as predators and parasites are important natural control agents and play a major role in reducing pest numbers. Only when natural control is absent or pest numbers grow beyond the capacity of natural agents, do other control measures become necessary. Beneficial insects are a vital part of IPM and include beetles, bugs, ants, wasps, spiders, earwigs, flies, mantids, lacewings and damselflies.


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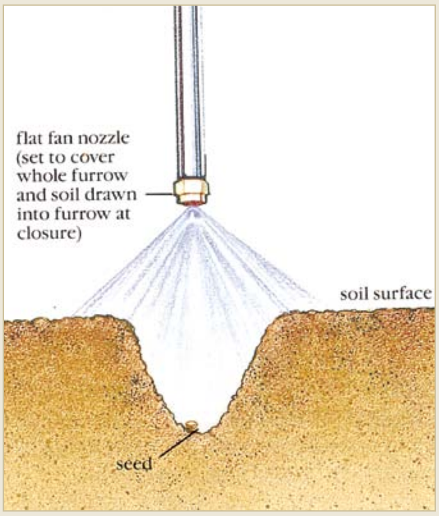
PICTURE 158: Severe damage to maize ears caused by a combination of insects including green vegetable bugs and heliothis.
PICTURE 159: Collecting leafhoppers in a lucerne crop with a blower/vac in to determine insect numbers.

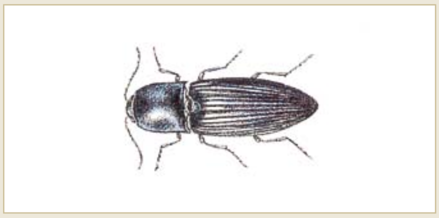
Field cricket. The adult and immature stages of field crickets, feed at night on the leaves and stems of seedlings and young plants. They also feed on the flowers, developing fruits and seeds of mature plants.



In-furrow application of insecticide for soil dwelling insect control.

(1) Pie–dish beetle (adult false wireworm) Length 16–19mm.

(2) False wireworm have hard, round bodies with a pointed, upturned tail segment (pie-dish beetle larvae). Length about 3.5cm when fully grown.



(1) Click beetle (adult true wireworm) Length 9–13mm.

(2) A wireworm with soft, semi–flattened body and a forked tooth–edge tail segment. Length up to 2cm when fully grown.

Wingless cockroach. These insects are most active during the summer months causing crop damage at night by chewing seedlings off at ground level.

Black field earwig. These insects feed on the germinating seed and roots of young plants, killing or weakening them. This damage can continue until the plants are 60 cm high and can result in severe crop lodging. Damage mostly occurs in areas with heavy black soils.

PICTURE 160: Soil dwelling insect pests can cause significant damage to establishing crops. (Source: courtesy of DowElanco)

PICTURE 162:
(a) Red-banded shield bug
(b) Green vegetable bug
Both insects are serious pests of grain and pasture legumes.

PICTURE 164: Grain sorghum damaged by sorghum midge. The insect is usually prevalent in irrigated crops.

PICTURE 161:
(a) Predatory shield bug (b) Assassin bug
Both beneficial predatory insects play a major role in reducing insect pest numbers. They are shown here feeding on heliothis.

PICTURE 163:
(a) Heliothis caterpillars (shown here on a sorghum head) are a frequent pest of most crops of the Top End.
(b) Northern armyworm is a more sporadic pest.

PICTURE 165:
(a) Riptortus feed on seed crops and grain legumes.
(b) Crusader bugs have a straight proboscis which is a characteristic of plant-sucking bugs.

Green Vegetable bug and egg raft

14.3 DISEASE IN CROPS AND PASTURES

Plant diseases are caused by many species of fungi, bacteria, mycoplasmas, viruses and nematodes. Some diseases are transmitted by vectors such as insects, fungi or nematodes. The development of disease depends upon a number of factors and if one or more of these are absent, disease will not develop or will be reduced in severity.

Disease development depends upon:

- susceptibility of the crop or pasture to disease
- the presence of a virulent disease organism
- environmental conditions favourable for infection and disease development.

Townsville stylo (*Stylosanthes humilis*) is a legume similar to Verano and Amiga stylo and was planted over vast areas of the NT and north Queensland. In the mid 1970s it was devastated by anthracnose; a leaf and stem disease caused by the fungal pathogen *Colletotrichum gloeosporioides*. Large areas of stylo pastures were wiped out, illustrating the damage which can be caused by a virulent plant disease.

New species with better disease resistance have since been released but there is still a threat that a new race of anthracnose may develop and infect one or more of the current stylos. To combat this threat, it is recommended that a number of stylos (i.e. Seca, Siran, Verano and Amiga) be sown in a mix so that if one should succumb to disease the others will persist and remain productive.

The retention of mulch may favour the build up of certain disease organisms which cause leaf spots and stem and head rots. These can damage crops when conditions are favourable. Burning crop residues to reduce disease has been practised in other agricultural areas but is not recommended in the Top End due to the negative impact of reducing soil surface cover.

Conservation tillage can reduce the incidence of certain diseases by improving the conditions for crop growth and thereby increasing resistance to infection. Fungal diseases such as charcoal rot

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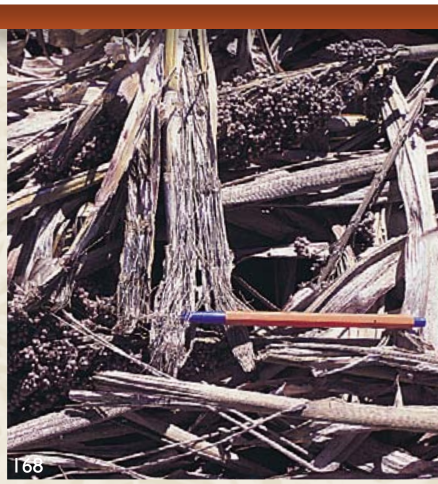

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(*Macrophomina phaseolina*) and stalk rot of grain sorghum (*Fusarium moniliforme*) are accentuated by high soil temperatures and moisture and nutrient stress. Maintaining mulch, good nutrition, weed control and using resistant varieties will reduce the incidence of such diseases.

