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Prepared by: Dr Clinton Revell, Geoff Moore and Sam Crouch
Department of Primary industries and Regional Development (WA)

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Mosaic Agriculture – A guide to irrigated crop and forage production in northern WA

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Executive summary

Mosaic agriculture built around small, dispersed irrigation developments has been identified as one of the significant opportunities to transform beef production systems of northern Australia. The Department of Primary Industries and Regional Development's (DPIRD, formerly DAFWA) 'Mosaic Agriculture' project with co-funding from Northern Beef Development and the MLA Donor Company focussed on building the value proposition of this technology.

The development of water resources for irrigation has created the opportunity for the introduction of more productive forage species to supplement rangeland grazing and remove some of the seasonal production risk. Outside the Ord River Irrigation Area, there is over 4,000ha of private irrigation projects growing fodder and horticultural crops across the west Kimberley and Pilbara, predominantly using centre-pivot irrigation systems. The area continues to increase with a number of new projects at various stages of the feasibility, approvals or development phase.

While there is considerable information from other tropical environments in Queensland and the Northern Territory, there was a need to evaluate candidate species in the unique environment (soils, climate) of the Pilbara and Kimberley regions of WA. The main objective of the project was to quantify the seasonal production and feed quality profiles of a range of tropical annual and perennial forages, and develop locally relevant best-management guidelines. This objective has been achieved with relevant information on irrigation management and animal production compiled into a comprehensive extension package for existing and potential irrigators, agri-business and industry (refer attached DPIRD Bulletin 4915 'Mosaic Agriculture – A guide to irrigated crop and forage production in northern WA'. Given the additional constraints in WA for using non-indigenous plants on pastoral lease, a second objective was to develop and field test a rigorous, site specific system for assessing environmental weed risk of key forage species.

Experimental sites were established on commercial irrigation operations from Port Hedland to Fitzroy Crossing and also utilised an irrigation facility at the Broome North wastewater treatment plant (Water Corporation). The sites covered a range of soil types and climatic conditions. Experiments included species evaluation (annual and perennial grasses, tropical legumes, herbs) and a range of management practices (forage production over time, response to cutting regimes, crop nutrition and impacts on nutritive value). Information was used to inform production systems based on cut and carry systems (hay, baleage, silage) and direct grazing systems (stand and graze).

Data from these experiments was then utilised in an economic model to explore the profitability of an investment in irrigation for a range of production scenarios. The results highlight the importance of producing high quality pastures and forage, with the maximum benefit achieved when the irrigation development is fully integrated into the cattle production system. One of the most profitable scenarios was to conduct early weaning of calves and feed them with high quality irrigated hay to allow breeders to recover body condition, and thereby improve conception rates and reduce mortality rates. The analyses undertaken in this study highlight the high capital cost of development and point out that the payback period can be 7 to 13 years depending on the cattle management scenario. While small-scale irrigation developments (even 30-50ha) can be profitable, investment decisions should be made carefully given the high sensitivity to feed quality, sale price of steers, hay yield and discount rate.

A series of four field nurseries were established in key environments (climate, soils) in the Kimberley and Pilbara to assess whether a wide range of forage grass and legume species could persist and/or spread. The trials were established under irrigation to simulate episodic events, where plants can potentially spread following a cyclone or extremely high rainfall year. The data from these field trials has contributed to a revised weed risk assessment (WRA) system for the WA Rangelands. Over 30 forage species have been assessed using the revised protocol. Of these, 11 species (including Rhodes grass, panic grass, pearl millet, lablab, cowpea and a range of stylos) are considered to have little or no weed risk. The potential

distribution of each species was assessed using new mapping techniques based on soil types (land systems) and climate (annual rainfall, growing season temperature and elevation) developed in collaboration with Charles Sturt University (CSU).

