


Mixed cropping on the Atherton Tablelands

A manual for Best Management Practice

Barron Catchment Care
www.barronrivercatchment.org.au
July 2016


ISBN: 978-0-9807715-1-0

The production of this Best Management Practice manual was completed by the Barron River Catchment Management Association (operating as Barron Catchment Care), with funding obtained from the National Landcare Program and Terrain NRM.

Barron Catchment Care acknowledges the support of all who assisted with the production of the manual, in particular our members, Tablelands growers, Terrain NRM, and K Sorensen, J Kilpatrick and B Barnett who each contributed to early drafts of the BMP.

Disclaimer: *The most recent information was used in the compilation of this manual. However, the information included within this manual is to be used as a guide only. All actions taken on private land are the responsibility of the land owner.*

Barron River Catchment Management Association Inc.

Australian Government
Department of Agriculture, Fisheries and Forestry
National Landcare Programme

terrain NATURAL RESOURCE MANAGEMENT

Foreword

The Tablelands Regional Council aims to maximise the economic potential for the region's primary industries on a sustainable basis, assisting industries to become more efficient, innovative, resilient and profitable in the long term. Appropriate agricultural management practices are vital in achieving this goal, not only for efficient agricultural production, but also for the health of the catchment within which farming occurs.

Barron Catchment Care, a volunteer based catchment-management organisation working to achieve sustainable resource management, identified a need for a manual outlining best management practices (BMPs) for farmers growing a mix of crops within the Barron River system. Significantly, the Barron River flows into the Great Barrier Reef.

The manual outlines the position of arable 'mixed cropping' as it relates to the region's geography and land use, and includes BMPs for mixed cropping as a specific agricultural system. The BMP manual is a valuable tool to assist farmers identify, adapt and use modern and effective technologies and practices. There is particular reference to potatoes, peanuts, maize and grass crops, as these are the key components of the arable mixed cropping system.

The writers of this manual consulted extensively with farmers in its development, and the recommendations are practical and achievable. They examined the whole-of-farm operation, and cover key aspects of irrigation, planting, nutrient management, soil health, soil conservation and the management of on-farm water and weed and pest management. These are considered within the context of the unique and often challenging growing environment on the Atherton Tablelands.

The wide range of variables influencing farming and the rapid evolution of new agricultural technologies makes recommending specific practices for general application difficult. The authors of this manual do not attempt to do this, but focus on the key principles underpinning best practice. By following the detailed yet easy to understand material the manual provides, farmers will be able to maintain and improve farm profitability and at the same time maintain the health and productivity of the natural resources and systems.

On behalf of Tableland Regional Council, I commend Barron Catchment Care for the production of this best management practice manual.

Executive Summary

Appropriate management practices are vital to assist agricultural industries to become more efficient, innovative, resilient and profitable, while maintaining the health of catchments within which farming occurs.

Barron Catchment Care identified a need for a manual to outline best management practices (BMPs) for farmers managing mixed cropping systems within the Barron River system on Queensland's Atherton Tablelands. Significantly, the Barron River flows into the Great Barrier Reef.

The BMP manual treats the 'mixed cropping' system as a specific agricultural system as it relates to regional geography and land use. The mixed cropping area (MCA), defined by the red basaltic soils from near Mareeba in the north to Ravenshoe in the south, has a total area of 18,100 ha under mixed farming.

The BMPs for mixed cropping outlined in this manual are intended to help farmers identify, adapt and use modern and effective agricultural technologies and practices. The specific focus is on potatoes, peanuts, maize and grass crops, key components of the mixed and rotational farming in the region. As these sectors have no formal industry organisational structure, the manual is designed to guide improved productivity, encourage resource-efficient production, and help farmers meet future government regulatory requirements.

This manual emphasises practical and achievable recommendations, and farmers were consulted extensively in its preparation. Operational areas covered include crop planning and rotation, establishment, irrigation, nutrient management, and weed and pest management. There is particular emphasis on soil water management and soil health for sustainable production.

Key topics and components discussed include:

1. Water availability as a determinant of crop yield and quality: influence of soil type; infiltration and evaporation rates; soil water monitoring; timing of crop operations to maximize water use and irrigation efficiency; the use and maintenance of suitably designed irrigation equipment.

2. Optimum nutrient use for optimal growth and yield: nutrient budgeting as it relates to crop requirements, soil nutrient content and export through run-off and leaching; soil and crop monitoring; fertiliser formulation and application; strategies to efficiently utilise available nutrients (crop rotation) and minimise nutrient losses from the farm system.

3. Soil health as it relates to optimal crop production and the influence of farming practices: cultivation practices and other operations by heavy machinery; crop rotation and the addition of organic matter to maintain or restore soil health; the need to monitor soil health, including soil chemistry and physical and biological components, and the fertiliser application and agricultural practices for their optimisation.

4. Crop rotation is an essential element of the mixed cropping system. The key points discussed include: the choice of crop rotation components to optimise nutrient use and minimise the need to treat weeds, pests and diseases; plant variety selection; the timing of operations to optimise crop growth and ease of harvesting.

5. Crop management to maximise crop yield while efficiently using resources: optimising crop plant population distribution; monitoring for crop weeds, pests and diseases; timely completion of key crop

management operations; the use of efficient and well-calibrated and maintained farm equipment.

6. The management of on farm water as it relates to peak water flows after heavy rainfall events, mostly in the early wet season, is a critical element of farming within the MCA. Key topics discussed include: the management of water runoff through contour banks, surface drainage, and detention basins; methods to maintain high levels of soil organic matter; crop conformation to reduce run-off; strategies to minimise the exposure of soil to heavy rainfall events; the management of creek and riverbank vegetation.

7. Farm record keeping includes records of soil monitoring and crop management particularly weed and pest control and fertiliser application. These aspects are discussed within the context of farm profitability, meeting the requirements of quality assurance programs, and the demonstration of good farming practice.

Farmers' knowledge of the environment and farming systems will progress over time. New technologies will also evolve to improve their capacity to monitor crop productivity and the natural resource base, enhance the precision of agricultural practices and record and analyse farming practices. Farmers may incorporate new crops into their mixed cropping enterprises, and changes in Government policy may influence future farmer choices. Because of these considerations, the focus within this manual is on the key farming and natural resource management principles important within the MCA. This approach enables the formation of management targets, with the means to attain these changes over time. Barron Catchment Care has produced this BMP manual to engage with farmers in the MCA and, through an iterative process of review and refinement, meet their profitability and natural resource management goals.

Contents

Introduction

"When tillage begins, the other arts follow.
The farmers, therefore, are the founders of civilization."

Daniel Webster, 1840

Purpose of the manual

This manual includes Best Management Practices (BMPs) for farming the Mixed Cropping Area (MCA) of the Atherton Tablelands. Optimum land management best practices are of vital importance, not only for efficient agricultural production within the MCA but for also the health of the Barron River system, which drains most of the area. The Barron River then flows into the Coral Sea to the north of Cairns and affects the inshore water of the Great Barrier Reef Marine Park.

The purpose of the manual is to outline the position of 'mixed cropping' as it relates to the geography and land use of the region and to outline BMPs for mixed cropping as a specific agricultural system. There is particular reference to potatoes, peanuts, maize and grass crops as these are key components of the mixed crop system. Other farming activities completed in the MCA, notably producing sugar cane, bananas and avocados, are not covered in detail as they are not components of the conventional mixed farming system and each industry already has its own BMP or equivalent.

The need for a BMP manual arose because the four main crop types (maize, potatoes, peanuts and grass seed/hay) that comprise a single integrated farming system within the MCA are not collectively serviced by any unifying industry organisation capable of producing an overall BMP document suitable for participants of the mixed cropping system. Such a document would be used to encourage and demonstrate the adoption of sensible practices used to optimise the management of key farming resources, notably topsoil and water, to maximise long-term production efficiency and minimise off-farm effects.

This manual combines information from scientific research with practical experience. It has been developed with input from experienced growers and reflects management practices already adopted by many local farmers. It is not a definitive manual for mixed cropping, but should be used as a guide to assist in identifying where improvements in farm efficiency and sustainability can be made.

This manual examines whole-of-farm operation, covering aspects of irrigation, planting, nutrient management, soil health, and weed and pest management. Key messages from each chapter are summarised in a box at the start of the chapter. A table of practices considered outmoded compared to recommended best practice and to those projected for the future is presented at the end of each chapter.

Improvements to farming technology and new marketing opportunities lead to continual changes to farming practices, as do changes to restrictions. These social factors overlie key resource factors such as variable climate and soils over short distances, and all ultimately result in widely differing opportunities to grow specific crops or apply particular land management techniques. Such a wide range of influential variables creates problems in recommending specific practices for general application. This has obliged us to limit this document to management principles and to avoid making specific recommendations about, for example, the use of irrigation or choice of cultivars to grow.

Farming systems

Five agricultural management zones are discussed within this manual (Figure 1). Each variously includes a range of short- and long-term crops and pastures as determined by local soil type, topography, climate and management considerations, but are unified through the extensive use of a mixed farming system.

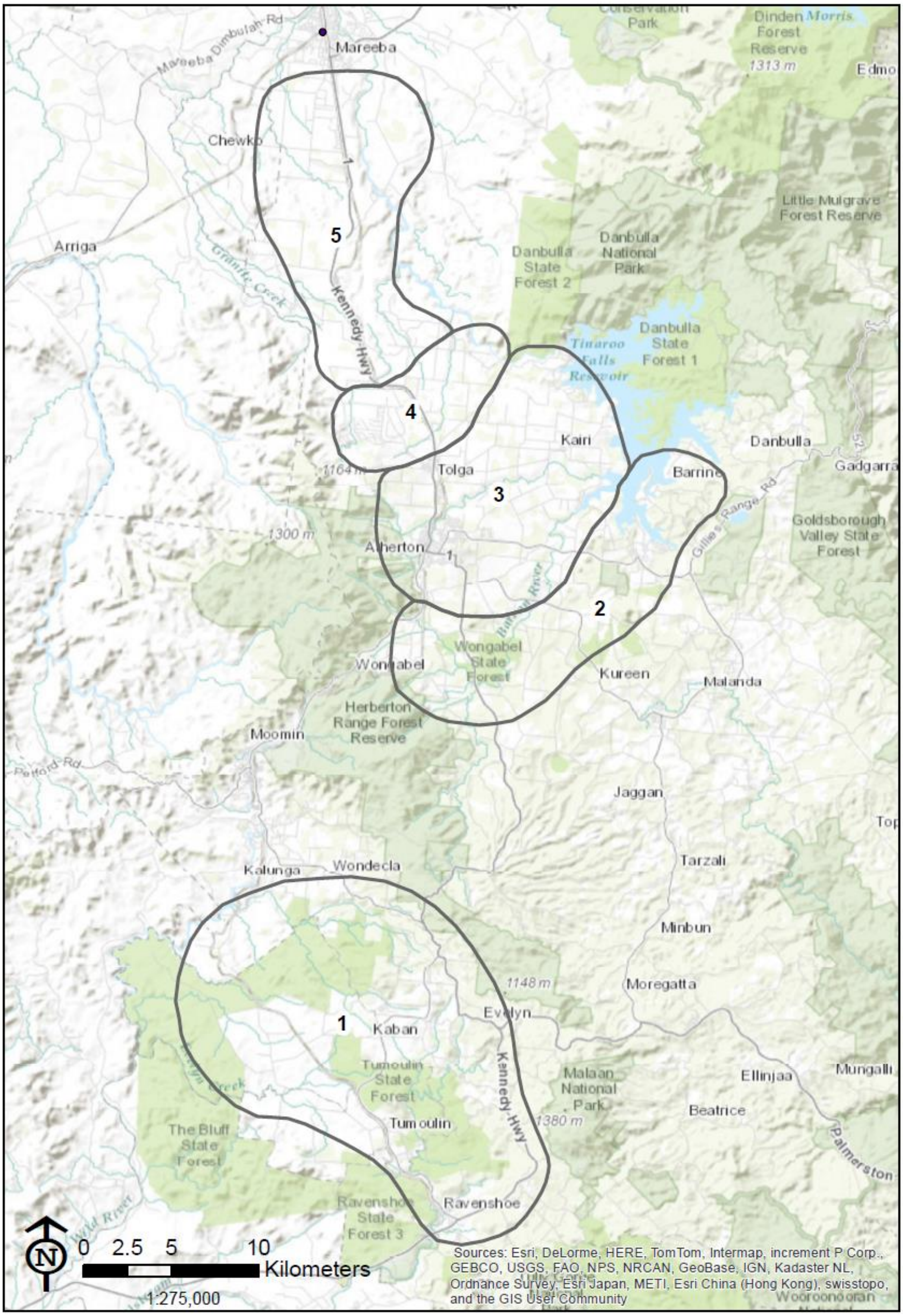


Figure 1. The five generalised agricultural zones used in this manual. Each is determined by locally varying influences of climate, topography and soil type.

Mixed cropping

Most of the farmers of the MCA are, through necessity, mixed farmers. They rely on a range of crops that vary with changing opportunities and profitability. Versatility is an essential requirement of today's farmers. Crop rotation (growing crops in succession on a given area, occasionally concurrently) is a cornerstone of mixed cropping and is necessary to sustain long-term productivity from mixed crops.