Disease management, like all pest management, requires an integrated approach. Strategies include:

- crop rotation
- use of resistant and adapted varieties
- correct planting time and agronomy
- insect vector control
- adequate soil fertility and appropriate pH
- use of fungicides and seed dressing
- management of mulch levels
- strategic tillage
- quarantine to prevent disease entry
- farm and machinery hygiene.

Common plant diseases of field crops

The most common diseases in crops and pastures are foliar and stem diseases. Head and grain moulds in sorghum may occur in prolonged wet weather. Seed and seedling rots can occur but are largely controlled by fungicide treated seed.

Leaf spots, blights and rusts thrive in prolonged wet weather and high temperatures. Leaf spot in peanut (*Cercospora* spp.) and rice blast (*Pyricularia grisea*) can be particularly damaging in certain seasons. Leaf spot survives in seed and old peanut debris. Control involves crop rotation to reduce inoculum, sowing non-infected and treated seed and applying fungicides immediately the disease becomes evident. Rice blast is a leaf and stem disease which survives on rice stubble. Burning stubble will reduce inoculum levels but resistant varieties and rotation offer more sustainable long term control.

Many soil borne organisms infect plants when conditions favour their development. Such diseases include charcoal rot of sorghum and stem blight of mungbean, sesame and soybean caused by *Macrophomina phaseolina*.

Insect vectors and plant disease

There are several insect species which transmit plant disease in the same way as vectors spread animal or human disease. A vector is an organism that does not cause disease itself but transmits infection by

Wallaby ear virus in a young maize plant.

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PICTURE 166: Powdery mildew on mungbean grown under irrigation in the dry season.
PICTURE 167: Sorghum affected by charcoal rot (*Macrophomina phaseolina*).
PICTURE 168: Stem disorder caused by charcoal rot.
PICTURE 169: Cercospora leaf spot in peanuts can become a major disease if not controlled through management and resistant varieties.
PICTURE 170: Wallaby ear is a serious disease of maize which dwarfs crops (as shown in the stunted plants on the right) and renders them unviable.

conveying pathogens from one host to another. Classic examples are the anopheles mosquito (which acts as a vector for malaria by transmitting the malarial parasite to humans) and the paralysis tick in livestock.

Leafhoppers (described in the Insect Section) are prevalent in the Top End and transmit a range of plant diseases including "wallaby ear" virus in maize, "littleleaf" in lucerne and plant "yellows" or stunting in many other crops. Once the plants have been infected with these diseases they cannot be "cured" and will be permanently debilitated or eventually die. Management of such diseases involves prevention and control of the vector before the disease becomes prominent.

Systemic insecticidal seed treatment is one of the most effective preventative measures. Strategic spraying of the vector, growing trap crops, rotating crops and growing resistant varieties are other methods of control. Specific knowledge of the pest and its biology is required to effectively manage such insect transmitted diseases.

Crop monitoring, an essential component of insect management.

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PICTURE 171: Leafhoppers transmit "littleleaf" in lucerne crops; symptoms are discoloration of the leaf margins and stunted plants with small bunched leaves.
PICTURE 172: A potato leafhopper similar to the insects which infest lucerne and maize crops. Photo by: Steve L. Brown, University of Georgia, www.forestryimages.org

15 Summary

Intensive agriculture in the Top End is relatively new and challenging but offers tremendous potential if developed and managed correctly. Success depends on a thorough understanding of the physical environment, sound crop and animal husbandry, sustainable land use practices and good financial and marketing strategies. Along with this is the need to deal with the raft of state, federal and international regulations and policies that are on the horizon.

Conservation farming and sustainable grazing practices are imperative in moderating the impacts of climate change and the increasingly erratic weather patterns that are predicted for this region. Integrating crops, livestock and pastures into flexible and adaptive farming systems will allow greater utilisation, management and protection of the natural resources of the Top End.

If agriculture is to take advantage of the production and market opportunities that arise and make a real contribution to the increasing global food demand, farming systems must be conservative, sustainable and smart. Adaptive, conservation farming and grazing systems are the only viable choices for dealing with the challenges ahead.

Protecting our soil, rivers and aquifers and maintaining healthy agricultural and natural ecosystems, are as much a global and ethical imperative as producing more food.

Glossary

Acidic soil
Soil with a pH value of less than 7.0. In highly acid soils some nutrients and elements become toxic, while others are unavailable resulting in poor plant growth.

Acidification
The process by which soils become increasingly acidic due to leaching of minerals such as Ca, Mg, K and N.

Aflotoxin
Any of several related toxic compounds produced by the fungi *Aspergillus flavus* which infects many food crops including peanuts.

Agricultural biodiversity
Refers to the variation of life forms within a farming or agricultural ecosystem and is often used as a measure of the health of biological systems.

Agro-ecosystems
An agro-ecosystem is the system of organisms, (i.e. plants, animals and microorganisms), their association and interaction with each other and with the agricultural environment. Ecosystems refer to the abundance, distribution, energy, role and progression of organisms within the environment.

Alkaline soil
Opposite to acidic. Soils with a pH value greater than 7.0.

Amelioration of soil
To correct or improve the condition of the soil through some practice such as liming or cultivation etc.

Annual
A plant that completes its lifecycle within one year and then dies.