Rhodes grass (*Chloris gayana*) is the dominant forage currently used under irrigation in northern WA because of its productivity, resilience and adaptation to the environment. Experimental results re-affirm its value, but have highlighted some important challenges to optimise performance. The stage of re-growth and plant maturity has a dramatic effect on the nutritive value, largely as a consequence of changes in the leaf to stem ratio of the sward. The leaf fraction of Rhodes grass has much less fibre than the stem fraction and generally higher protein, reflected in higher metabolisable energy. Management systems that encourage growth of leaf relative to stem (such as short grazing rotations) are critical to optimise the nutritive value of Rhodes grass in direct grazing systems. The trade-off in dry matter production and nutritive value to optimise animal growth rates is best managed with regrowth cycles of about 21 days (longer in the cooler months of the dry season and shorter in the warmer months of the wet season). Growing the pasture for 6-8 weeks substantially lifts hay yields (growth rates can exceed 200kg DM/ha per day and can equate to 35-40t DM/ha per year), but feed quality deteriorates rapidly.

A key outcome of this work was the exceptional performance of panic grass (*Megathyrsus maximus*), yet to be used commercially on any scale, and this species should be considered as an alternative to Rhodes grass in all production systems. Panic grass consistently maintained a higher nutritive value than Rhodes grass, though all perennial grasses were generally of lower quality compared with the sweet sorghum hybrids (*Sorghum* spp.) and maize (*Zea mays*). Research also highlighted the high nutritional inputs (particularly nitrogen and phosphorus) required to achieve high productivity from grass-based production systems growing on inherently low fertility, sandy soils.

Forage options particularly for the cooler 'dry' or winter growing season were also investigated. Maize and sweet sorghum appear to be the best prospects combining rapid early growth and high forage quality. Grazing cereals (such as oats and barley) appear to be the most suitable of the temperate grasses, and could be incorporated into an annual cropping rotation.

Analysis of the feed quality of tropical legumes highlighted their generally superior nutritive value compared with the warm season (C4) grasses, particularly cowpea (*Vigna unguiculata*) and centro (*Centrosema pascuorum*). However the legumes are typically slower to establish and are constrained by lower overall productivity compared with grasses (assuming nitrogen non-limiting), particularly during the cooler winter growing season (perhaps with the exception of lablab (*Lablab purpureus*) in coastal environments). Research is still required to develop robust legume options and associated management packages to compliment grass-based irrigated forages for growing animals.

Industry was strongly engaged throughout the project. Producers provided input into the research directions and a number of well-attended field days and workshops were held to present and discuss project outcomes. Aspects of the research were also presented at key industry events such as the Kimberley and Pilbara Cattlemen's Association (KPCA) annual conferences. A clear need was identified to provide pastoralists with a local information source to guide decision-making when considering whether to invest in an irrigation development. While there are clear benefits for pastoral businesses, irrigation is a substantial investment, requires specialist skills and may not be the most cost-effective technology to lift productivity or reduce business risk in all situations.

The attached publication brings together information generated in the project with a range of other industry extension material to provide a complete package for pastoralists to assist with decisions about the feasibility of investing in irrigation, system design, implementation and management requirements to optimise performance. This publication will also help to address the ongoing need for up-skilling and training as retaining experienced staff in remote locations is a significant challenge for the industry.

Publications arising

DPIRD Bulletin 4915 (2020) Mosaic Agriculture – A guide to irrigated crop and forage production in northern WA (Eds G. Moore, C. Revell, C. Schelfhout, C. Ham and S. Crouch)

MacLeod ND, Mayberry DE, Revell C, Bell LW and Prestwidge DB (2018) An exploratory analysis of the scope for dispersed small-scale irrigation developments to enhance the productivity of northern beef cattle enterprises. *The Rangeland Journal.* https://doi.org/10.1071/RJ18026 (published online 22 August 2018).