The key local crops are presently peanuts, potatoes, maize and tropical grasses grown for seed, hay and cattle pasture. Lesser but still commercially significant crops include sugar cane, seed of pasture and green manure legumes, lupins for stock-feed meal, and a few winter cereals. Green manure crops sometimes planted solely for soil amelioration include lablab and tropical soybeans among the legumes, and forage sorghum of the grasses. Grass-based pasture has two roles: one as permanent pasture on land that is too steep, rocky and unsuited for cropping; and the other as a component of a rotation system in cropping in the moister southern districts. As for seed and hay crops, pasture provides complete ground cover, slows run-off, traps sediment, and builds organic matter during a resting and recuperation phase in a rotation.

Market forces and government policy influence fluctuations in land use from year to year, and with them details of land management with respect to rotation, soil conservation and the need for irrigation. Any enforceable central policies towards BMPs need to incorporate a high degree of flexibility and provide for frequent review in the light of changing circumstances.

Grass pastures

Long-term grass pastures occupy significant areas of the MCA. Many were originally used for dairying, but most now carry beef cattle, and most occupy land that is too steep, rocky, infertile or poorly drained for crop production. Some occupy better soils that, for a variety of reasons, are not presently under cropping. Well-managed, long-term pastures provide complete ground cover, slow run-off, trap sediment and build soil organic matter. However, both economic and managerial factors limit their use.

The annual return per hectare from cattle under all but the most intensive management can seldom be justified on good potential crop land within the MCA. Also, some farmers find it difficult to incorporate cattle into their cropping enterprises, and the cost of constructing fences and yards may be difficult to justify for small operations. As a result mixed cropping (or producing other arable or horticultural crops) is the normal activity on soils with cropping potential.

Minor field crops

Besides the crops receiving detailed attention in this manual a small area occupied by minor crops is important to individual farmers. These include dry season crops that require low inputs but have a relatively high risk of failure. These are grown mostly at the southern end of Districts 2 and 3 where there is usually sufficient soil moisture from drizzle to carry them through without need for (and hence cost of) irrigation. The most important is white lupin (Figure 2), the grain of which is sold locally for use in stockfeed mixes. Oats, wheat and rice are also occasionally grown as opportunity crops.

Green manure crops grown for soil conditioning include forage sorghum and the legumes lablab and soybean. The legumes fix useful amounts of atmospheric nitrogen thereby reducing the need for fertiliser application to subsequent crops, and all provide an opportunity to reduce soil pathogens though varying the type of plant host. The legumes are also grown for seed in Districts 4 and 5.

A limited amount of maize silage is produced both for feeding dairy cattle and fattening bullocks.

Figure 2. Lupins grown as a rotation crop in District 3.
(photo Bryony Barnett)

Early history of cropping on the Atherton Tablelands

Following the initial land surveys on the Atherton Tablelands in 1882, Chinese transients from the Palmer River goldfields were the first to grow maize and peanut crops on leased pockets of land cleared by white settlers. As more native forests were cleared, the Chinese farming pioneers established the first commercial maize and peanut industries, the small beginning of a grass/legume (maize/peanut) rotation. Both the Tableland Peanut and Maize Marketing Boards were established in the early 1920s to market these crops.

Continuous production of annual crops depleted soil structure, increased numbers of invasive weeds, pests and crop diseases, and ultimately reduced yields. In 1963 the Atherton Tableland Investigation Committee was appointed to review the unsatisfactory economic position of the maize industry. The committee identified two main problems:

- "the lack of suitable maize varieties with a higher yield potential than standard varieties, and
- a long-term decline in soil fertility resulting in decreased productivity."

Actions implemented to address the problems included:

- an expanded maize breeding and research program to develop more suitable disease-resistant and higher-yielding maize varieties;
- establishment of the Australian Peanut Breeding Program by the Queensland Department of Primary Industries in 1977 to develop varieties best suited to the Tableland soils and conditions;
- development of agricultural extension programs, between the early 1960s and mid 1990s, to improve agricultural practices;
- the establishment of mixed cropping rotations—with maize, peanuts and potatoes as the three major annuals—were developed;

- the development of a tropical pasture seed and hay industry in the 1960s and 1970s. This provided an important pasture break in the annual cropping rotation, adding organic matter to the system, one of several practices introduced to improve soil structure; and
- the promotion of best management farming practices (Figure 3), based on practical experience, research and extension, which have been adopted over time.

Figure 3. Tolga farmer Clive Shorey works his maize crop in the 1950s. How the machinery has changed!

For further information on the management of red basalt soils on the Tablelands please refer to:

Kilpatrick J (2010). *The current situation and best management practices for the red clay loam cropping soils on the Atherton Tablelands.* Background paper for Barron Catchment Care. www.barronrivercatchment.org.au

Atherton Tablelands Mixed Cropping Area (MCA)

Although the Atherton Tablelands Mixed Cropping Area (MCA) forms a single identifiable agricultural unit, there are local variations in topography, climate and soil which affect farming practices. The MCA is defined by the extent of easily cultivated red basaltic soils on the Tablelands, and the range of field crops under rotation. It is bounded to the east by mountains; to the south by country too steep or wet for arable farming; to the west by rugged, drier and less fertile land; and to the north by the Mareeba–Dimbulah Irrigation Area (MDIA) where, historically, the relatively infertile soils and drier climate supported distinctly different farming systems.

The MCA is in a region noted for its diverse landscape and land use. The total area under mixed farming is approximately 18,100 ha, comprising several hundred titles. Many of the original small farms in the area have been combined into bigger units for economic viability. Increasing production costs over time have reduced net returns per hectare. Where extensive areas are cultivated, higher capacity and more expensive farm equipment has been introduced to reduce labour costs and improve efficiency (Figure 4).

Figure 4. Larger farms require large machinery to work the area efficiently while conditions are suitable for farming operations.
(photo Bryony Barnett)

The distance from markets has always been an important consideration for crop selection on the Tablelands. Road transport presently dominates freight movement in both directions and, while local road conditions are good, the links to southern markets are regularly disrupted during the wet season. The resulting high cost of freight to transport produce to southern markets and bring equipment and agrichemicals northwards significantly affects the economics of farming.

Climate

Current climate

The Atherton Tablelands, located at ~17°S and close to the eastern seaboard, is within the Wet Tropics regional area. Steep rainfall gradients occur over short distances within the MCA; the amount and duration of rainfall decreasing from southeast to northwest. Within the cropping areas median annual rainfall declines from approximately 1,370 mm (with ~55% falling December–March) in District 1 (~1,000 m above sea level [asl]) to 1,340 mm (also ~55%) in District 2 (750 m asl), and continues to decline in a north westerly direction to ~930 mm (~65% wet season component) in District 5 (375 m asl). The high rainfall over the wet season increases the incidence of crop diseases in susceptible crops. Heavy storm rainfall during November to January and heavy monsoon-influenced rainfall typically during January, February and March can also cause significant erosion of exposed topsoil. In the more elevated, southern districts of the Tablelands (particularly Districts 1, 2 and 3) the dry season brings prolonged periods of light rain or drizzle, which is a major limitation to cropping.

The cropping land is mostly located at elevations between 400 and 1,000 metres above sea level. This moderates temperatures compared to the adjacent coast and provides excellent conditions for the growth of many economically significant crops. Temperatures are influenced significantly by elevation within the Tablelands, with mean maximum and minimum temperatures increasing as the elevation of cropping land declines progressively from south to north. Median winter temperatures are too low for satisfactory growth of many truly tropical crops, while typical wet season temperatures are too warm for most temperate crops, especially when combined with heavy rainfall and low solar radiation due to persistent cloud.

There is a widespread risk of winter frost over approximately five months, particularly in July, which restricts the distribution and timing of susceptible crops. This risk increases with elevation but inconsistently, because of local topographic influences, and few areas can be treated as wholly frost-free.

Predicted future climate

Over the past few decades international research agencies have measured a trend in global warming due, in part, to an increase in atmospheric carbon dioxide levels. This is expected to influence environmental conditions globally, including changes to daily temperatures and rainfall. These changes will overlie otherwise natural influences on weather.

Projected changes in temperature and rainfall will clearly have implications for land-based primary industries and there may need to be adjustments in practices to cope with changes in plant growing environments, including increases to mean daily maximum and minimum temperatures, increased evaporation and altered rainfall patterns. There may be significant changes to mixed cropping systems in the MCA as some crops become more difficult to grow (or easier) and the opportunity to grow new crops better suited to these new growing environments and new markets are identified. In particular, there may be a shift away from temperate crops to those better suited to higher temperatures.

In north Queensland trends in mean daily temperature show consistent increases in the frequency of hotter minimum and maximum temperatures over the last 40 and 20 years, respectively. Although based on probabilities, current models indicate changes to rainfall in north Queensland will not be as extreme as in other areas of Australia. Mean total wet season rainfall is likely to remain similar to present, but the dry season component is more likely to decrease over current values. This may further influence farming activities in terms of scheduling crops and managing irrigation. One key prediction of considerable relevance to the MCA is that the overall number of cyclones forming in northern Australia is likely to decline considerably, but there will be an increased likelihood of higher-magnitude cyclones. This may have significant implications for the management of high-volume rainfall and choice of crops grown.

Soils

The extent of mixed cropping land within the MCA approximately follows the distribution of basalt-derived soils. The basalt has weathered into the easily worked, free-draining red soils that are favoured for crop farming. This area is being steadily reduced, however, as farmers compete with urban development, particularly adjacent to townships.

The physical and chemical nature of basalt soils vary depending on their origin (depth and age of original lava flow), climatic history and former native forest type. In general, soils formed under rainforest ('scrub soils' or krasnozems) have deeper profiles and lower clay content than those formed under sclerophyll woodland ('forest soils' or euchrozems). The former can be cultivated sooner after rain but dry out quickly, especially on the surface. This is a problem for establishment of small-seeded crops and has implications for timing of sowing when irrigation is not available to supplement rainfall.

Soils that have developed under high rainfall conditions tend to be more acidic than low rainfall soils, with more available sulphur and lower levels of potassium and available phosphorus. All basalt-derived soils are prone to zinc and molybdenum deficiency. Much of the native phosphorus in these red soils is fixed to clay particles (as is fertiliser phosphorus), especially where raw subsoil is exposed through either erosion or deep ploughing.

Water

'Dryland' (no irrigation) farming is no longer economically sustainable on any of the MCA and irrigation has become necessary everywhere for profitable crop farming. Irrigation use varies from rainfall supplement in summer to complete dependence in some dry season crops. There are three sources of irrigation water: surface supplies from rivers and creeks; bore water occurring naturally at depth within the basalt; and reticulated water from Tinaroo Dam. All such water for cropping is now regulated.

Districts of the Mixed Cropping Area (MCA)

The five general districts in the MCA are distinguished by common characteristics (elevation, climate, soils) important for farming (Figure 5).

District 1: The ***Top Tableland*** district covers Kaban, Tumoulin, Ravenshoe and Evelyn. It is over 1,000 m in elevation and is considerably cooler than the other cropping districts; frosts are widespread during most winters. A distinct weather gradient occurs across the district, with total annual rainfall and winter drizzle diminishing markedly from east to west. The basaltic soils change along the rainfall gradient, from deep well-drained scrub soils in the east to shallower, less well-drained forest soils with more clay in the west. Much of the eastern part spends long periods under grass. Potatoes are a particularly important crop. They are grown further into the warmer months than elsewhere, but are at much greater frost risk during winter. Surface water is available for irrigation in the eastern part of the district but the Kaban area is mostly dependent on bores.

District 2: ***Atherton South*** extends roughly from Lake Barrine along either side of the Barron River to Wongabel, and forms a strip between the damp dairying country to its south and the drier District 3 to the north. The advantage of excellent scrub soils is offset by a high likelihood of drizzle and a greater frost risk on low-lying ground. The district contains more sown pasture for both beef and dairy cattle than Districts 3 to 5. The district uses both bore and surface water.

District 3: ***Atherton Central*** includes the towns of Atherton, Tolga and Kairi, and extends north to a boundary with District 4 near Tolga. It contains the greatest continuous area of deep scrub soils, though these are interrupted in places by patches of shallower, inferior soils where the basalt is thin and the influence of the underlying granite is felt. This district is relatively level and is the key mixed-cropping area. The area is typically sown to maize, peanuts and potatoes that are rotated with grass leys for seed and hay production. It contains increasing areas of avocados and a variable area of sugar cane. Drizzle, though less problematic than for District 2, can interfere with farming operations, particularly during the harvesting. Frost, though not experienced every year, presents a risk in most low-lying areas. Most farms are irrigable from underground water present within the basalt formations. A few properties draw water from Lake Tinaroo.

District 4: ***Tolga North*** has its northern boundary at Rocky Creek. It is distinguished from District 3 by having lower total rainfall with less drizzle, slightly more sunshine with warmer temperatures, negligible frost risk, and the prevalence of forest rather than scrub soils. For many years it was considered inferior farm land to that of District 3, but since the exploitation of underground water it is considered to be equally productive. Its mixed cropping systems are the same as in District 3, although bananas and some other horticultural crops are encroaching on field crops.

District 5: ***Walkamin to Mareeba***, the most northern district, covers an area of shallow basaltic soils with large boulders. An abrupt change in elevation at Rocky Creek gives this district a distinctive climatic character with temperatures noticeably higher than those of District 4, increasing to the north as the country slopes down. Only the south of the district experiences drizzle and frosts are rare. These features, coupled with availability of reticulated irrigation water, are suited to a wide range of crops, particularly those that require a reliable dry season. Sugar cane, coffee and orchard crops compete for arable land with maize, peanuts and seed crops. Leguminous seed crops are an important part of the economy and the rotation systems. The boundaries of the district align with the edge of the shallow basaltic soils.