Arable land
Land which is capable of the production of cultivated crops.

Available water
The portion of water in the soil which can be used by plants.

Beneficial insects
Insects which are natural enemies of crop and pasture pests and thus play a role in reducing pest populations.

Biological control
The use of naturally occurring insects or disease organisms to assist in control of pests in crops and pastures.

Biomass
Biomass in the agricultural context refers to vegetative matter produced by crops and pastures and is measured in kilograms or tonnes per hectare.

Bio-security
A set of preventive measures, laws and practices designed to eliminate or reduce the introduction of exotic plants, insects or pathogens which would damage or negatively impact agricultural or natural ecosystems.

Boomspray
Mechanical device consisting of a chemical tank, pump, boom and nozzles designed to apply agricultural chemicals.

Buffering capacity
The capacity of a soil to resist changes in pH.

Build-up (climate)
A term used to describe the period that coincides with the early part of the wet season when the temperature and humidity increase prior to the onset of the monsoon.

Calibrate (chemical)
Accurately measure the output per unit area of chemical from a boomspray or other application device.

Carbon sequestration
Any process or system which achieves the long-term storage of carbon dioxide or other forms of carbon to mitigate the effects of global warming. Carbon is captured through biomass production, maintaining forests or establishing forestry plantations. It has been proposed to mitigate the accumulation of greenhouse gases released by the burning of fossil fuels.

Carrying capacity
The ability of a unit of land to adequately support a given number of livestock without degrading the resource.

Cation exchange capacity (CEC)
The capacity of a soil to exchange cations (positively charged ions) between the soil and the soil solution. CEC is used as a measure of fertility, nutrient retention capacity and the capacity to protect groundwater from cation contamination.

Combine
A planter designed to sow a range of crops and pastures in narrow rows, usually less than 500 mm.

Compaction of soil
Compression of the soil surface or sub-soil through the movement of stock or machinery leading to reduced water infiltration and restricted root growth.

Conservation farming
A broad term referring to a combination of farming techniques designed to conserve soil and water. It usually involves mulch retention and reduced tillage.

Contour
An imaginary line connecting points of equal height over the land.

Contour bank
A soil conservation bank constructed on or close to the contour to slow and trap runoff water.

Contour tillage/farming
A system where tillage or farming is carried out on or near the contour of the land to slow the flow of surface water.

Conventional cultivation
A term referring to traditional practices where several tillage operations are carried out and plant residues are incorporated prior to planting.

Coulter
A disc used on conservation tillage planters to cut surface mulch and allow tines or furrow openers to pass without blockage.

Cover crop
A quick growing crop used specifically as mulch to protect the soil.

Crust
A hard soil surface layer that is compacted, and which restricts the entry of water and the emergence of seedlings.

Cultural management
The use of agronomic practices to disrupt the lifecycle of pests and disease, such as rotations, cultivation and resistant varieties.

Cyclone
A tropical low pressure system associated with rising warm air and clockwise air circulation which generates high velocity winds and heavy rain.

Degradation of soil
Physical and chemical damage or a reduction in the soil's productive capacity due to processes such as erosion, acidification, salinisation or weed infestation.

Desiccant
Chemical applied to crops to hasten the dry-down period; enables earlier harvesting and reduces seed loss.

Dhal
De-husked, split legume seed used in Asian cooking.

Digestibility
The percentage of the total plant which can be digested or absorbed by the grazing animal for its metabolism and growth.

Dispersible soil
A structurally unstable soil which readily disperses into its constituent particles (clay, silt, sand) in water. Highly dispersible soils are normally highly erodible.

Diversion bank
A soil conservation bank designed to divert water before it reaches a designated site or cropping area.

Dry matter
The portion of plants or vegetation which is not water.

Dryland farming
Rain-fed production of crops and pastures.

Emission trading
The control of greenhouse gas pollution by providing economic incentives for achieving reductions in emissions. Government sets a limit or cap on the amount of a pollutant that can be emitted. Companies or other groups are issued emission permits and are required to hold an equivalent number of allowances (or credits) which represent the right to emit a specific amount.

Erosion
The wearing away of the land surface by the action of wind and/or water.

Evaporation
The conversion of water to vapour and its subsequent loss from free water bodies or the soil surface.

Evapotranspiration
The combined loss of water to the atmosphere through transpiration from plant surfaces and evaporation from the soil surface

Floodplain
Practically level land situated close

to a channel which is subject to overflow or flooding.

Foliar herbicide
Herbicide which is applied to the foliage of plants and is taken up through the leaves.

Furrow
A slot or depression created by the passage of planter tines into which the seed is placed. Furrows are also created by cultivation.

Genetic engineering
The direct manipulation of an organism's genes. Genetic engineering uses molecular cloning and transformation techniques to alter the structure and characteristics of genes. In agriculture, genetic engineering is used to change crop characteristics and infer disease and insect resistance and tolerance to herbicides such as glyphosate.

Genetically modified organism (GMO)
An organism whose genetic material has been altered using genetic engineering. DNA molecules from different sources are combined into one molecule to create a new set of genes which is then transferred into an organism, giving it modified or novel genes. Roundup Ready® and BT crops are examples of GMOs

Global positioning system (GPS)
Is a space-based global navigation satellite system which provides three-dimensional (latitude, longitude, altitude) information. GPS receivers access data to locate, map and navigate. GPS is now widely used in agriculture to guide machinery for increased efficiency.

Global warming
The increase in the average temperature of the Earth and oceans. Temperatures increased 0.74 ± 0.18 °C during the last century. Global warming is caused by increasing concentrations of greenhouse gases resulting from fossil fuel burning and deforestation (Intergovernmental Panel on Climate Change (IPCC))

Glyphosate
Translocated non-selective herbicide used in conservation farming systems. The active ingredient in Roundup® herbicide.