Moore G and Revell C (2016) Innovative field nurseries to assess weed risk in the rangelands of Western Australia *In* Proceedings of 20th Australasian Weeds Conference in Perth 11-15 September 2016. pp. 213-217
http://caws.org.nz/old-site/awc_contents.php?yr=2016

Munday C, Moore G, Whitsed R, Byrne M and Revell C (2018) Refining the environmental weed risk assessment for non-indigenous plants which may have agricultural potential *In* Proceedings of 21st Australasian Weeds Conference at Bondi (Sydney) 10-12 September 2018. pp. 72-76
http://caws.org.nz/old-site/awc_contents.php?yr=2018

Munday C, Byrne M, Moore G and Revell C (2016) Introducing non-indigenous plants to the Western Australian rangelands - what can weed risk assessment contribute? *In* Proceedings of 20th Australasian Weeds Conference in Perth 11-15 September 2016. pp. 210
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Geoff Moore
Clinton Revell
Chris Schelfhout
Christopher Ham
Samuel Crouch

Introduction

By Mosaic Agriculture team

Key messages

- Irrigated agriculture creates opportunities for the northern cattle industry in Western Australia to:
    - target cattle to a broader range of markets outside traditional selling periods
    - implement a range of herd management and weight gain strategies
    - produce fodder for on-station use
    - provide a feed buffer against dry seasonal conditions
    - better control genetic improvement
    - diversify the business through the sale of fodder.
- Challenges facing irrigation in the north include; new skills acquisition, remoteness, navigation of government approval processes (Section 1.3) and minimisation of environmental impact.
- The decision to invest in irrigation should be weighed against the opportunity cost of alternative investments that increase station productivity.
- Each irrigation development is unique and requires an investment plan tailored to the specific circumstances and realistic production assumptions. Economic modelling provides an insight into potential whole of station benefits and the key factors affecting profitability (Section 1.2).
- There are many decisions to be made including the site selection (Section 1.5), choice of plant species (Sections 3.1 to 3.7) and the production and feeding system (Section 1.1).

Agriculture in the WA rangelands has relied on extensive grazing of native vegetation, with isolated irrigation precincts at Carnarvon and on the Ord River near Kununurra. Recently, there has been considerable interest in mosaic agriculture* based on irrigated forages using

*Mosaic agriculture in the rangelands is about intensification of agriculture production in small pockets of the landscape.

groundwater or surface water resources in the west Kimberley and from mine de-water surplus in the Pilbara.

The area under irrigation (outside the Ord River precinct) has increased from about 600ha in 2006 to ~4,200ha in 2020 and continues to expand with a number of new developments being planned. The total area under irrigation will always remain a minor land use in spatial terms (currently less than 0.01%) as it is constrained by finite water resources. Despite this comparatively small area the benefits and economic impact of irrigated mosaic agriculture to the economy and the northern beef industry can be substantial.

Western Australia's rangelands contain multiple unique ecosystems with high environmental, economic, social and cultural values. The natural landscapes include distinct geology, hydrology, hydrogeology and landforms, and a range of vegetation communities, habitats and endemic flora and fauna. Some significant landscapes have been recognised at national and international levels and are World Heritage listed. Unique cultural heritage features throughout the rangelands which is integral to the lives of Traditional Owners (TO) as they continue customary responsibilities of looking after their country.

Given this context, and existing regulatory processes, irrigation developments must be both sustainable and minimise or mitigate any impact on environmental, cultural or social values. In addition, developments may require formal agreements with the TO which include social and/or economic benefits. This is best achieved through a co-operative approach between Traditional Owners and the agriculture sector, while keeping the community adequately informed.

Opportunities with irrigation

History tells us that the benefits of irrigated agriculture in northern Australia are not always easy to realise, but it does create opportunities for the pastoral cattle industry.

These opportunities include: the ability to market cattle when they are ready, access to alternate markets through a broader range of livestock (genetics, weight and condition), a suite of weight gain and herd management strategies, production of fodder for on-station use, protection against drought and reduced grazing pressure on the rangelands. There are also community benefits through alternate employment opportunities and broader economic benefits.

Irrigation enables the production of bulk fodder for pastoral operations such as mustering, yard work or for holding stock in preparation for transport. In these situations the feed quality is less important as the aim is to maintain stock in their existing condition. Self-supply avoids freight costs that can be considerable. The benefits are amplified following poor or failed wet seasons when the price of hay can increase substantially due to limited supply. However, the area required to replace hay purchased for on-station purposes is relatively small. For example a hay requirement of 250t would require only 10ha of production from a forage yielding 25t/ha.