Figure 5. The diverse landscape of the Tablelands looking northeast from Halloran's Hill, Atherton, across the mixed cropping of District 3 towards District 2 and Mount Bellenden Ker.
(photo Bryony Barnett)

For further information on predicted changes to crop growing environment in north Queensland please refer to:

Moran C, Turton SM and Hill R (Editors) (2014). *Adaptation pathways and opportunities for the North Queensland NRM Cluster region Volume 1: Introduction, Biodiversity and Eco-system services.* James Cook University, Cairns.

Moran C, Turton S and Hill R (Editors) (2014). *Adaptation Pathways and Opportunities for the Wet Tropics NRM Cluster region Volume 2: Infrastructure, Industry, Indigenous peoples, Social adaptation, Emerging planning frameworks, Evolving methodologies and Climate adaptation planning in practice.* James Cook University, Cairns.

Factors Affecting Crop Yield

Long-term economic viability requires high levels of crop production over a prolonged period. This requires conservation of key resources (topsoil, water and infrastructure) while efficiently managing these to grow crops (or pastures). Within an effective mixed farming system consideration is given to the management of previous and future crops, as well as the immediate needs of the current crop. Nineteen factors have been identified that strongly influence crop yields (Table 1). Some can be controlled by growers, while others cannot. However, all of these factors can affect the yield and quality of the crop in some way.

Environmental factors cannot be controlled, but growers can adapt by applying best practice management to get the best crop yield. For example, frosts and wind can greatly affect a potato crop but these effects can be minimised. Windbreaks will reduce the effect of wind on the crop, and monitoring weather conditions can forewarn of frost events, allowing time to irrigate or aerial spray.

Growers do have some control over soil moisture and crop susceptibility through cultivar selection. The level of control is steadily improving through research and the adoption of new technology, particularly irrigation systems.

Table 1. Factors affecting crop yield and potential for their control by landholders.

Not controlled by grower	Partial control	Controlled by grower
Frost free period	Moisture/rain	Days grown
Day length	Cultivar	Seed/tuber quality
Air temperature		Plant nutrition
Light intensity		Pests and diseases
Soil type		Plant population
Humidity		Timely operations
Soil temperature		Crop rotation
Wind		Soil drainage
		Soil health

Irrigation Management

To ensure maximum water efficiency and adequate water supply to the crop:

- **Understand the soil type, infiltration and evaporation rates, and weather conditions.**
- **Monitor soil water content.**
- **Base the irrigation schedule on results of soil monitoring.**
- **Plant when soil moisture levels are high enough for seed emergence.**
- **Use suitably designed irrigation equipment.**
- **Maintain irrigation equipment.**

Water efficiency

Water availability is a major contributor to crop variation, affecting both yield and quality. Water needs vary considerably between crops and during crop development. Crops should not be over watered. So, as far as possible, watering should be timed to take advantage of off-peak rates for electricity use as margins between cost and return are small. Water application to potatoes is presented in the example below.

Example—Water for potatoes

Each growth stage of potatoes has different water requirements (Figure 6). From planting to emergence it is important to maintain sufficient moisture to optimise growth while avoiding excess that will place the seed pieces under stress, making them prone to disease. From emergence to bulking, depending on rainfall, irrigation rates should increase as the needs of the growing plant increase.

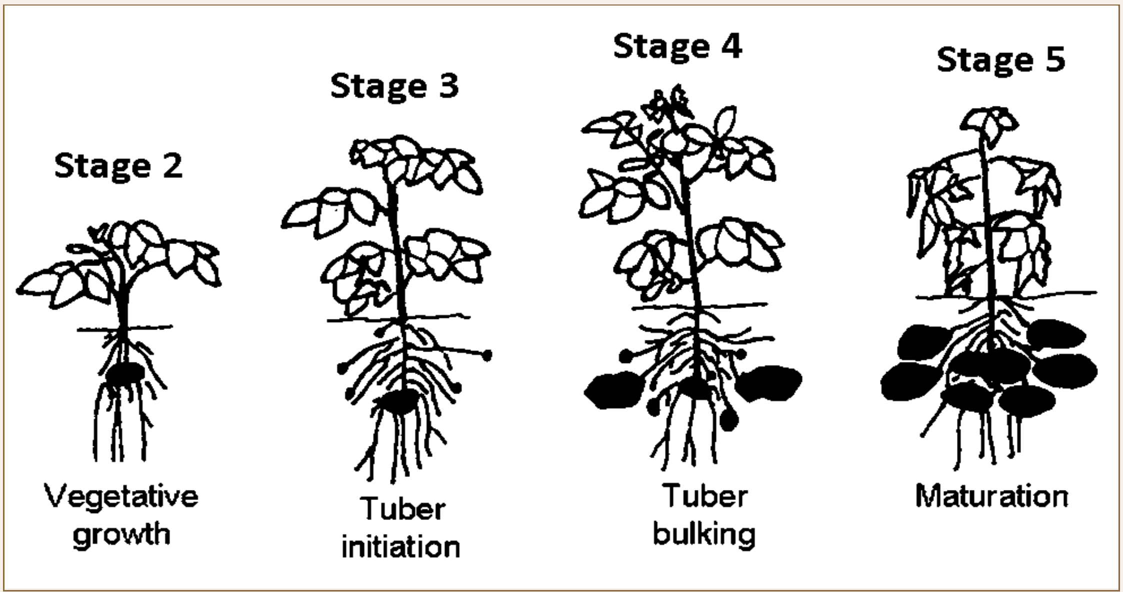


Figure 6. **Key growth stages of a potato crop.**

Some key practices to follow for water efficiency in potato cropping are:

- Know the evaporation rate of the area.
- Use irrigation scheduling tools and soil moisture monitoring equipment.
- Only apply water when it is needed, that the soil can hold, and the crop can use.
- Monitor the irrigation system—know how much water has been applied and how much is delivered in a certain time.
- Check the uniformity of application of the system.
- Change and maintain nozzles regularly.

Irrigation management accounts for the relatively small root zone of potatoes compared with other crops. An irrigation depth of 60 cm is generally recommended for potatoes and is applicable for most of the irrigation season.

Tools for optimising irrigation application

Most irrigation in the MCA is applied to crops by one of three key systems: solid set (pipes placed in parallel rows within a crop and attached to a pump); travelling irrigators (irrigators with a single point of release that travel through a crop as they are drawn along a cable); and overhead travelling systems (moving irrigation booms with multiple release points moving from either a central point [pivot] or perpendicular to the edge of the crop [lateral]) (Figure 7). Flood irrigation systems are not used extensively within the MCA.

Figure 7. Lateral irrigation system watering potatoes at Stage 1.
(photo Bryony Barnett)

There is a range of irrigation tools available, from simple to fully automated irrigation systems that monitor the entire soil profile and water the crop automatically as required. These systems, used in conjunction with soil moisture monitoring probes, should ensure the crop gets sufficient water while avoiding over watering. Moisture probes measure soil moisture to identify the ability of the soil to supply crop needs.

The type of water monitoring system chosen depends on which irrigation method is used. It is more difficult to add automated systems to a solid-set system. EnviroSCAN™ (monitoring probes with data-logging capacity) can be connected to centre pivots and laterals and an automated system installed (Figure 8).

Figure 8. EnviroSCAN™ and data loggers ensure efficient water use.

There are various computer software programs available for attachment to irrigation systems, including probes that can be matched with the optimum schedule for a particular crop. The software accounts for crop needs, soil type, weather conditions and evaporation rates. Attaching these systems to a weather station further refines the system to local conditions.

The use of irrigation systems that monitor soil moisture, while initially expensive, will reduce water use and save money in the long-term. Efficient water use will also increase the cost-effectiveness of fertilisers by ensuring that nutrients do not wash off the paddock or leach through the soil profile.

Overall, using an automated system is cost-effective, good for increased consistency in crops and will save time. It also provides records of water use to enable successive crop yields to be linked to water use. Irrigation schedules can be altered to maximise outputs and minimise costs.

Irrigation design

Effective, efficient design of an irrigation system is essential to achieve the best results for each crop. It is worthwhile using a consultant or expert who will ensure that your system meets the precise needs of the crop as it relates to soil and climate characteristics. ***Note: Many systems as supplied by the retailer are not well calibrated.***

There are many factors that influence the supply of water to a crop, in particular:

- soil type and composition (clay:silt:sand)—affects movement of water in and through soil, and the water holding capacity of soil;
- evaporation—affects how fast a crop uses water;
- crop canopy coverage—also affects how fast a crop uses water;
- organic matter—affects how much water soil can hold (for every 1% increase in soil carbon up to 144,000 L/ha extra can be held in the soil);
- type of irrigation system;
- uniformity of water application;
- pump efficiency; and
- irrigation management and timing.

Taking the contours of the paddock into account when planting will improve the efficiency and distribution of applied water across the whole paddock, reducing the number of dry spots or waterlogged areas.

Table 2 incorporates suggestions for improving decision-making regarding water scheduling and application.

Table 2. Recommended best practice for irrigation of mixed crops.

Outmoded Practice	Current Best Practice	Future Directions
Out-moded, less efficient, irrigation methods used.	Adoption of irrigation practices that more efficiently deliver water to crop roots evenly across the crop (centre pivot, lateral).	Further adoption of superior (precise and efficient) irrigation systems as they are developed.
Irrigation schedule based on calendar or naked eye.	Irrigation schedule based on tensiometers/ EnviroSCANs and local weather forecasts.	Irrigation scheduled by fully automated system, connected to EnviroSCANs in most paddocks, with link to weather station on farm.

Outmoded Practice	Current Best Practice	Future Directions
Same irrigation rate across all paddocks.	Irrigation rate across paddocks adjusted according to soil type and infiltration rates from soil moisture monitoring equipment.	Soil types and characteristics mapped and input into irrigation scheduling software in automated system.
Evaporation rate estimated by sight.	Bureau of Meteorology web site used to calculate evaporation rate and wind speed for farm, then used in irrigation schedule.	Weather station on farm will indicate evaporation rate, wind speed and temperature. Irrigation schedule designed accordingly.
Infiltration rate and soil characteristics ratio (clay:silt:sand) not known for farm.	Infiltration rate and ratios known and calculated into irrigation schedule.	Infiltration rate and ratios known and mapped across farm and input into automated irrigation system.
Distribution uniformity of irrigation system not known.	Distribution uniformity at industry standard guidelines (80–85%).	Distribution uniformity greater than 90% across whole farm.
No Land and Water Management Plan (LWMP) done for farm.	LWMP completed for whole of farm.	LWMP completed for whole of farm, with GIS and GPS mapping and infrastructure points shown.
Water pump and mains not designed for irrigation system or crop needs.	Water pump designed for irrigation system. Delivers crop needs with minimal friction loss through suitable main lines.	Water pump designed for low pressure systems.
Manually start and stop irrigation system.	System attached to EnviroSCANs. Irrigation starts automatically based on received data. Allows 24 hour schedule.	Software such as WISA™ or AQUAman™ used in irrigation system for most efficient schedule. Allows 24 hour schedule.
Equipment repaired as required.	Yearly maintenance done on all irrigation infrastructure and spray nozzles.	Regular seasonal maintenance done on all irrigation infrastructure.

Further information on water management in crops can be sourced from the following web sites:

Department of Environment and Resource Management. Water management information fact sheets.
www.dnrm.qld.gov.au/water

Growcom Land and Water information under the Queensland ‘Water for Profit’ program.
www.growcom.com.au/land-water/water-for-profit

Nutrient Management

To ensure optimum nutrition of the crop and minimal loss of applied nutrients:

- **Understand the nutritional needs of the crop as it relates to yield.**
- **Consider the surpluses or deficits of key nutrients from previous crops when planning a crop rotation.**
- **Complete soil sampling prior to sowing and submit for total and plant available nutrient testing; measure soil pH.**
- **Formulate fertiliser mixtures based on soil test results and crop needs.**
- **Apply nutrients in a timely manner for crop uptake.**
- **Use methods that minimise losses through run-off and leaching of soluble nutrients. Consider split-applications of soluble nutrients and avoiding periods of high rainfall, particularly on sloping sites.**
- **Monitor the crop for symptoms of nutrient deficiencies, particularly during active growth, and correct as required.**

Nutrient budgeting

Different crops require different amounts and combinations of nutrients for optimal growth and yield. The nutrients are sourced from those already in the soil and through the application of fertilisers. A nutrient budget is used to calculate the amount the plant needs (as applied fertiliser)—through estimating crop needs, the nutrient levels already held in the soil, and those exported from the paddock in the crop or as run-off or leaching—to get the optimal yield from the crop. It is not practical, and often not possible, to estimate all components of the budget. However, the two most immediately important ones, the nutrient levels needed by the crop and those available in the soil, can be readily estimated.

Crop needs are obtained by experience, by discussion with an agronomist and through published recommendations. The amounts of nutrients available for use by the crop are obtained through soil tests, preferably interpreted with the help of an experienced agronomist familiar with local conditions. For example, while soil test methods attempt to discriminate between *available* and *unavailable* nutrients, availability to the crop depends on other factors that may change during land preparation and crop growth. Despite any deficiencies with soil tests, it is as well to begin preparation for each crop with best estimates of available and required nutrients. It is sensible practice to complete regular soil tests on each paddock at least once a year (often at the same time each year to identify trends in changing nutrient levels). Some growers find they need to do soil tests after each crop.