Greenhouse gases
Atmospheric gases that absorb and emit radiation which cause the greenhouse effect. The main greenhouse gases are water vapor, carbon dioxide, methane, nitrous oxide, and ozone. Greenhouse gases moderate the temperature of the Earth but increasing greenhouse gas emissions are leading to accelerated global warming.

Green manure crop
Crop grown for the purpose of improving soil fertility and structure and which is returned to the soil.

Groundwater recharge
The process by which surface water moves through the soil and strata to recharge aquifers. It is a vital process for the maintenance of ground water reserves.

Growth promotant
Synthetic hormone administered to livestock to enhance feed conversion and growth rates.

Hardpan
A compacted and hardened layer of sub-soil which impedes water flow and root growth.

Herbicide
Chemical which is biologically active and used to kill or control the growth or emergence of specific plants and weeds.

Herbicide translocation
A process whereby herbicides are taken up and distributed within the conductive tissue of plants.

Hybrid
Plant or animal resulting from a cross between parents which are genetically different.

Immobilisation of nitrogen
The conversion of N to an organic form in microbial or plant tissue which is unavailable for uptake or use by plants.

Improved pastures
Introduced or exotic pasture species with superior nutritional or growth characteristics to native pastures.

Infiltration
The rate at which water is taken into the soil, usually measured in mm/hr.

Inoculum (plant disease)
The disease organism or its parts that contact the plant and cause the infection.

Integrated pest management (IPM)
Pest management systems which incorporate a range of practices to keep pests below economic injury levels. IPM includes chemical, cultural, biological, physical and quarantine controls.

Ironstone gravel
Gravel nodules high in iron oxides found in many soils in the Top End.

Kaolinite clay
Hydrous, non-expanding clay mineral containing aluminosilicates and having a 1:1 crystal structure.

Lateritic soil
Soils of various textures containing 10 to 50% ironstone gravel in the surface layers or within the profile.

Leaching
The downward removal of nutrients and chemicals in solution through the soil.

Legume
A member of the Leguminosae or pulse (beans and peas) family most of which use *Rhizobium* spp. associations to fix atmospheric nitrogen.

Legume inoculation
Coating legume seed with a specific culture of *Rhizobium* bacteria to promote effective nodulation and enhance nitrogen fixing.

Legume understorey
Legume pasture grown in conjunction with an annual crop.

Ley or ley farming
Refers to the practice of rotating legume pastures with annual crops to improve soil structure and fertility and provide grazing for stock. The pasture phase is the ley phase.

Liming
Application of lime (calcium oxide CaO) or a similar neutralising material to reduce soil acidity.

Liveweight gain
Increase in animal liveweight when measured from a specific point in time.

Major elements or nutrients
Chemical elements required in the largest quantities for plant growth, i.e. nitrogen, phosphorus, potassium.

Methane
(CH_4) is the principal component of natural gas and a potent greenhouse gas with a high global warming potential. Ruminant ani mals are large methane emitters.

Micro-nutrient (trace element)
Nutrients or elements required in minute quantities but which are essential for plant growth i.e. zinc, copper and iron.

Mimosine
Toxic amino acid found in the foliage of leucaena (*Leucaena leucocephela*).

Mineralisation of nitrogen
The conversion of N from an organic form to an inorganic form as a result of microbial decomposition. It can then be utilised by plants.

Minimum tillage
A system where tillage is reduced to the minimum required to achieve a suitable environment for plant establishment.

Monitoring
Regular inspection of crops to identify insect and disease activity in order to determine whether control measures are necessary. Monitoring is an integral part of integrated pest management.

Mulch
A natural layer of plant residue or live vegetation on the soil surface. Mulch may also be artificial, e.g. plastic or paper.

Mutagenesis
A plant breeding technique in which genetic mutation occurs to confer specific desirable traits.

Native pastures
Natural pastures consisting of original non-introduced plant species.

Nematodes
Microscopic wormlike organisms some of which are parasites of crops and pastures.

Node
Slightly enlarged portion of the stem where leaves, buds or roots arise.

Nodulation
The process by which legume roots are colonised by rhizobium bacteria and nodules are formed.

Non-selective herbicide
A herbicide which is non-specific and controls most vegetation to which it is applied. Glyphosate is an example of a non-selective herbicide.

No-tillage
A system of establishing crops and pastures without prior cultivation. Specialised planters are used and weeds are controlled using herbicides.

Noxious weed
Any plant which is deemed harmful, damaging or causes a loss in production or intrinsic values may be declared noxious. Its control will be determined by relevant legislation.

Nutrient
An element which is taken up and used by plants for growth and reproduction.

Organic farming
Farming without the use of chemical fertilisers and pesticides.

Oxalates
Oxalic acid found in many plants causing gastroenteritis or hypocalcaemia (low blood calcium levels) in livestock. Kazungula, buffel and other pastures may contain oxalic acid. Horses are particularly susceptible to oxalate poisoning.

Pasture decline
A gradual process of productivity decline associated with nutrient immobilisation or loss of productive species.

Pasture utilisation
The proportion of total pasture dry matter consumed by livestock. Usually expressed as a percentage of the total.

Percolation
The downward movement of water through saturated soil.

Perennial
A plant which continues to grow from year to year.

Permeability of a soil
The ease with which water enters and passes though the soil.

Pesticide
Term used for any chemical used for the control of weeds, insects or disease in crops and pastures.

pH of soil
A numerical scale indicating the degree of acidity or alkalinity of a soil with pH 7.0 being neutral.

Podsolic soil
Soils with texture profiles which change from light at the surface to bleached, heavier clay layers at depth. Usually poorly drained and subject to waterlogging in the wet season.