- range of herd management strategies

When the irrigated pasture and fodder production is integrated into the pastoral enterprise the benefits can flow across the herd and are not confined to the animals grazing the pivots. Herd management strategies such as early weaning, increasing the pre-mating weight of maiden heifers or spike feeding heifers in their last trimester of pregnancy can have flow-on benefits for improved conception and reduced mortality across the herd (Section 1.2).

- range of weight gain strategies

Irrigation opens up a range of weight gain strategies; for example, feeding cattle to meet live export specifications in one year rather than holding them over for another year.

Irrigation enables pastoralists to strategically put weight on specific classes of cattle, primarily bringing steers and bulls to market weight. The flexibility of being able to feed cattle

to market requirements outside the traditional trading period could create an opportunity for forward selling contracts or a price premium. For example, the 'Darwin light steer' price index is consistently 10-20+% higher during the wet season compared with the dry season.

- a buffer against dry seasonal conditions,

Irrigated pasture or conserved fodder enables pastoralists to reduce the impact of dry seasons or droughts by maintaining the core breeding stock. Good feed budgeting means less pressure to sell cattle when market prices are low and conversely to purchase stock when prices increase post-drought.

- better control over genetic improvement.

Confining a selection of the breeding herd to irrigated pastures provides an opportunity to have greater control over genetic improvement. Introducing new genetics to animals in improved physical condition and in a controlled environment increases the likelihood of success in introducing improved traits. Irrigation also opens up the opportunity to select higher value breeds which require a higher level of nutrition.

- Diversify the business through the sale of fodder

Producing and selling fodder can be a core business or opportunistic when there is surplus fodder to the station's requirements or to take advantage of high prices.

In the future it may be possible to produce cash crops where the plant residues from processing may be used for feeding cattle. Potential crops such as cotton or peanuts are currently constrained by a lack of supporting infrastructure, the requirement for scale and/or distance from processing plants.

Irrigation can be used as a tool in any combination of the above strategies and pastoralists should evaluate the feasibility of each option according to their circumstances.

Challenges

Irrigated mosaic agriculture is a fledgling industry in northern WA and has faced a series of challenges. Some of these challenges were specific to a new industry, but others remain.

- Government approvals – at a minimum an irrigation development usually requires a water license, a clearing permit and a diversification permit (pastoral lease), but can be much more complex (e.g. Native title negotiation, EPA referral, flora and fauna surveys, Aboriginal Heritage surveys etc). The approvals process can be challenging, costly and time consuming – for a guide to the process refer to 'The approvals and regulatory framework', Section 1.2.

- Limited industry and specialist support – the combination of a new industry in a remote location spread over a broad geographic area creates a series of challenges including; access to and retaining skilled labour, agri-business support and specialist skills for agronomic and irrigation support.

Northern Australia is a challenging environment and has a history of ambitious, but ultimately failed development ventures.

Pioneering farmer Jack Fletcher with a line of tractors at Camballin in the early 1980s. The project was abandoned in 1983 after floodwaters destroyed infrastructure and crops.

- Environment – the climate in northern WA presents both opportunities and some unique challenges including tropical cyclones and the high incidence of extreme temperatures from October to April (refer to 'Understanding the climate, Section 1.3). In general the soils are highly leached and very low in most nutrients – refer to 'Understanding the soils', Section 1.4. In a mosaic agriculture context, seed predation by birds restricts the growing of many crops through to grain production, especially in the Kimberley. Insect pests such as locusts and armyworms are a seasonal challenge towards the end of the wet season.

Existing irrigators are keen to support new irrigation developments as they see the benefits to the beef industry as a whole. They want to share their experience so new irrigators can learn from the trial and error approach of early adopters.

For improved market access – a key message is that 'consistency of supply' is essential. A larger area of irrigation for pasture and fodder production can lengthen the supply period for beef from northern WA.

Opportunity cost

When considering any investment in irrigation it is important to compare alternative investment opportunities to increase station productivity.