Soil nutrient deficiencies can also be identified through monitoring the crop as it grows, through monitoring for nutrient-specific symptoms, particularly at times of high growth rates (high nutrient load), or through leaf sampling and analysis. Tractor-mounted scanners can also be used in some instances to assess leaf nutrient content. Remedial action can sometimes be achieved, provided there is sufficient time for the crop to respond and the nutrient is applied in a form and manner whereupon it is readily absorbed by the crop.

For high yields of market-suitable products both annual and grass crops need ample available levels of all growth-limiting nutrients. For those with a relatively short season of rapid growth (e.g. maize and potatoes) the need for rapid uptake demands high levels of major elements that may leave appreciable amounts of residual fertiliser in the ground. The effects of this are especially noticeable after potatoes and they are widely exploited for subsequent crops in the rotation. Since the cost of fertiliser is a major factor in the farm budget, residual nutrients are a significant resource in the rotation system. The removal of bulk vegetation, as maize silage harvesting or haymaking, is an often overlooked factor that depletes all major and some minor nutrients in the soil, the levels of which therefore need timely attention before new crops are begun. Extraction of key nutrients can range in the order of ~3,070 kg/ha for nitrogen and potassium and ~3–30 kg/ha for phosphorous, calcium and magnesium depending on type of crop and its growth.

Major nutrients (macronutrients)

The main nutrients needed by plants for growth are nitrogen (N), phosphorus (P), potassium (K), sulphur (S), calcium (Ca) and magnesium (Mg). While their functions within plants are beyond the brief of this manual it should be noted that these must be available to plants in considerable amounts and the availability must match plant demand as the crop develops (Figure 9).

Figure 9. Sub-surface fertiliser applicator places nutrients in the plant root zone.

In all cropping situations levels of available soil N can change rapidly and measured values, while indicative of general fertility, are merely a starting point for most rapid-growing crops. Such crops may need both pre-sowing and top dressings of nitrogenous fertiliser for good production. Bacteria in root nodules of leguminous plants, such as peanuts and pasture legumes, can fix atmospheric N and legumes, thus, generally need at most occasional brief strategic dressings of N. Legumes can also be used as a source of nitrogen for subsequent crops if the crop residues are incorporated into the soil. The progressive decomposition of organic matter under crop management systems provides a valuable if unnoticed source of N, which is one of many reasons for maintaining high levels of readily decomposed soil organic matter. Following are examples of N requirements for potatoes and maize.

Example—balanced N for potatoes

Getting nitrogen to the potato plant in the correct quantity affects most of the factors related to tuber yield and quality including size, grade, and transporting/storage quality. Both an inadequate and excessive supply of nitrogen can have major impacts on crop yield.

Example—N for high maize yields

Adequate nitrogen supply is one of the three key factors required for high yielding maize crops. Typically, 22–27 kg of nitrogen is required per tonne of grain produced. About 12–16 kg of this is removed with the grain; the remainder is in the residue.

Levels of plant available P and K are important on the red basaltic soils as found in the MCA. Most available P is located in surface layers of soil and is, therefore, also depleted by erosion. Immobilisation of P by subsoil clay recently exposed through either erosion or deep ploughing can significantly reduce P availability to plant roots. Potassium is readily leached out of the crop root zone by heavy rain or excessive irrigation. The same applies to other mobile elements (N, S); especially when organic matter is depleted, as the clay minerals of these soils have poor nutrient retention properties.

While N, P and K demand the most attention, other macronutrient must always be taken into account as their deficiency (or excess) can also strongly influence crop development. Sulphur levels are often only marginally adequate in the MCA, especially on the drier soils of District 5. Sulphur deficiency is often overcome because it is a secondary constituent of some fertilisers such as superphosphate, gypsum and sulphate of potash. Calcium is widely applied as ground limestone to correct excess soil acidity or as dolomitic limestone, which also contains Mg. In addition to correcting soil pH, both are key nutrients for normal plant function and the correct balance between the two is required as an excess of one may induce a deficiency of the other. Professional advice is recommended in cases of doubt.

Trace elements (micronutrients)

Trace elements are also necessary in appropriate levels in the soil for normal plant growth and development, but usually in small amounts. Excessive levels can be toxic to plants and it is recommended, therefore, to seek professional advice regarding the application of a particular trace element unless already very experienced in its use.

The key trace elements are zinc (Zn), iron (Fe), molybdenum (Mo), manganese (Mn), copper (Cu) and boron (B), although Fe deficiency is rare in the MCA. On Tableland soils marginal Zn deficiency is widespread and rapidly growing field crops occasionally require application as a fertiliser. The development of Zn deficiency in sugar cane attributable to bulk removal of vegetation has been reported and its possibility over time might be anticipated after repeated bulk removal of other kinds of vegetation.

Molybdenum levels are commonly marginally low. Since vigorous legume nodulation, important for fixing atmospheric N, is very sensitive to Mo deficiency it is good practise to apply Mo to leguminous crops particularly if this has not been conducted for two or three years (see example following). Rapidly growing crops of other non-leguminous types may require Mo supplementation. Copper (Cu) and Boron (Bo) deficiency also occur occasionally and precautionary applications may be recommended for potatoes.

Example—legumes and trace elements

All legumes are net nitrogen fixers, obtaining most of their needs from the atmosphere via root nodule bacteria. Adequate levels of trace elements, particularly molybdenum, need to be maintained to ensure effective nodulation.

Fertiliser application

In general, macronutrients (N, P, K, S, Ca and Mg) should be applied to the soil prior to, or at, planting so they are available for the crop as it grows. The exception is N, which is sometimes strategically applied during crop growth to synchronise development (grass seed crops) and correct deficiencies. The application of soluble forms of N and other soluble nutrients must be completed with particular care to avoid losses from the crop through run-off during high rainfall events (along with top soil) and leaching from the profile. This is particularly important on sloping sites, where sowing along the contour can greatly reduce losses. Split applications during crop development can significantly reduce losses in some crops over high-rainfall periods. Losses can also be reduced by using an organic fertiliser (manure), which releases nutrients more slowly, or through the use of inorganic slow-release fertilisers. Some fertilisers (e.g. urea) can also be lost as gases under certain conditions and must be managed accordingly. In all cases there should be consideration of the capacity for the fertiliser to meet crop needs, the likelihood of losses, and cost.

Phosphorus will usually be required in the MCA, and is often applied by incorporating pre-plant fertilisers into soil. Soluble forms of P can be applied through irrigation systems but their compatibility with the irrigation water should be checked first. All manures contain P and manure from grain-fed animals is a particularly rich source.

Potassium is also usually applied at, or before, sowing and care must be taken to ensure it is not over-applied as it can be toxic to plants. Potassium is very soluble and, therefore, prone to run-off or leaching. Sulphur is moderately soluble and also prone to loss. Calcium is usually applied as lime, gypsum, dolomite (with Mg) or along with S and P in superphosphate. Whereas Mg is rarely deficient in basalt soils, care should be taken to maintain a suitable Ca:Mg ratio (e.g. through the excessive use of dolomite).

Trace elements are often applied before planting and mid-season, as required by the crop. Pre-planting application of micronutrients is sometimes achieved through incorporation into N-P-K fertiliser. The use of foliar sprays during the season better ensures that the nutrients are placed where the plant needs them. The use of fertigation systems also increases the efficiency of nutrients applied to a crop as the nutrients go directly to the crop root zone in a soluble form, which will improve uptake.

In the past, fertiliser was mostly broadcast over the entire crop; including areas where it was not readily taken up by crop plants (broadcasting is still appropriate for more uniformly spaced crops such as grass seed crops). This practice is inefficient for crop nutrition and can encourage weed growth. The use of precision applications, such as banded applications, foliar sprays and application of nutrients through using fertigation (applied with irrigation water) systems can result in more efficient fertilising of crops. Banded application can be useful for row-planted crops as it places nutrients where the plant requires them, stops the fertiliser burning the seed stock, and reduces competition from weeds. This reduces fertiliser waste and nutrient run-off from the paddock and saves money. The development and broader adoption of precision application technology that meters fertiliser application based on crop nutrient needs will further these benefits.

Using inoculants to improve nutrient availability

Rhizobium seed inoculants enable legumes to establish effective nitrogen-fixing symbioses, especially on new ground, and should be used as a precaution in case the bacteria are deficient in the soil. The use of bio-stimulants, such as compost teas and bacterial inoculants, may also boost useful microbes in the soil and control nematodes and harmful fungi.

Managing soil acidity

Soil reaction (acidity or alkalinity) is measured as soil pH. Soil pH ranges from 0 to 14, with a pH of 7 being 'neutral'. Levels below 7 are acidic and above 7 are alkaline. Soil reaction will often be the first cause of nutrient deficiency in a crop as it can affect nutrient solubility, soil biology and nutrient transport in the soil. Acidity can also reduce the effectiveness of fertilisers and chemicals, so it is important to identify areas of high acidity.

Tableland soils tend towards a natural acid reaction in districts of relatively high annual rainfall, but tend to neutrality in drier districts. Soils derived from granitic, rhyolitic or metamorphic rock are also naturally prone to acidity in wetter areas. Acidity is also induced by the leaching of nitrate from the soil, by the removal of large amounts of green vegetation, and from the use of acidic fertilisers such as superphosphate. Acidification is therefore a widespread possibility within the MCA and should be considered within mixed-cropping systems.

Most crops and pastures grown locally perform progressively poorly as soils become more acid and the availability of key nutrients (notably P) is reduced, while levels of others such as aluminium become toxic to plants. Waterlogging tends to aggravate these problems and to provoke Mn toxicity in soils where Mn levels are naturally high. An agronomist may advise on the best pH level for different crops. Peanuts, for example, prefer a slightly acidic soil as this assists nutrient uptake.

Soil acidity in the surface layers is relatively easy to identify using simple soil pH tests and can be corrected before sowing a susceptible crop (such as potatoes) through the application of a Ca fertiliser such as lime or dolomite. Increasing the levels of organic matter will also slow soil acidification. Both will usually benefit crops over the following few years. Sub-soil acidification is more difficult to treat, but has so far not been a significant issue in the MCA.

Table 3 includes a range of practices for optimising nutrient management for crop growth and minimising losses of nutrients from the crop system.

Table 3. Recommended best practice for managing nutrients.

Outmoded Practice	Current Best Practice	Future Directions
Soil nutrient testing not done.	Soil nutrient testing done across whole farm before planting.	Soil nutrient testing done across all paddocks preferably at least once per annum and no less than once per cropping cycle to identify optimum level of nutrient inputs.
Leaf testing not done.	Leaf testing used throughout growing season to apply nutrients as needed.	Leaf testing used with portable infra-red scanners on tractor to indicate plant health. Then mapped using GPS and entered in software program to calculate adjusted nutrient rates across farm.

Outmoded Practice	Current Best Practice	Future Directions
Nutrient budget of crop not known.	Nutrient budget of the crop calculated for the whole farm.	Nutrient budget calculated, with soil characteristics and irrigation uniformity used to plan nutrient supply.
Nutrients broadcast over entire paddock.	Variable rate of nutrients applied to each paddock, with soil tests and soil types taken into account.	Variable rate of nutrients applied to each paddock, with soil tests and soil types taken into account. Soil pH mapped, nutrient zones identified and input into GPS.
Agronomist not consulted about crop performance and nutrient requirements.	Agronomist consulted, along with soil tests done, to achieve best conditions.	Specific nutrient management plan developed for paddocks, based on soil tests, leaf tests and past yields on site.
Potatoes* Fertiliser applications not timed with potato growth stages.	Fertiliser applications timed with changing potato growth stages.	Fertiliser applications timed with changing potato growth stages. Monitoring of crop stages done throughout season, with agronomist input.

* Potatoes warrant special mention because of the amounts of nutrients applied and the impact of application rates and timing on growth.

For further information on broad principles on the nutrition of crops, please refer to:

Food and Agricultural Organisation (FAO) Feedipedia: Animal feed resources information system. www.feedipedia.org

Kelley R, Barnett B, Bainbridge Z, Brodie J and Pearson R (2007). *Nutrients, Catchments & Reefs:* A guide to nutrients in your landscape. Produced for the Catchment to Reef Joint Research Program. www.rrrc.org.au/catchment-to-reef

Loch Donald S (2006). Soil nutrient testing: how to get meaningful results. Department of Primary Industries and Fisheries, Redlands Research Station, Cleveland.

Peverill KI, Sparrow LA, Reuter DJ (Eds) (1999). *Soil Analysis: An Interpretation Manual.* CSIRO Publishing.

Soil Health

"To be a successful farmer one must first know the nature of the soil."

Xenophon, 400 BC

To ensure optimum soil health for mixed crop production:

- **Understand how soil health relates to soil chemistry, biology and physical structure.**
- **Monitor soil compaction, water infiltration rates and chemistry (pH, electrical conductivity plus key crop nutrients).**
- **Monitor changes in organic matter content in soils over the annual cropping phase.**
- **Consider implementing cropping strategies that increase organic matter content and improve soil biology, such as including a two to four year grass (or legume) phase in the rotation, using green manure crops, retaining crop residues, or applying organic fertilisers or mulches.**
- **Complete fertiliser application and correct pH based on soil testing.**
- **Consider using farm operations and equipment that minimise soil compaction, such as controlled traffic, minimum tillage, machinery with less weight per unit ground area, and avoiding operations during wet periods.**

What is a 'healthy' soil?