Pod-sucking bugs
Insect pests of the Hemiptera family which have sucking mouth parts and feed on the sap of immature pods and seeds.

Precision farming/agriculture
A system in which new technologies, such as global positioning systems (GPS), sensors, satellites or aerial images are used to assess, monitor and address crop and soil variation. Information is used to achieve greater precision in planting, fertiliser and pesticide application and accurately predict and monitor crop yields.

Presswheel
Device or small wheel used on planters to assist in covering the furrow, improving seed-to-soil contact and enhancing emergence.

Proboscis
Piercing, needle-like mouth parts of plantsucking bugs and predatory shield bugs.

Prussic acid
Hydrocyanic acid (HCN) formed in sorghum plants as a result of stress or rapid growth. Causes poisoning in livestock.

Red earth
Class of soils which are the massive structured red clay loam and sandy loam soils of the Top End.

Reduced tillage
Synonymous with minimum tillage.

Rejuvenation of pastures
Renovation of “run-down” pastures by undertaking weed control, reseeding, fertilising or other practice to improve productivity.

Remote sensing
The acquisition of information on an object, geographical area or phenomenon, by various techniques to monitor changes in land condition and crop health. It supports data collection on the

ground, ensuring in the process that areas or objects are not disturbed.

Residual herbicide
Herbicide which is soil-acting and controls germinating weeds over an extended period.

Rhizobia
Bacteria which colonise the roots of legumes and are capable of fixing atmospheric nitrogen for the benefit of the plant.

Rhizome
Underground stems formed by many plants as a means of vegetative spread.

Rilling (erosion)
Small intermittent channels only centimetres deep which usually occur as a result of runoff on newly cultivated land.

Rotation
A management system where crops and pastures are grown in alternate years to control weeds, insect pests and diseases and maintain soil structure and fertility.

Row-crop planter
A precision planter designed to sow crops in discrete rows of 0.5 to 1.0 m. Usually used in maize, cotton and peanut production.

Ruminant (or enteric) fermentation
Fermentation that takes place in the digestive systems of ruminant animals such as cattle and sheep etc. Ruminants have a special stomach (rumen) that allows them to digest tough, fibrous plants and grains through a microbial fermentation process.

Runoff
Rainfall in excess of the infiltration rate which is lost as surface flow.

Satellite imaging
The capture of images of the Earth by satellites to provide visual information on crop, land and natural resource condition and change. Satellite imagery is the basis for precision farming information systems.

Sediment
Suspended soil particles which are carried away in runoff water and are deposited further down the slope.

Seed-firming wheel
A term given to a specific type of presswheel which presses the seed lightly into the bottom of the furrow rather than compacting soil on top of the seed.

Seed inoculation
Application of a specific rhizobium culture to legume seeds to induce nodulation and nitrogen fixation.

Selective herbicide
A herbicide which controls a specific group of plants but is inactive against others, i.e. grass herbicides.

Semi-arid tropics
A term given to a tropical area in which there is a distinct dry period which severely limits plant growth.

Soil microbes
Beneficial and harmful species of bacteria, fungi and other microscopic organisms which are a part of the soil's ecology.

Soil structure
The physical arrangement of soil particles into units or aggregates.

Sowing point
The part of the planter which physically engages the soil creating a furrow into which the seed is placed.

Stocking rate
The number of stock units run on a particular area of land.

Strip cropping
Growing crops in an arrangement of strips that serve as protection against wind or water erosion.

Stubble
Plant residue left over from a crop

Supplemented cattle
Cattle which are provided with mineral or fodder supplementation to overcome temporary deficiencies in nutrition.

Surfactant
Chemical additive which improves the dispersion, spreading and wetting action of herbicides or other chemicals.

Sustainable
Term used to describe agricultural practices which allow continued and viable production without degrading natural resources.

Tahini
Paste made from sesame seed.

Tillage
Cultivation or mechanical working of the soil.

Tilth
The physical condition of the soil as related to ease of tillage, fineness of seedbed and impedance to seedling emergence.

Tindall clay loam
Class of sandy clay loam and clay loam red earth soils with structured B horizon. Agriculturally important and found in the Katherine-Daly Basin.

Tine
Shank on a planter or cultivator to which sowing or cultivating points are attached.

Tippera clay loam
Similar soil type to Tindall but has a massive hard structured B horizon.

Top End
Northern-most area of the Northern Territory of Australia (above 16°S) in which the production of dryland crops is possible during the wet season.

Trace elements (micro-nutrient)
Elements or nutrients required by plants in minute quantities but which are essential for healthy plant growth.

Trafficability
Refers to the ability to travel or drive over the land in order to carry out some operation, i.e. cultivating, spraying or sowing.

Transition period
The period between the dry season and the onset of the wet season when sporadic storms cause spoilage of dry feed.

Trap-cropping
The practice of growing a sacrifice crop to encourage insect pests which may later be chemically or physically controlled.

Tropics
The geographical region between the Tropics of Capricorn and Cancer.

Vector
Insect, fungus, nematode or other organism which transmits disease.

Water holding capacity
The amount of water a soil can hold and make available for plant use. Sands and clays have low and high water holding capacities, respectively.

Waterlogged
Saturated with water. Conditions detrimental to plant growth. Common problem in some soils during the wet season.

Waterway
A structure designed to collect runoff water from diversion and contour banks and carry it safely to a discharge area or natural water course.

Wetting agent
Synonymous with surfactant.

Appendices

APPENDIX 1 – DECLARED WEEDS

For information on how to identify and control declared weeds contact the Weed Management Branch of NRETAS by phone or email (08 8999 4567, weedinfo.nretas@nt.gov.au).