Would these provide a better return on investment or be a lower risk? For example, before investing in irrigation ensure that basic animal husbandry has been addressed, such as wet season phosphorous (P) supplementation. Alternative investment opportunities include:

- supplementing with urea (dry season)
- herd segregation including weaner management
- additional water points and/or fencing to open up more country for grazing
- subdividing large paddocks to improve pasture utilisation
- improved genetics
- dryland improved pastures such as adding a legume to native pastures
- dryland cropping in higher rainfall areas

There are many factors to consider, the irrigation industry in northern WA is still a fledgling industry. Ask lots of questions – there is plenty of information available from DPIRD, existing irrigators and others in the industry. As with any new enterprise there is a learning curve, so experienced irrigators suggest the development budget should allow for 20 to 30% lower productivity over the first two years. Do all your sums first before starting to seek any licences or approvals (Section 1.3).

1.1 Farming system options

By Mosaic Agriculture team

Key messages

- An irrigation development creates the opportunity for an intensification of agricultural production and each system will have its own design requirements
- For beef production, a key question is whether to focus on a stand and graze (direct grazing) or a cut and carry system?
- The opportunity for broadacre cash crops is currently limited, while horticulture will most rely on individual businesses identifying market opportunities.
- When developing an investment plan ensure the production targets are realistic and explore the sensitivity of different cost and production scenarios on financial performance.

Investment by pastoral stations in irrigation infrastructure creates opportunities for the introduction of more productive crop and forage species to supplement rangeland grazing. Irrigated crops and pastures, either for stand and graze or fodder production, offer a means of improving the nutrition of cattle, especially during the long dry season when cattle often lose weight.

Irrigation systems can include sprinkler systems; either set sprinklers, centre pivots or lateral move systems; surface furrow irrigation systems and sub-surface or surface drip systems. Potential water sources include: surface water capture or an existing surface water system; shallow or deep unpressurised groundwater (requires pumping) and artesian or semi-artesian groundwater systems which generally do not require pumping (Section 2.1).

While there are a range of intensive farming systems, in this bulletin we focus primarily on:

(i) stand and graze, which is the direct grazing of irrigated pasture, often with some form of rotational grazing, and

(ii) cut and carry, which is based on the feeding of conserved fodder away from the area under irrigation (such as a feed-lot).

We refer to hay as the conservation of dry pasture (10-12% moisture); round bale silage, or baleage (also haylage) as the conservation of higher moisture content forage (40-50%

moisture) in plastic wrapped bales, often with the use of an ensiling inoculant, and pit silage as green chop (50-60% moisture) which is ensiled in pits or bunkers under tarpaulins.

Farming systems

(i) **Stand and graze** − the direct grazing of irrigated pasture, often with some form of rotational grazing, in practice usually a warm season perennial grass.

This is a common use and direct grazing is often considered to be more efficient than cutting and feeding animals, but this may not always be the case.

- The ‘sweet spot’ for high quality and good biomass is narrow and it is difficult to maintain the pasture consistently in or near this condition – when grazing is delayed the biomass increases rapidly, but the nutritive value declines (energy, protein).
- Pasture growth rates vary considerably between summer and winter. With good management pasture growth rates are consistently high from October to April. However, daily pasture growth rates change quickly especially at the beginning of winter and increase rapidly again with rising temperatures in August and September. Growth over winter will depend on the species and location.
- A realistic upper figure for pasture utilisation is about 50% for a well-managed system.
- Stock avoid grazing excreta patches, so the pasture regularly needs to be re-set to remove the effects of patch grazing by making hay or mulching (Section 4.2).

(ii) **Cut and carry** – involve harvesting the crop and feeding animals off-site, either in yards such as a feed-lot or paddocks. This could involve making hay, round bale silage (baleage) or pit silage.

An easier system to control as the feed is stored and used as required.

- A broader range of crops can be grown (Section 3.1), including sweet sorghum and maize for high quality silage (Section 3.3).
- Utilisation or feed efficiency is higher than for stand-and-graze with utilisation rates of at least 80% achievable.
- Better match of the crop-pasture to the growing conditions, especially for the inland zones where the growth of warm season grasses and tropical legumes is greatly reduced over winter.