'Healthy' soil is fundamental to achieving high crop yields and quality over time and is the key resource of mixed farming systems. A healthy soil allows efficient use of water and nutrients by the plant, reduces the amount of diseases and pests attacking the crop, and can significantly reduce soil erosion.

Soil health is determined through the interaction of the chemical, biological and physical characteristics of the soil, and how these are managed:

- Soil chemistry—The soil requires an optimal balance of nutrients, minerals and pH to maintain soil structure, composition and water holding capacity for plant growth.
- Soil biology activity—The 'living' component of the soil, including micro-organisms, earthworms, and 'good' nematodes and fungi occurring in the soil. These organisms, and their diversity, have an important role in the uptake of nutrients by plants.
- Physical structure—This relates to the way soil particles are aggregated or clumped, and the amount of space between these clumps. A soil with good soil structure contains many pores and spaces allowing drainage, aeration and growth of plant roots.

Each of these can be influenced by farming operations and the local farming environment (soil type, rainfall, etc). Within the MCA, where cropped soils are seasonally subjected to high rainfall events, the maintenance of surface stability is a key priority for farmers. This relates to the prevention of localised movement (which risks exposure of infertile sub-soil within cropping areas) or total loss of soil particles from the paddock through erosion. Methods to minimise soil loss are covered in the chapter 'Soil conservation and rain water management'.

On Tableland soils, the other key factor for soil health is the maintenance of appropriate levels of soil organic matter. Organic matter helps to bind soil particles together and improves the soil's ability to hold nutrients and moisture. This latter point is extremely important for crop nutrition on the red basalt soils in the MCA, and maintenance of high organic matter levels is critical for successful mixed farming.

Management to maintain soil health

Mixed cropping relies heavily on cultivation, tillage and the use of heavy machinery, all of which damage soil structure causing soil compaction, surface crusting and reduced storage of soil moisture. Some implements (rotary hoes) can cause sub-surface compaction and impede drainage. Soil organic matter can also be significantly diminished through mixed cropping operations, particularly under the hot and wet conditions when cultivation is typically completed. All can impede nutrient extraction by plants through reducing root penetration, soil aeration, moisture retention, and drainage and affect water run-off, potentially causing soil erosion.

As organic matter declines over time under annual cropping (serving to release nutrients, sustain microorganisms and soil animals such as worms in the process) it needs to be replenished to maintain good soil health. This can be achieved through:

- crop rotation, using a short-term (two to five years or more) break in the annual cropping cycle;
- growing cover crops; and
- the addition of organic matter, green manures or composts.

Within the MCA a grass (common) and/or legume (occasional) break in the rotation is extremely effective for replenishing organic matter levels. Tropical grass seed crops have been a financially viable method to achieve a two to four year 'break' in annual cropping and although seed production is often combined with the removal of nutrients as hay the fertiliser application for seed production means there are still significant benefits from the rotation. Green manures from annual legume crops otherwise grown for grain or seed are also highly effective, as are the surface residues from crops such as sugar cane and maize. Other methods to lift organic matter levels, such as applying compost or manure to replenish organic matter, are perfectly practicable on a small scale and may become more widespread in future.

Some damage to soil health caused by soil compaction is inevitable under modern farming practices, contributing to surface sealing of unprotected surfaces under normal rainfall events and subsequent poor infiltration. Passage of the wheels of most modern farm machinery also leads to some level of soil compaction if done on moist soil, and vehicles with high axle loadings such as lime trucks are particularly damaging. Normal cultivation activities attend to upper-level compaction but deliberate deep ripping may be necessary to correct deep compaction. Restriction of traffic to specific lines ('controlled traffic') is now widely used for row-planted crops to localise compaction, resulting in less overall damage throughout a crop and more efficient farming operations (fuel use, agrichemical application). The traffic lines can be permanent, or changed systematically from season to season to allow recovery of previously compacted lines. Minimum tillage methods decrease traffic (Figure 10) and simply delaying heavy machinery activities until soils dry out or using vehicles that impart less weight per unit area can significantly reduce soil compaction. The application of gypsum on certain soils or the incorporation of organic matter will also contribute to reducing compaction.

Exposure of the soil surface can result in significant losses of topsoil, particularly during high rainfall events such as early season storms. Wind erosion of cultivated areas can also be very damaging. Leaving crop stubble or mulch on the soil surface secures topsoil and maintains moisture within the soil profile. The retention of stubble or mulch also returns organic matter to the soil and boosts soil carbon (Figures 11 and 12).

Figure 10. Minimum till machine using coulter ripper for zonal tillage.

Figure 11. Kronos mulcher returns organic matter back into the soil.

Figure 12. Stubble left after maize harvest to improve soil structure, organic content and soil carbon levels.
(photo Bryony Barnett)

Monitoring for soil health

A few key indices can be measured to estimate soil health:

- **Water infiltration rate** is the rate at which water enters the soil. The infiltration rate is affected by the water content of the soil, soil structure, soil type and compaction. The soils of the Tablelands generally have good water infiltration (if well-maintained). Knowing the infiltration rate of the soil is necessary for planning an effective irrigation schedule.
- **Soil compaction** in layers below the surface can be measured easily using a soil penetrometer. Soil compaction can also be identified by measuring soil bulk density (which is dependent on the soil type), organic matter content and air spaces within the soil. This is more difficult to perform but will show changes in compaction through time.
- **Electrical Conductivity (EC)** is a measure of total salts in the soil and is a key component of a soil test. The greater the amount of salts held within the soil the greater the conductivity. High rainfall and good internal drainage on the red basaltic soils of the Tablelands means that salinity (the build-up of salts to levels where they interfere with plant growth) is not usually of concern. However, some chemical fertilisers contain salts, which can change the clay content of the soil, leading to poor water retention and infiltration. Hence, a high EC reading can indicate an over application of fertiliser.
- **Soil pH** is an indication of whether soils have an acidic or alkaline reaction, which greatly influences the availability of key nutrients (and toxic chemicals) to the crop. The measurement of soil pH is a standard component of soil tests, but can also be measured with a simple field kit. Attention to soil pH is usually left to a cropping phase (particularly potatoes) in the rotation when liming to combat acidification is both economically justified as well as necessary. At the same time the opportunity is taken to check for and correct nutrient imbalances and deficiencies. Professional advice on the interpretation of soil tests is recommended.

Although these tests do not provide a comprehensive assessment of soils they can be done quickly and inexpensively and greatly assist the monitoring of management decisions of soil health. By doing these each year any trends in soil health will be detected early, allowing time to make adjustments.

Methods for optimising soil health are presented in Table 4.

Table 4. Recommended best practice for ensuring healthy soil.

Outmoded Practice	Current Best Practice	Future Directions
Have a good idea of soil type differences, but not mapped.	Aware of soil types on farm and they are mapped for reference.	Completed soil survey of farm, mapped to GIS and placed within farming software for management of the differing zones.
Soil nutrient testing not seen as useful tool. Use past nutrient rates.	Soil nutrient testing completed across whole of farm.	Soil nutrient testing across all paddocks at least once in each rotation cycle to identify optimum level of nutrient inputs.
Soil improvements based on chemical inputs alone.	Crop stubble, green cover crops, compost and legumes used to improve soil fertility. Optimise chemical fertiliser efficiency and use conservation tillage methods.	Apply best practice but may also apply compost tea or organic matter.
Fertiliser application rates based on past applications and local knowledge.	Fertiliser rates based on a soil test taken once a year, to balance needs of the crop.	Fertiliser rates based on soil tests sampled in each paddock or each new crop to indicate optimum level of fertiliser inputs.
No monitoring of soil acidity.	Yearly acidity testing across paddocks to highlight any changes to acidity in soils.	Yearly acidity testing done across all paddocks and mapped to GIS, to show areas of change across whole farm.
Erosion issues on farm not identified.	Erosion sites on farm identified and management actions in place to reduce loss. Major run-off water directed to sediment retention structures.	Erosion hot spots identified and mapped to GIS with management plan in action. Minimal loss of sediment from the farm.
No record of changing salt (EC) levels on farm.	Yearly record of changing salt (EC) levels from either groundwater or fertiliser inputs on the farm, with problem areas identified.	Yearly record of salt (EC) levels through farm mapped by electromagnetic surveys. Nutrient and irrigation adapted to these zones.
No contour banks on farm.	Contour banks in place where required.	Contour banks or contour ploughing in place and mapped. Paddock design based on contours.

Outmoded Practice	Current Best Practice	Future Directions
Crop stubble removed, burnt or ploughed in soon after harvest.	Crop stubble left after harvest to reduce soil loss through wind/rainfall.	Crop rows and inter-rows have crop stubble or mulch applied after harvest to reduce soil loss from paddocks.
Soil compaction from machinery occurs but not considered an issue.	Controlled traffic on farm. Machinery limited to set laneways and roads to limit compaction.	GPS guidance system on machinery with controlled traffic and permanent beds, limiting compaction to inter-rows.
Reduced tillage not practiced.	Minimum tillage/conservation practices to reduce passes over soil to reduce soil structure loss.	Minimum tillage/conservation practices in conjunction with precision GPS to reduce cultivation overlap.
No green mulch/ organic matter tilled into soil. Cash crop grown every year.	Every two to three years, green mulch crop/organic matter crop tilled back into soil to boost soil carbon and organic matter ratio in soil.	Every two to three years, green mulch crop/organic matter crop tilled back into soil. Compost may also be placed out on paddock in appropriate amounts.

Some useful publications for understanding soil properties and health include:

Brady N and Weil R (2002). *Elements of the Nature and Properties of Soils (2nd edition).* Pearson-Prentice Hall Publishers, New Jersey.

Magdoff FR and Weil R (2004). *Soil organic matter in sustainable agriculture.* CRC Press, Boca Raton, Florida.

McGarry D, Sharp G and Bray SG (1999). *The Current Status of Soil Degradation in Queensland Cropping Soils.* Queensland Department of Natural Resources and Water.

Crop Management

Good crop management will increase the yield and quality of the crop. Strategies to increase the productivity and marketability of crops include:

- **Selecting varieties suited to production and the market.**
- **Using optimum dates of planting (sunlight hours, soil temperature and likely soil moisture).**
- **Using optimum row spacing, bed shape and plant density.**
- **Effective and timely control of weeds and pests.**
- **Optimum timing and efficiency of harvest.**

Crop rotation

Sensible crop rotation is critical to the long-term success of mixed cropping systems in the MCA (Figure 13). Before rotation was adopted, growers had many problems with diseases and pests, ultimately resulting in reduced productivity. Crop rotation also provides an opportunity, through a grass break, to replenish soil organic matter, which is essential for moisture and nutrient retention, surface stability, and the health of the root environment, for subsequent annual crops. Without such a break organic content of the soil may become seriously depleted. Importantly, the nutrients (and organic matter) from the last crop will influence the yield of the subsequent crops and may significantly reduce production costs.

Figure 13. Grass crops, grown for seed and hay, are an important part of crop rotation on the Tablelands. *(photo Bryony Barnett)*

In short, rotating crops has multiple benefits. It:

- reduces pest, disease and weed incidence;
- restores organic matter in the soil; and
- allows greater marketing and selling diversity.

It also allows the transfer of benefits of nutrients from one crop to another as:

- planting potatoes after peanuts will reduce nitrogen inputs, and provide well-drained, biologically healthy soils;
- sowing maize or a grass crop after potatoes will utilise any unused nutrients left after that crop;
- maize and grass crops will supply organic matter to the soil, benefitting the next crop; and
- legume crops add significant organic matter and nitrogen to the system.

Note: It is important to know which herbicides were applied to the previous crop before planting, as the new crop may react to residual herbicides and reduce yields.

Examples for crop rotation using peanuts and grass/legume seed crops are presented below.

Example—peanuts as part of mixed-cropping rotations

Peanuts should only be planted for a maximum of two years and then rotated with another crop, e.g. Rhodes grass, sorghum or maize. The management of peanut volunteers, during and after planting, will help to control diseases and pests between cropping seasons.

Example—grass and legume seed crops as part of mixed-cropping rotations

Tropical grass seed is produced primarily through Districts 3 and 4, often in association with haymaking. It requires both specialist skills and specialised machinery. In the past its use in the rotation with annual crops has provided the most feasible route for the restoration of soil organic matter. However, to be profitable a grass crop must produce a high seed yield in its first year after sowing. This is achieved by using high sowing rates, selective herbicides and the strategic use of irrigation.

The species and cultivars of grass used depend on market demand, both export and domestic. The domestic market for hay has its own preferences for grass types and this, along with the ease with which a particular grass fits into the rotation system, also influences choice of cultivar.

Fertiliser, harvesting and seed drying are among the greatest costs of seed production. Large applications of nitrogenous fertiliser (for example 200 kg/ha of urea per crop) are needed to produce a well synchronised and high yielding seed crop for harvest. The need for other major nutrients varies with crop history and the need to replace soil minerals removed in hay. Harvesting is mostly completed using high-powered conventional combine harvesters, though seed of a few problematical crops is brush-harvested with machines designed specifically for the purpose.