Schedule of classes

- A/C
- B/C
- C

A	To be eradicated	Reasonable effort must be made to eradicate the plant within the NT
B	Growth and spread to be controlled	Reasonable attempts must be made to contain the growth and prevent the movement of the plant
C	Not to be introduced to the Territory	All Class A and Class B weeds are also considered to be Class C weeds.

*Area to which declaration applies is all of the Northern Territory unless otherwise stated.

Schedule class A/C*	
Botanical name	Common name
Acacia catechu	Cutch tree
Acacia nilotica	Prickly acacia
Alternanthera philoxeroides	Alligator weed
Andropogon gayanus	Gamba grass
Annona glabra	Pond apple
Asparagus asparagoides	Bridal creeper
Asphodelus fistulosus	Onion weed
Barleria prionitis	Baleria
Cabomba spp.	Cabomba
Chrysanthemoides monilifera	Bitou bush/boneseed
Cryptostegia spp.	Rubber vine
Dalbergia sissoo (Area: N of 18° S latitude)	Dalbergia
Datura ferox	Longspine thornapple
Echium plantagineum	Paterson's curse
Eichhornia crassipes	Water hyacinth
Jatropha curcas	Physic nut
Lycium ferocissimum	African boxthorn
Martynia annua	Devil's claw
Mimosa pigra (Area: S of 14° S latitude)	Mimosa, giant sensitive plant
Nassella neesiana	Chilean needle grass
Nassella tenuissa	Mexican feather grass (Class A) All of the NT
Nassella trichotoma	Serrated tussock
Parthenium hysterophorus	Parthenium weed
Prosopis spp.	Mesquite
Rubus fruticose agg.	Blackberry
Salix spp. *except S. babylonica, S. X calodendron & S. X reichardtiji*	Willows (except weeping willows, pussy willow and sterile pussy willow)
Ulex europaeus	Gorse
Ziziphus mauritiana	Chinee apple, Indian jujube

Schedule class B/C	
Botanical name	Common name
Acanthospermum hispidum	Star burr, goat's head
Alternanthera pungens	Khaki weed
Andropogon gayanus	Gamba grass
Argemone ochroleuca	Mexican poppy
Calotropis procera (Area: S of 16 °30' S latitude)	Rubber bush
Carthamus lanatus	Saffron thistle
Cenchrus echinatus	Mossman River grass
Emex australis	Spiny emex
Hymenachne amplexicaulis	Olive hymenachne
Hyptis capitata	Knob weed
Hyptis suaveolens	Hyptis
Jatropha gossypifolia	Bellyache bush
Lantana camara	Common lantana
Lantana montevidensis	Creeping lantana
Leonotis nepetifolia	Lion's tail
Mimosa pigra (Area: N of 14 ° S latitude)	Mimosa, giant sensitive plant
Mimosa pudica	Common sensitive plant
Opuntia spp. (Area: S of 18 ° S latitude)	Prickly pears
Parkinsonia aculeata	Parkinsonia
Pennisetum polystachion	Mission grass
Pistia stratiotes	Water lettuce
Ricinus communis	Castor oil plant
Salvinia molesta	Salvinia
Senna alata	Candle bush
Senna obtusifolia	Sicklepod
Senna occidentalis	Coffee senna
Sida acuta	Spinyhead sida
Sida cordifolia	Flannel weed
Sida rhombifolia	Paddy's lucerne
Stachytarpheta spp.	Snake weeds
Tamarix aphylla	Tamarisk, athel pine
Themeda quadrivalvis	Grader grass
Tribulus cistoides	Caltrop
Tribulus terrestris	Caltrop
Xanthium occidentale	Noogoora burr
Xanthium spinosum	Bathurst burr

(Includes all class A and class B invasive weeds)

Schedule class C	
Botanical name	Common name
Acroptilon repens	Creeping knapweed
Ageratina riparia	Mistflower
Amaranthus dubius	Chinese spinach
Ambrosia artemisiifolia	Annual ragweed
Ambrosia psilostachya	Perennial ragweed
Austroeupatorium inulaefolium	
Baccharis halimifolia	Groundsel bush
Boerhavia erecta	
Brachiaria paspaloides	Common brachiaria, Thurston grass
Chromolaena odorata	Siam weed, Christmas bush

Clidemia hirta	Koster's curse, soap bush
Coix aquatica	Job's tears
Croton hirtus	
Datura spp.	Thornapples
Digitaria fuscescens	Common crabgrass
Digitaria insularis	
Diodia sarmentosa	
Echinochloa glabrescens	Barnyard grass
Echinochloa stagnina	
Egeria densa	Dense waterweed
Elodea canadensis	Canadian pondweed
Equisetum ramosissimum	Horsetail, scouring rush
Equisetum spp.	Horsetails
Eriocaulon truncatum	
Eriocereus martinii	Harrisia cactus
Eriochloa polystachya	Carib grass
Fimbristylis umbellaris	Globular fimbristylis
Hybanthus attenuatus	
Hyptis brevipes	Lesser roundweed
Ischaemum timorense	Centipede grass
Kochia spp.	Burning bush
Kochia scoparia (all except subsp. *Trichopyla)*	
Lagarosiphon major	Lagarosiphon
Leptochloa chinensis	Red sprangletop, feathergrass
Leptochloa panicea	Sprangletop
Limnocharis flava	Yellow burrhead, yellow sawah lettuce
Miconia spp.	Velvet tree
Mikania cordata	
Mikania micrantha	Mile-a-minute
Mimosa invisa	Giant sensitive plant
Myriophyllum spicatum	Erasian watermilfoil
Orabanche spp. (all except *O.minor* and *O.cernua var.australiana)*	Broomrape
Paederia foetida	Lesser Malayan stinkwort
Piper aduncum	
Rhodomyrtus tomentosa	Downy rose myrtle
Rotala indica	Toothcup
Sacciolepis interrupta	
Salvinia cucullata	Salvinia
Salvinia natans	Salvinia
Schoenoplectus juncoides	
Scirpus maritimus	
Sorghum halepense	Johnson grass
Spermacoce mauritiana	
Striga angustifolia	Witchweed
Striga asiatica	Witchweed
Striga spp. (all non-indigenous)	Witchweed
Trapa spp.	Floating water chestnut
Xanthium spp.	Burrs

The Weed Risk Management (WRM) process is currently being used to evaluate existing weeds on this list as well as new invasive species. *The Northern Territory Weeds Management Act 2001* determines weed management responsibilities.