Leguminous seed crops have different requirements from those of grasses. They can (in general) only be safely grown in the drier Districts 4 and 5, where disease pressure is low and where the reliable dry season permits the imposition of the slight water stress that is necessary for vigorous seeding. Weed control is more problematical than for grass crops and needs greater skills in use of selective herbicides and crop rotation. Crops are preferably combine-harvested using conventional open fronts, but some that shed their seed too readily are taken with specialised suction harvesters.

Crop establishment

Row spacing, bed formation (where used) and plant population density all affect crop productivity and vary with the crop and, sometimes, the variety (Figure 14). The optimum plant population density and row configuration is important for maximum yield potential and for the control of diseases and weeds and minimisation of soil erosion. High plant populations per hectare are possible (and profitable) if correctly managed but this requires precise management of nutrients, water, pests and diseases. Recent improvements in farm machinery have enabled this, but careful monitoring of the crop is required to avoid damage to the crop; or nutrients, soil or agrichemicals moving off the crop.

Figure 14. Peanut crops planted using GPS allows uniform spacing in single or double rows.

Examples for peanuts and potatoes are presented below.

Example—peanut crop management

Peanuts are a summer grown crop, with irrigation used to supplement rainfall if required. Crops are row-planted.

Consistent placement of peanut plants will ease irrigation placement and improve water use efficiency.

Inter-row cultivation during the growing season is not good practice as it can damage the peanut plant and result in loss of yield. Weeds are best controlled through selective herbicides combined with sensible crop rotation.

Example—potato crop management

- **Soil temperature**—The best soil temperature for potato growth is between 15° and 20°C. Planting should be avoided at temperatures below 10°C and above 26.5°C.
- **Closed canopy**—Having a closed canopy cover for 90–100 days (during the vegetative to tuber bulking stage) is important to achieve high yields and crop quality. Having good vegetation cover can also reduce frost damage to the plant.

Crop productivity

- **Bed formation**—Good bed formation is needed for root set, to gain the maximum tuber size and numbers and to improve water drainage. Poor drainage can cause fungal and disease outbreaks (Figure 15).
- **Plant population density**—Higher planting densities are required in winter cropping, due to low light levels and seed piece decay, and to increase the canopy cover. If you are growing potatoes for the fresh market then plant spacing will be wider due to larger tuber size than if planting a variety for crisps. Plant spacing depends on the potato variety, size of the seed piece, and the age of the seed.
- **Row spacing**—Row spacing is dependent on the type of machinery used and whether it is fitted with GPS. Closer row spacing will increase the yield per hectare, and will also decrease soil erosion and the incidence of disease.

Figure 15. Bed forming is essential for high potato yields to allow good root and tuber formation and drainage.

Selection of crop varieties and seedstock

There are many varieties of potatoes, peanuts, maize and seed crops on the market, with new varieties appearing regularly. The grower's choice will depend on market demands, final use and the disease history of the farm (Table 5). With an increase of diseases and pests, it is considered good practice to buy seed stock from certified seed sellers (where possible). Seeds should be tested for potential germination performance and sowing rates adjusted accordingly to achieve desirable plant populations.

Table 5. Selecting varieties for cropping.

Maize	Peanuts	Potatoes	Pasture and fodder
Varieties chosen will depend on final use (silage, grain for human or animal food), disease potential and maturity time.	Varieties chosen will depend on market demand, disease history on the farm, and location.	Varieties chosen will depend on market demand, final use as processed or fresh market, season, seed availability, and disease resistance.	Varieties chosen will depend largely on market demand, with the easily established and easily eradicated Rhodes grass dominant at present. Legume seeds tend to be confined to the drier districts.

Weed And Pest Control

Best practice for controlling weeds and pests in crops uses a combination of tactical (rotation), biological, chemical and mechanical techniques:

- **Reduce weed seed loads in soil prior to sowing through preventing seeding, cultivation or herbicide control.**
- **Become familiar with the identification of weeds and pests likely to be encountered in the crop and plan optimal controls and crop rotations, including management of nearby areas which could act as refuge to pests.**
- **Ensure all equipment is in excellent operating condition and calibrated to reliably apply agri-chemicals within tolerance.**
- **Ensure all safety equipment is in excellent operating condition and accreditation is up to date.**
- **Apply pre-emergent herbicide spray before planting.**
- **Apply post-emergence selective herbicides at appropriate growth stages for weed control.**
- **Do not irrigate for 12 to 24 hours after cultivation for weed control.**
- ***For potatoes:* Cultivate beds at hilling and a second time before the canopies close and when soils are dry.**
- **Monitor for crop pests during critical periods and complete timely control with well-calibrated equipment.**
- **Observe recommendations and warnings on product labels and operate within locally applicable regulations.**

Integrated weed and pest management

Weeds can reduce crop yield considerably as they compete with the crop plants for water and nutrients. They can also impede harvesting and affect post-harvest management and marketing. Weed and pest outbreaks may be due to poor health of the plant or soil. Soil diseases can arise from repeat sowings of the same crop within the same area, so crop rotation is sound basic practice.

Below is an example of integrated pest and disease control for peanuts.

Example—peanut pests and diseases and their control

Peanut diseases can have a major impact on crop yields and quality and an integrated approach to control is recommended. Early control is recommended for both pests and diseases to reduce the opportunity for increase within the crop and damage sufficient to reduce yields.

Diseases of seedlings

Crown rot, found in most soils in Queensland, is a common disease of seedlings. It will kill weak seedlings and is likely to occur when soil temperatures are high and losses can be severe. Crop rotation should be used to reduce fungal populations and fungicide seed protectants applied prior to sowing.

Other soil borne diseases

Soil borne diseases include Sclerotinia, white mould and CBR (*Cylindrocladium* black rot). Rotation of crops with non-host crops, and general farm hygiene practices (cleaning tractors and other machinery) are the best ways to reduce these soil borne pests. A fungicide applied to the soil before symptoms appear can act as a protectant.

Diseases of established plants

The main leaf diseases are leafspot, rust and net blotch. If these diseases are left uncontrolled total loss of leaves and eventual plant death can occur. Foliar diseases can be managed effectively with fungicides. Generally, chemical application should commence four to six weeks after planting (earlier if peanuts have been planted as the previous crop) and prior to the onset of symptoms. These diseases are extremely difficult to eradicate once widespread in the crop so prevention is the best approach.

Insects and their control

The main foliage pests on peanut plants are Heliothis (*Heliocoverpa* sp.) and cluster caterpillar (*Spodoptera* sp.). These can rapidly increase to large numbers, so the crop should be monitored regularly, particularly when flowering and pegging occurs. Sucking insects include vegetable jassid and the lucerne leafhopper, which can infest the crop at any stage. Thrips, mirids and mites may also become a problem. Populations of these pests should be monitored and control, usually through the timely use of registered insecticides (chemical or biological), undertaken accordingly.

Soil insects

White-fringed weevils, white grubs and cane grubs are the main soil insects that will infest the peanut plant. Mechanical cultivation or soil-applied insecticides can be used to control these insects.

Weed management

An effective weed management program should consider the type of weeds present, available herbicides and crop rotation options. A combination of cultivation, spraying and crop rotation will deliver the best results and reduce the need (and cost) of chemical applications.

For best results, cultivation and chemical applications should be integrated. ***Note: Cultivation before planting will control established weeds, but will also encourage the emergence of new weeds from soil-seed reserves.*** Weed seed banks should be minimised through careful rotation and weed control, but it may be necessary to use a selective pre-emergent herbicide before planting. It may be necessary to manage plants along headlands so they do not become a source of pests or weed seeds.

Weed control options for potatoes and grass seed crops are given the in following examples.

Example—weed control for potatoes

Post-plant cultivation at hilling eliminates early germinated weed seedlings. This reduces the size of weed seedlings to be controlled. A second cultivation before the row closes over may eliminate the need for chemical weed control.

Competition from early season weeds will reduce yields if they are not controlled within four to six weeks after the potato plant emerges. Weeds that emerge after potato plants have covered the rows usually will not compete with the crop, but they may produce seeds that will infest subsequent crops and interfere with the harvest.

To maximize weed control effectiveness and to minimize compaction cultivation is best done late in the irrigation cycle when soils are relatively dry. Recently cultivated crops should not be irrigated for 12 to 24 hours, to allow for complete desiccation of uprooted weeds.

Example—weed control in grass seed crops

Weeds in grass seed crops can compete with the crop for nutrients and, if not treated, contaminate the final product with weed seeds, potentially limiting marketing options (or deeming the product unsaleable). This is particularly important in the first year when annual plants compete with the crop (usually being out-competed by the crop after the first dry season), but perennial weeds can present problems in subsequent years.

Whereas most broad-leaved weeds (with very few exceptions) can be controlled using post-emergence applied selective herbicides, grass weeds are usually troublesome to control (with a few exceptions). Many hard-to-control grasses are also common in the MCA, so site selection and management of previous crops are important considerations when sowing a grass seed crop.

A sensible strategy is to follow a leguminous crop (such as peanuts or lablab), where grasses have been controlled using selective herbicides, or a well-fertilised crop (such as potatoes), whereupon the fertiliser can be used to promote rapid growth of the grass seed crop and, therefore, early canopy closure.

The crop should be managed to achieve a high population of vigorously growing plants. This normally involves broadcasting seeds at high sowing rates (6–10 kg/ha) into a level and friable seedbed and rolling and irrigating (if rainfall is limiting) after sowing. Nitrogen fertilisers can be applied as a side dressing if growth slows in the first cycle, and at the beginning of every crop cycle thereafter.

Selective herbicides should be applied as directed on the product label, with particular attention to timing, application rates and methods, and safe operation, including the possibility of spray drift. Attention should be paid to crop vigour, soil moisture (to avoid compaction) and forecast rainfall to avoid poor control and run-off.

Biological control

The biological control of pests and diseases includes methods that avoid the application of inorganic chemical products to crops, thereby avoiding some potential safety and off-crop effects (and potentially the costs). There may also be market advantages for using these approaches.

Some biological control methods include:

- planting varieties bred to be resistant to certain pests and diseases;
- introducing insects that control persistent insect pests; and
- the use of microbial inoculants to help soil biota repel nematodes and soil diseases.

Chemical control

The use of chemicals is regulated to ensure safe use and product effectiveness. Certification such as Chemcert and ACDC are required for handling chemicals under these regulations. Keeping records of chemical use is a requirement under Freshcare and other quality assurance schemes.

Programs such as Infopest™ provide a National database of chemical usage and are a way of identifying the correct chemical, application rate and method (an agronomist should be consulted if there are any doubts regarding any of these specifications). Chemicals should be applied as specified on the label or permit, including alternation of active ingredients to avoid pest or disease resistance.

It is also important to use equipment suited to the application of chemicals to particular crops and to ensure they are of excellent working order. Regular calibration of spray equipment and the fitting of appropriate and effective nozzles are particularly important. The use of methods (avoiding windy conditions) and equipment that minimises spray drift (e.g. hooded sprayers) are also sensible practices (Figure 16). The adoption of newer technology, such as GPS-guided tractors and applicators fitted with weed detection sensors can also reduce the amount of herbicide applied to a crop, thereby avoiding any potential damage to the crop, saving money and reducing the risk of off-site damage.

Figure 16. Hooded sprayers reduce spray drift and improve spray efficiency.

Following is an example of chemical control of weeds in maize crops.

Example—weed control in maize crops using band spraying

Weeds in maize crops have traditionally been controlled using a combination of rotation, cultivation and selective herbicides. However, band spraying (the application of herbicides in bands between plant rows) can reduce chemical usage up to 60% and still give effective control as spray is applied where it is needed. This also reduces resistance build-up in weed species. Band spraying is becoming more common as the machinery and technology becomes available. The use of GPS to accurately place plant beds, and calibrating the sprayer to row widths improves the efficiency of this method.

Methods to optimise weed control, while minimising the application of herbicides and off-crop damage, are presented in Table 6.

Table 6. Recommended best practice for controlling weeds and pests.

Outmoded Practice	Current Best Practice	Future Directions
Chemical application based on calendar or on past rates.	Chemical application based on frequent monitoring, with 14 or 21 day follow-up to control problem.	Chemical application based on weekly monitoring of pest and weed incursions, with 14 or 21 day follow-up to control problem.
Same chemical product used over the cropping seasons.	Chemical product changed periodically to reduce build-up of resistance, using different classes of chemicals.	Chemical product changed to reduce build-up of resistance.
Machinery used that broadcasts chemicals over whole paddock, with overlap of spray passes.	GPS guidance system used on machinery to spray directly on the rows, with no overlap between passes. Hooded sprayers may be used.	GPS guidance system used on machinery for spray applications with IR sensors (such as Weedseeker) to spray only on identified weeds/pests.
Spray equipment not calibrated for different use, nor maintained regularly.	Spray equipment calibrated for different spray jobs and products and equipment maintained regularly.	Nozzles and equipment used for specific jobs and equipment maintained seasonally.
Only chemicals used to control weeds and pests in crop.	Integrated Pest Management used across farm (chemical, mechanical and biological controls).	Integrated Pest Management used across farm. Chemical sprays attached to GPS guidance system to deliver directly to problem area.
No records kept of spray jobs or pest incidences.	Records kept in database of spray jobs—how much and what product used. The pest identified and the appropriate product used to remove pest/weed problem.	Farming software used to detail and map location of pest/weed problem. Areas affected entered into GPS guidance system, where machinery sprays directly to problem area. IR imaging used to problem areas.
Empty product drums disposed of on-farm.	Empty product drums disposed of through drumMUSTER program.	Empty product drums disposed of through drumMUSTER program.

Soil Conservation And Rain Water Management

Poor management of excess rainfall results in poor crop growth through poor soil aeration and plant nutrition and damage from diseases. It can also cause loss of soil through erosion. Key actions to manage excess water on-farm, include:

- **Becoming familiar with the passage of water on-farm following high rainfall events and how this relates to your catchment (upstream and downstream).**
- **Managing water run-off through contouring, surface drainage, detention basins, etc and, so far as possible, direct the water that leaves one's property along routes that cause the fewest downstream problems.**
- **Being aware of the importance of soil organic matter in the maintenance of soil condition and, wherever possible, insert a restorative break into the crop rotation program in the form of a grass or leguminous ley.**
- **When planting row crops ensure rows follow contours.**
- **Minimise the period of bare soil exposed to potential rainfall events and avoid pulverising soil through excessive cultivation.**
- **Revegetating river/creek banks at least 5 m from the bank.**

Perhaps the greatest seasonal challenge to land managers within the MCA, on both farm catchment scales, is the management of peak water flows after periods of heavy rain. This occurs most commonly in the lead up to the wet season. Water run-off is now accelerated compared to pre-European times following clearing of land for cultivation and urban development. This can lead to creek bank and gully erosion, loss of topsoil and nutrients, and ultimately reduced productivity. Erosion products (soil and agri-chemicals) can also enter waterways and eventually enter the Great Barrier Reef system causing environmental damage if in significant amounts.

Whole-of-catchment strategies are required to manage excess water, but key works can be completed on-farm. Drainage should remove water from cropping areas, as well as any excess run-off that may build up after heavy rain, but do so in a way which minimises downstream damage to properties and waterways.

Rain water penetration and drainage on red basaltic soils

Most of the red-soil cropping country of the MCA (frequent in Districts 1,2 and 3) has topsoil that is readily permeable to rain water when well-managed, and a deeply weathered subsoil that allows water penetration down to the basalt rock. The rock itself usually contains enough fissures to allow rain water to drip steadily into the aquifers, so these soils present few moisture penetration problems. However, surface drainage patterns that developed on a predominantly wooded and undisturbed pre-agricultural landscape cannot cope with the greatly increased peak run-off of rain water accompanying present land use without risking serious damage. Creeks, the immediate conduits of excess surface water, become overloaded with the consistently heavier peak run-off causing damage both to farmland and to creek banks.

Loss of organic matter, through over-cropping in the past, destroyed soil-crumb structure and significantly reduced the permeability of soils to rain water. Such damage can increase surface flow and de-stabilise surface layers which, if left unchecked, can cause irreversible gully erosion. Many soils in the MCA have some degree of soil-wash damage and severe gully erosion has already developed in a few areas where flows and gradients increase as they get closer to larger natural drainage lines (such as the Barron River).

Improved soil and organic matter conservation management over time has stabilised farm land. However, accelerated water run-off from ever-increasing urban areas has resulted in greater and earlier peaks in run-off volume. This has contributed to severe creek-bank damage and erosion, gully erosion and flooding.

Other soils

There are a few areas in the MCA where soils have poorer drainage than those of the red basalt soils. Both isolated volcanic craters and former basalt flows blocking older drainage lines have created swamp areas. For agriculture, the profiles of these soils tend to be relatively shallow and have impermeable clay subsoil limiting their use. Poor drainage is also found over large areas of forest soils within Districts 4 and 5. These soils are readily amenable to the installation of modern pipe drains provided there is sufficient slope for water to flow, but to date cost has restricted such drainage to limited areas of very highly valued land. Improved drainage is otherwise generally limited to measures to facilitate surface run-off.

Reducing the risks of excess rainfall

High water volumes due to localised storms and widespread rainfall events are characteristic of the climates of the humid tropics, and extreme events can exceed any measures likely to be taken to mitigate water damage. Risks of damage from excessive rainfall can, therefore, never be wholly eliminated. Importantly, any form of cultivation increases these risks. Much can be done however to reduce the risks of such damage, and the individual land holder can contribute significantly to both personal and the community's benefit. There are three key methods for managing excess soil water on-farm:

- Optimise organic matter content—this increases the soil water-holding capacity of the soil thus greatly reducing surface run-off, and improves soil crumb structure, which greatly accelerates downward penetration of water through the profile.
- Sensible choice of cultivation practices and equipment—some implements (e.g. rotary hoes) can excessively pulverise soil resulting in small soil particles that impede water infiltration and are prone to wash.
- Contouring slopes—as some wash is inevitable contouring is used to control its extent and direction.

Control of water run-off

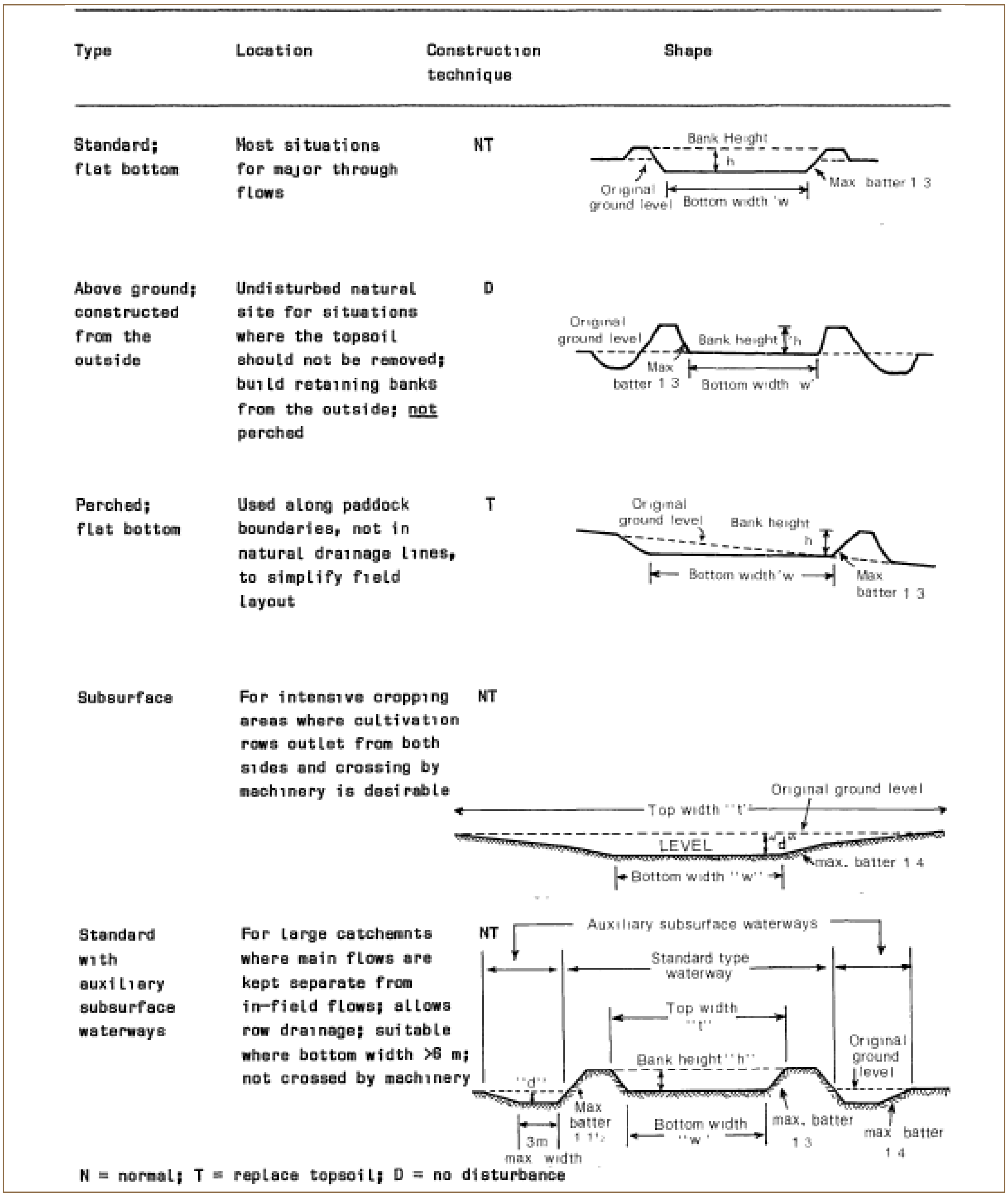
Run-off control structures are required in most sloping situations where land is cultivated (Figure 17).

Figure 17. Grassed waterway between paddocks reduces soil loss and slows water run-off. *(photo Evizel Seymour)*

Soil conservation structures include waterways, contour banks, diversion banks or spreader channels. The advice of a soil conservationist should be sought when planning any works on property and the works undertaken in accordance with any applicable regulations.

Waterways

Where possible, waterways to carry run-off water should be well grassed and located in natural drainage lines as these are the safest locations when a run-off event exceeds the design capacity. Occasionally, run-off control layouts require the construction of artificial waterways. These should be designed to carry at least a 1 in 10 year run-off event. Where waterways are not located in natural drainage lines the design frequency should be for a 1 in 50 year storm, as the damage caused if they overtop can be severe. There are alternative cross-sectional shapes as shown in Figure 18.



Type	Location	Construction technique	Shape
Standard; flat bottom	Most situations for major through flows	NT	
Above ground; constructed from the outside	Undisturbed natural site for situations where the topsoil should not be removed; build retaining banks from the outside; not perched	D	
Perched; flat bottom	Used along paddock boundaries, not in natural drainage lines, to simplify field layout	T	
Subsurface	For intensive cropping areas where cultivation rows outlet from both sides and crossing by machinery is desirable	NT	
Standard with auxiliary subsurface waterways	For large catchemnts where main flows are kept separate from in-field flows; allows row drainage; suitable where bottom width >6 m; not crossed by machinery	NT	

N = normal; T = replace topsoil; D = no disturbance

Figure 18. Characteristics of waterways used in the Atherton–Mareeba district.
From Shepherd RN and Macnish SE (1989). *Land Management Field Manual, Atherton–Mareeba District.* Queensland Department of Primary Industries, Brisbane.

The establishment of dense grass cover within drains requires careful management. It is important to replace topsoil for a seedbed to maximise seedling establishment and water should not be discharged into the grassed waterway until it has greater than 60% grass cover. Slashing and fertilising are important aspects of maintenance. There may be an opportunity to cut hay from a well-grassed waterway if managed appropriately. Suitable grass species for stabilising waterways on the Tablelands are listed in the section 'Plants for ground cover of soil conservation earthworks'.

Contour banks

Contour banks are used to intercept run-off water and carry it to a waterway or stable disposal area. Broad-based banks (that can usually be adjusted to match machinery size) are generally most suitable for cropping the red soils of the Atherton Tableland, although narrow-based banks might be preferred in cane production and contour mounds will be used for horticultural crops. Different types of banks are illustrated in Figure 19.

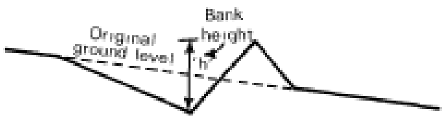
Type	Location	Cross-section
Narrow based – triangular channel	Shallow soils, non-cracking soils; may be used on all slopes where banks are required	
Broad based	Soils which are deep; essential on cracking clay soils; only used on slopes of less than 5%	
Broad based topside	Cracking clay soils <60 cm deep on slopes <8%; duplex soils on gentle slopes <3%	

Figure 19. Characteristics of contour bank types used in the Atherton–Mareeba district.
From Shepherd RN and Macnish SE (1989). *Land Management Field Manual, Atherton–Mareeba District.* Queensland Department of Primary Industries, Brisbane.

Land slope influences optimum contour spacing. For land of slopes less than 2% a spacing of 100 m between banks is acceptable. This space should be reduced as slope increases, until at 7–10% slope banks should be spaced approximately 30 m apart. Contour bank lengths should generally be less than 500 m for cropping red basalt soils.

Contour banks constructed to maintain a non-scouring water velocity (usually 0.2% or 0.3% gradient) are generally not parallel, but parallel contour layouts can be designed and constructed where paddocks have even slopes. Where paddocks are worked parallel to a fence line (tramlining) or where controlled traffic farming is carried out machinery will work over contour banks at varying angles. To minimise problems it is best to design controlled traffic layouts to operate so that wheel tracks and rows are as close as possible to 90^{o} to the contour banks. To achieve this, herringbone layouts can sometimes be used.

In all situations, but especially where banks are worked over by machinery, regular maintenance to de-silt channels and rebuild banks is needed over time.

Diversion banks

Diversion banks are large contour banks that are usually not cultivated and allowed to grass-up. They are used to protect cultivated areas from water coming from further up the slope and to divert water from unstable areas. They are usually designed to cope with a 1 in 50 year storm. Channel gradients should not exceed 1%.

Spreader channels

Spreader channels are level channels used to spread concentrated flows of run-off onto grassland. Water is diverted into the spreader channel using a contour or diversion bank. The first 20 m of the spreader has a slight gradient to help the spreader fill evenly. Water will then spill evenly over the length of the spreader channel.

Detention structures

Detention of water as close as possible to where it falls is critical in maintaining moisture in soil profiles, replenishing aquifers and preventing damage downstream. Maintaining good coverage of topsoil by retaining stubble/trash after harvest is a primary method of detaining water in cropped land.