APPENDIX 2 – COMMON INSECT PESTS OF CROPS AND PASTURES

Insect	Crops affected	Important comments
Wireworms & false wireworms	Sorghum, maize, pastures and legume seed crops	Damaging at establishment and seedling stage. Determine numbers & activity with bait. Use seed treatment or in-furrow chemicals. Presswheels reduce pest mobility.
Earwigs	Range of crops and pastures	Damaging at establishment period & seedling stage.
Scarab beetles	Range of crops and pastures	Occur at establishment period & seedling stage.
Locusts and grasshoppers	Sorghum, maize, legumes and pastures	Young hoppers damage establishing crops. Adults damage vegetative and maturing crops.
Helicoverpa (heliothis) caterpillars	Wide range of crops and pastures	Active all season, particularly damaging at flowering, grain and pod development. Chemical control if at damaging level.
Armyworms and various caterpillars	Wide range of crops and pastures	Sporadic pests of vegetative parts. Large numbers will damage crops.
Bean pod borer	Mungbean, soybean and other legume crops	Feed on flowers and the maturing pods. Difficult to control when inside the pod. Early detection necessary for control.
Sesame leaf roller	Sesame	Feed on leaves, flowers and maturing pods.
Sorghum midge	Grain sorghum	Feed on florets and immature seeds preventing development of grain. Resistant varieties are available. Chemical control at flowering. Not serious in dryland but damaging in irrigated crops.
Plant hoppers, aphids, thrips and mirids	Range of crops and pastures	Damage crops by sucking sap and transmission of plant diseases.
Pod suckers i.e. green vegetable, riptortus & other shield bugs	Grain legumes and legume pastures	Suck sap from immature pods and seed. May cause significant damage to grain and pasture legumes. Must be detected at flowering and early pod stage for effective control.
Stem borer moth	Rice	Larvae chew through and feed within the stem damaging head & reducing grain fill.
Leaf roller	Rice	Larvae eat and roll leaves into tubes in which they later pupate.
Caseworm moth	Rice	Feed on leaf surface.

APPENDIX 3 – COMMON DISEASES IN CROPS AND PASTURES

Disease	Crops affected	Important comments
Charcoal rot	Sorghum	Occurs under moisture stress in susceptible varieties. Crops lodge as a result. Use tolerant varieties and reduce stress with mulch.
Stem rots and blights	Sorghum, maize, legume crops and pastures	Occur under moisture stress and high temperatures. Can kill seedlings. Use tolerant varieties and maintain mulch.
Crown rots	Peanut	Favoured by excessively wet conditions and plant injury. Improve drainage and avoid plant damage.
Damping-off, i.e. seed and root rots	Most crops and pastures	Damage seed or roots of seedlings under prolonged waterlogged conditions. Improve soil drainage, use rotations and fungicidal seed treatment.
Head and grain moulds	Maize, sorghum, millet	Occur in prolonged moist conditions after grain maturity. Sow at correct time and use openheaded varieties.
Leaf spots and blights	Most crops and pastures, serious in rice and peanut	Organisms survive in infected volunteer plants and stubble. Use crop rotation and resistant varieties. Apply fungicides to high value crops like peanut. Control volunteer plants.
Bacterial leaf blights	Most crops and pastures, serious in legume crops	Diseases survive in infected seed and plant material. Favoured by rainy weather. Use resistant varieties and crop rotation.
Viral diseases	Maize, peanut and most crops and pastures	Spread by sap-sucking insect vectors such as aphids, white fly and leafhoppers. Control insects and use virus-free seed.
Little leaf	Most legume crops and pastures	Spread by insect vectors such as aphids, white fly and leafhoppers. Control insects.
Rusts	Sorghum, maize, legume crops and pastures	Minor diseases at present. Controlled by crop rotation, cultural practices.
Powdery mildew	Mungbean & other crops	Minor but damaging to susceptible varieties in the dry season under irrigation.

APPENDIX 3 *CONTINUED* –
COMMON AND SCIENTIFIC NAMES OF PLANT DISEASES

Grain Sorghum	
Grain mould	*Aspergillus flavus*
Assoc. head mould	*Fusarium* sp. *Penicillium* sp., *Curvularia* sp. *Drechslera* sp.
Leaf spot	*Bipolaris sorghicola, Drechslera* sp.
Tar spot	*Phyllachora sacchari*
Grey leaf spot	*Cercospora sorghi*
Upper stalk rot	*Fusarium moniliforme*
Charcoal rot	*Macrophomina phaseolina*
Bacterial leaf streak	*Xanthomonas campestris pv. holcicola*
Bacterial leaf spot/streak	*Pseudomonas* sp.
Rust	*Puccinia purpurea*
Red stripe	*Johnson grass mosaic virus*
Sesame	
Leaf spot (small)	*Cercospora sesami (Mycosphaerella sesami)*
Pod/stem/leaf spot	*Corynespora cassiicola*
Ashy stem blight	*Macrophomina phaseolina*
Leaf spot (large)	*Pseudocercospora sesami (Mycosphaerella sesamicola)*
Powdery mildew	*Oidium* sp.
Little leaf	*Tomato big bud phytoplasma*
Mungbean	
Leaf spot	*Cercospora cruenta*
Wet rot, blight	*Choanephora cucurbitarum*
Ashy stem blight	*Macrophomina phaseolina*
Damping-off, stem rot, base rot and leaf blight	*Rhizoctonia* sp., *Sclerotium rolfsii*
Powdery mildew	*Sphaerotheca fuliginea (Oidium* sp.)
Bacterial leaf spot	*Xanthomonas campestris pv. phaseoli*
Little leaf	*Tomato big bud phytoplasma*
Zonate leaf spot	*Undet. (Agonomycetales)*
Maldonado	
Blight, patch death	*Rhizoctonia solani*

Centrosema species	
Leaf spot	*Cercospora* spp.
Stem rot	*Macrophomina phaseolina*
Leaf blight	*Rhizoctonia solani*
Soybean	
Purple stain of seed	*Cercospora kikuchii*
Pod lesion, leaf spot	*Cercospora* sp.
Mould	*Choanephora cucurbitarum*
Flower blight	*Colletotrichum truncatum*
Seed rot	*Fusarium compactum*
Seed contaminant	*Fusarium proliferatum*
Ashy stem blight, pod and stem lesions	*Macrophomina phaseolina*
Rust	*Phakopsora pachyrhizi*
Bacterial wilt & blight	*Pseudomonas* spp.
Stem rot	*Pythium* sp., *Sclerotium rolfsii*
Bacterial pustule	*Xanthomonas campestris pv. glycine*
Little leaf	*Tomato big bud phytoplasma*
Peanut	
Kernel mould	*Aspergillus flavus*
Crown rot	*Aspergillus niger*
Early leaf spot	*Cercospora arachidicola*
Leaf spot	*Cercosporidium personatum*
Stem rot	*Macrophomina phaseolina*
Bacterial wilt	*Pseudomonas solanacearum*
Rust	*Puccinia arachidis*
Wilt	*Pythium myriotylum*
Stem rot	*Sclerotium rolfsii*
Maize	
Southern leaf blight	*Bipolaris maydis*
Grain mould	*Fusarium chlamydosporum*
Grain mould	*Fusarium proliferatum*
Java downy mildew	*Peronosclerospora maydis*
Tropical rust	*Puccinia polysora*

APPENDIX 4 – SOILS OF THE NORTHERN TERRITORY

There have been different classification systems used in the Northern Territory and Australia to describe soils. The Great Soil Group classifications (such as red earths and yellow earths) were used along with a factual key (for example, gradational and duplex soils) from the 1970s through to the 1990s and old reports refer to these soil classes. Since 1996, however, all states and territories have adopted the Australian Soil Classification.

The Australian Soil Classification describes fourteen soils orders across Australia with further subdivision under these broad groups. Some of these have not been described in the NT. The major soil orders across the territory are listed below.

For further information on the Australian Soil Classification refer to the link below.
http://www.clw.csiro.au/aclep/asc/asc.htm

The Australian Soil Classification (Isbell 2002)

Common across the NT

Kandosols
Soils without structure (formerly red and brown earths). Widespread across the Top End, Sturt Plateau, Tenant Creek and southern regions of the NT.

Rudosols
Very shallow soils or those with minimal soil development. Includes very shallow rocky gravelly soils across rugged terrain such as the Arnhem Plateau to the formless sands of the Simpson Desert.

Tenosols
Weakly developed or sandy soils. Commonly shallow (slightly more developed than Rudosols), although they can include the deep sand dunes of beach ridges, granitic soils and deserts where they develop some small change at depth.

Hydrosols
Seasonally wet soils. Top End floodplains, swamps and drainage lines including mangrove and salt marsh environments.

Chromosols
Soils with an abrupt increase in clay content from the top soil to subsoil. Restricted to small occurrences across plains and relict alluvial plains.

Dermosols
Structured soils. Common across the Tindal area and Daly River Basin.

Calcarosols
Soils with calcium carbonate often formed on limestone. Restricted to small pockets in Central Australia, Victoria River District (including Gregory National Park) and Katherine and Mataranka Districts.

Ferrosols
Iron rich soils generally formed on basalt. Restricted to volcanic landscapes of the Victoria River. District and to a smaller extent in the Roper River Catchment.

Vertosols
Cracking clay soils which may or may not be poorly drained. Common across coastal floodplains of the Top End, the Barkly Tableland and alluvial plains of the Victoria River District.

Uncommon across the NT

Sodosols
Soils high in sodium with an abrupt increase in clay content from the top soil to subsoil. Dispersive. Restricted to small occurrences in the southern region.

Anthroposols
Soils resulting from human activities. Common in urban environments, industrial areas and mine sites.

Kurosols
Soils with an abrupt increase in clay content from the top soil to subsoil, strongly acid at depth.

Organosols
Soils with high organic matter. Restricted to very small occurrences in peat swamps of some Top End floodplains. One known occurrence is on the edge of a back swamp of the Finniss River.

Podosols
Soils with organic materials and aluminium with or without iron. Restricted to coastal heath areas along the Australian coastline.

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By 2050, the world will need to produce around twice as much food as it does now, from less water, less land and increasingly degraded soil. The dwindling opportunities offered by changing global circumstances will only be captured if agriculture can meet the production, environmental and institutional challenges that are on the horizon.

If agriculture in the Top End is to develop, prosper and contribute to the world's increasing food needs, exceptionally good soil management is required to increase water and nutrient storage, improve efficiency and protect natural resources.

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