Partial on-farm detention of excess run-off water can be achieved using spreader channels or pondage banks (high diversion banks with closed ends). Alternatively, small detention basins can sometimes be built near the end of a diversion bank to hold back some water to reduce the peak flow.

In some landscapes keyline farming, which gently directs water away from the watercourse, will aid detention and improve soil moisture retention. In pasture land subject to compaction due to cattle periodic contour ripping of the soil (if not too rocky) will improve infiltration.

To reduce the severity of damage due to the large peak flows in a cropped or urbanised landscape, large detention basins (dams) can sometimes be constructed adjacent to streams where a suitable site is available. As well as reducing peak flow, such basins can act as silt traps and improve water infiltration to the aquifer (Figures 20 and 21).

Figure 20. Sediment retention dam with rock wall to reduce water velocity and trap sediment.

Figure 21. Sediment retention dam below paddock traps sediment and prevents it entering waterways.

Vegetation buffers along waterways

Grassed buffers between the paddock and waterways will reduce the amount of soil entering creeks. These buffers, together with healthy riparian vegetation, will help to filter nutrient loads entering the natural waterways. A buffer of a minimum distance of 5 m from the creek bank will help trap sediment leaving the paddock and prevent erosion of the bank.

Agronomic soil and water conservation measures

Cropping practices that maintain soil cover are key means to achieve soil and water conservation. Soil cover provided by a standing crop or retained stubble/trash reduces the shattering effect of raindrops on bare soil, enhances infiltration, and slows down water movement over the surface.

Well-planned rotations and careful management can be used to maximise soil cover. Rotations including a sown pasture phase achieve the cover goal, as well as restoring soil structure often destroyed by intensive tillage for crops. Sown pastures can be used for grazing (if fenced), hay production or pasture seed production. When included in a crop rotation, cereal crops such as maize or sorghum can provide a cover of plant residue after harvest that is left until tillage is required for a subsequent crop. In some locations winter crops such as barley, lupins and winter navy beans can also be introduced into the rotation. Minimum tillage should be used in planting cereal crops, particularly following legume crops such as peanuts and navy beans, as the residues are minimal making it easy to zero-till plant the next crop.

Management and preparation for planting should aim to minimise the severity of soil disturbance— this includes consideration of the number of passes by heavy farm equipment, the type of tillage used and timing to make optimal use of soil moisture.

Tined implements should be used in preference to discs to reduce damage to soil structure and destruction of residue cover. Where a fine seed bed is required strip tillage machinery, which intensively cultivates the soil only in the plant row, can be used. This final preparation should be left as late as possible before sowing/planting to minimise the opportunity for high rainfall events on bare ground.

Plants for ground cover of soil conservation earthworks

Most soil conservation earthworks built on local crop land need to be stabilised, where practicable, by a cover of densely-rooted vegetation, of which the most satisfactory forms are perennial grasses. The grasses chosen for this purpose may need to be tolerant of periodic but brief and severe seasonal drought at other times. They may be required to withstand a measure of grazing and must not to be toxic to livestock or be a notifiable weed. They must often be capable of being established in conditions of serious soil infertility if on exposed raw sub-soil. In addition, they must be species whose spread beyond their area of use is controllable, and of which seed (or if there is no alternative, cuttings) is readily available. They must be tough, well adapted to local soils and climatic conditions, and highly persistent.

The species most commonly used and which are most likely to fulfil these stringent requirements in the Tableland MCA are as follows:

Signal Grass (*Brachiaria decumbens* syn. *Urochloa decumbens*): Signal Grass is the most widely and successfully used grass in soil conservation work within the MCA. It can be reliably and quickly established under most conditions, provided fresh (dormant) seed is avoided and heavy sowing rates are used. It provides a relatively short, dense and highly protective ground cover under a wide range of local soils and conditions, but it lacks vigour on poorly drained country.

Humidicola (*Brachiaria humidicola* syn. *Urochloa humidicola*): A close relative of Signal Grass, Humidicola complements Signal Grass in thriving in poorly drained soils while being similar in many other respects. On sites of variable or uncertain drainage characteristics it is sensible to sow seed of a mixture of the two grasses, each of which will then in due course find its own niche. Humidicola is, however, slow to establish. For this reason it is common when seed of either grass is sown to include **Japanese millet** seed in the seed mix, as it provides good rapid ground cover during the first season while later conveniently dying out.

Indian Couch (*Bothriochloa pertusa*): There are several varieties of this low-growing, hardy grass; any of which are useful for revegetating surfaces that are expected to become neglected or be otherwise subject to harsh, dry conditions. Early flowering varieties may, however, become weedy and should be avoided. Indian couch is another species that is slow to establish. Its place is generally as a component of a mixture with more vigorous grasses, where it may colonise difficult patches of bare ground where the others have failed.

Other possibilities: A number of other species of grass might be used if the above-listed ones fail. **Pangola** (*Digitaria eriantha*), **Kikuyu Grass** (*Pennisetum clandestinum*) and **African Star Grass** (*Cynodon nlemfuensis*) were formerly recommended to vegetate contours, but they fell out of favour over the years for a variety of reasons. **Bahia grass** (*Paspalum notatum*), being tough and low-growing, is sometimes used successfully in amenity areas and drains but must be avoided where there is a risk of its spreading into pastures since it is relatively unpalatable to livestock.

Rhodes grass (*Chloris gayana*) may have a place in the high, cool, dry western fringes of District 1 or where risks of salinity exist. However, it has a poor reputation for long-term persistence in undisturbed ground.

Some native plants, particularly trees, have a role on uncultivable ground such as steep gullies, creek and river banks and detention structures well away from cropping land, and also for restoration of preserved natural vegetation. In addition, some native grasses have shown promise for revegetation of roadside works.

Establishing grasses in soil conservation earthworks

The principles of establishing soil-conservation grasses are generally the same as for pasture grasses, though the relatively small areas usually sown allow more flexibility in terms of choice of seed and fertiliser application rates. All of the grasses require a shallowly disturbed, fine seedbed to encourage germination and early establishment, although vulnerability of bare slopes to heavy rain limits the extent of soil disturbance. The aim should be to cover and firm down grass seed for best results. Irrigation, if available in early summer, is very helpful as it may allow the development of a protective grass sward before the season of destructive storm rain arrives. Sowing seed in prolonged cool or (in the absence of irrigation) dry weather is likely to result in poor establishment. A brief period after the end of the wet season sometimes allows an opportunity to sow seed, but the main period (given irrigation) is from when the soil warms up (usually from October onwards) until the start of the wet season.

A mixed general fertiliser should be applied at or soon after sowing to encourage rapid first year growth. Sowing on to raw subsoil, however, whether bare or mixed with topsoil, introduces soil nutritional problems that need special attention. Such soil is likely to be acidic, high in available aluminium, and will bind phosphorus so it is not available to plants. If so, the application of ground liming materials may be advisable to raise soil pH, and there may be no correction of phosphorus deficiency until the sites of fixation are satisfied, which at worst can take years. Subsoil is also slow to weather into a better-structured tilth resulting in impeded grass root development. The development of a protective perennial ground cover can, therefore, be very slow. For all these reasons it is best, wherever possible, to cover areas of subsoil with a generous depth of topsoil.

Suggestions for soil conservation and rain water management are given in Table 7.

Table 7. Recommended best practice for drainage.

Outmoded Practice	Current Best Practice	Future Directions
Paddocks not suitably prepared, with ponding patches occurring and erosion during heavy rain.	Paddocks prepared (where applicable) to follow contours in paddock to remove ponding. Run-off may be directed to sediment retention structures.	Paddocks prepared (where applicable) to follow contours in paddocks and contours mapped to GIS. Water paths directed to sediment retention structures via grassed waterways.
Planting doesn't follow contours and there are no contour banks in the paddocks.	Planting to contours with contour banks in paddocks.	Planting to contours with contour banks in place. Keyline design on farm to improve water infiltration rates.
Limited drainage and maintenance on drainage system.	Moderate levels of drainage, well-maintained and sufficient to handle heavy rainfall events in the majority of years.	Effectively designed and maintained drainage that uses mapped and surveyed water flows across farm and shallow, grassed waterways to remove sediment from water.
River/creek banks are not vegetated and bank collapse occurs.	River/creek banks are vegetated with trees, shrubs and grasses, extending 5 m from banks.	River/creek banks are vegetated with trees, shrubs and grasses, extending 10–15 m from banks. Riparian areas mapped to GPS guidance system to keep heavy machinery from causing damage.
No sediment or water retention dams.	Sediment and water retention dams in place to reduce run-off of soil and nutrients.	All drains and sediment/nutrient dams designed to contours to catch majority of run-off.

The following are useful publications when developing agricultural land management works:

Carey B and Stone B (2004). *Soil conservation measures: a design manual for Queensland.* Department of Natural Resources and Mines, Brisbane.

Department of Environment and Resource Management (2011). *Controlled traffic farming—soil conservation considerations for extensive cropping.* Fact Sheet L 146. www.qld.gov.au/dsitia/assets/soil/controlled-traffic-farming.pdf

Peverill KI, Sparrow LA, Reuter DJ (Eds) (1999). *Soil Analysis: An Interpretation Manual.* CSIRO Publishing.

Record Keeping

Good record keeping will help growers produce consistent high yielding crops and make reporting on quality assurance and demonstration of sound practice easier.

Farming software programs, designed for recording use and cost of chemicals and machinery, can be effective record keeping tools.

GPS data can be uploaded to software to record accurate location of applications.

Keeping precise and organised records of soil monitoring, weed and pest control, and fertiliser applications for each crop is important to show trends over time, and to reflect on the impact of any changes to crop management. Ultimately, this information is necessary to show if an individual crop or rotation (and the overall farming enterprise) is profitable.

Records can be kept as paper files, computer spreadsheets or by using specialised farm software, depending on personal computing capacity and operational needs. The move to farm software is encouraged with the advent of reporting requirements for new food production legislation.

Record keeping software

Computing software can used to store records of irrigation systems, fertiliser applications, fuel, labour time and costs. The software enables growers to view farm records in a table or database, saving on paperwork and make reporting easier.

There are many companies producing 'farm keeping' software. Some are specific to certain industries, others cover multiple industries. It is best to research the most suitable software for individual needs. Programs such as FarmKeeper™ and Farm Works™ (see example below), are designed solely for agricultural systems, and can record and cost everything you use on your farm.

Example—Farm Works™ farm management software

Farm Works™ can be connected to a GPS system and information downloaded directly to a computer, showing exactly where and how much was sprayed. Factors such as spray timing can be entered into the program then used to plan future work for each paddock. It can also be used to map the farm topography and therefore assist with planning drainage operations.

The benefits of upgrading to this technology include more efficient and easier record keeping and ready compliance with regulations requiring records upon the sale of a crop. The program can also be used to compile a report at a paddock scale, enabling assessment of input costs and returns for each paddock. The software comes in modules, so growers can buy according to skills and needs.

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Department of Environment and Resource Management. Water management information fact sheets. www.dnrm.qld.gov.au/water

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Dwyer G, Glanville T and Knowles-Jackson C (1994). *The Queensland Information Kit for Looking After Horticultural Land.* Queensland Department of Primary Industries, Nambour.

Kelley R, Barnett B, Bainbridge Z, Brodie J and Pearson R (2007). *Nutrients, Catchments & Reefs: A guide to nutrients in your landscape.* Produced for the Catchment to Reef Joint Research Program. www.rrrc.org.au/catchment-to-reef

Kilpatrick J (2010). *The current situation and best management practices for the red clay loam cropping soils on the Atherton Tablelands.* Background paper for Barron Catchment Care. www.barronrivercatchment.org.au

Loch Donald S (2006). *Soil nutrient testing: how to get meaningful results.* Department of Primary Industries and Fisheries, Redlands Research Station, Cleveland.

Magdoff FR and Weil R (2004). *Soil organic matter in sustainable agriculture.* CRC Press, Boca Raton, Florida.

McGarry D, Sharp G and Bray SG (1999). *The Current Status of Soil Degradation in Queensland Cropping Soils.* Queensland Department of Natural Resources and Water.

Moran C, Turton SM and Hill R (Editors) (2014). *Adaptation pathways and opportunities for the North Queensland NRM Cluster region Volume 1: Introduction, Biodiversity and Eco-system services.* James Cook University, Cairns.

Moran C, Turton S and Hill R (Editors) (2014). *Adaptation Pathways and Opportunities for the Wet Tropics NRM Cluster region Volume 2: Infrastructure, Industry, Indigenous peoples, Social adaptation, Emerging planning frameworks, Evolving methodologies and Climate adaptation planning in practice.* James Cook University, Cairns.

Peverill KI, Sparrow LA, Reuter DJ (Eds) (1999). *Soil Analysis: An Interpretation Manual.* CSIRO Publishing.

Shepherd RN and Macnish SE (1989). *Land Management Field Manual, Atherton–Mareeba District.* Queensland Department of Primary Industries, Brisbane.

Some Useful Web Sites

Barron Catchment Care
www.barronrivercatchment.org.au

Food and Agricultural Organisation (FAO) Feedipedia: Animal feed resources information system
www.feedipedia.org

Growcom Queensland 'Water for Profit' program
www.growcom.com.au/land-water/water-for-profit

Land and Water Australia
www.lwa.gov.au

Peanut Company of Australia (PCA)
www.pca.com.au

Queensland Department of Agriculture and Fisheries
www.daf.qld.gov.au

Queensland Department of Natural Resources and Mines
www.dnrm.qld.gov.au