There are some issues:

- Hay storage is a problem, so pit silage may be a better option.
- Greater investment in machinery and more usage results in higher maintenance costs.
- Feeding facilities with up to 500 head are permitted on pastoral lands, while feed-lots with more than 500 animals are regulated by DWER under the Environmental Protection Regulations Act 1987.

In general, producers move away from cut and carry systems as their area under irrigation increases for ease of management.

(iii) Fodder production for sale

Focusing on growing hay and/or baleage for sale is another option. Hay can be a valuable commodity in some years, but it is difficult and expensive to store in the medium-term and the price is volatile as the market is relatively small and easily saturated.

Silage is a good alternative for a cut and carry system, but is difficult to transport.

(iv) **Broadacre cropping** – growing of a cash crop where the by-products may or may not be useful for feeding cattle. Examples include: peanuts, cotton, grain sorghum, mung beans

There is currently limited potential for industrial crops like cotton or broadacre crops like peanuts due to the lack of local processing facilities. As a consequence the long distance and associated costs in transporting to the nearest processing plant are prohibitive. For a processing plant to be viable it requires scale and continuity of supply. In addition, most crops will need to be grown as part of a crop rotation, which substantially increases the area of irrigated land required and there needs to be a market for the other crops in the rotation.

(v) **Horticulture** – high value horticultural crops are attractive

Currently limited in scale, with small-scale horticulture away from the irrigation precincts at Carnarvon and on the Ord River near Kununurra. Requires specialised skills and for many crops access to a labour pool. Horticultural developments will rely on individual businesses identifying market opportunities.

A key question is whether to focus on a stand and graze (direct grazing) or a cut and carry system? There is not one size that fits all and the decision depends on the specific context.

In practical terms, many irrigators incorporate a combination of farming systems. For example, with stand and graze there is still a need to reset the pasture – therefore the ability to cut hay, and most producers would also want to grow their own hay for general on-station use, rather than purchase hay. Producers may also sell hay in excess of requirements and when market conditions are favourable, may opportunistically make additional hay for sale to take advantage of the high prices.

There is growing interest in highly intensive systems that may dramatically reduce water usage (section 2.1), operating costs and increase the production of beef.

For example, a single high yielding maize silage crop which produces 25t DM/ha grown over the dry season from May to September could conceivably result in 4000kg LWG per ha fed to 200kg steers.

> 1ha @ 25t DM/ha = 25t utilised at 80% efficiency = 20t consumed at a feed intake of 2.5% LW = 5kg per day per head (200kg steers) = 1kg LWG, could generate 4000kg LWG per ha @ $3kg =$12,000/ha

Perennial grasses are usually grown as a monoculture or as a mixture and are expected to persist for at least 4-5 years. However, with the annual pasture and crop options how they are integrated together in time (within and between years) is important. For example, the annual warm season (C4) grasses like hybrid sorghum, millet and maize are typically utilised over a 3-8 month period, often in an annual rotation sequence (Figure 1). The annual tropical legumes can possibly be utilised as a high protein source or as a green manure crop in the rotation.

Planning and expected production

Each irrigation development is unique in terms of scale, water supply and quality, site factors (soils, environment) as well as the proponent's financial and personal circumstances, so it is important to develop a specific investment plan. Economic modelling in this bulletin provides an insight as to potential whole of station benefits and the key factors affecting profitability (Section 1.2).

Figure 1. Conceptual integration of irrigated forage options in northern WA with potential sowing time(s) 'S' for the coastal agro-climatic zones (section 1.4). Lighter shaded areas represent periods of lower productivity. H is harvest time for fodder or grain.

Plant type / crop	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Warm season (C4) annual grass (forage sorghum)	S	S	S					S				
Temperate cereal (forage oats, barley)			H								→S	S←
Maize									S	S	S	
Temperate perennial legume (lucerne)											→S	S
Tropical annual legume*			S	S				S				
Warm season (C4) perennial grass** Permanent pasture		S	S					S	S	S		

*tropical legume (cowpea, lablab, centro); **Rhodes grass, panic grass

When developing an investment plan there is usually an overall target for production. Expected production is usually considered either in terms of kilograms (kg) of beef per ha per year, or tonnes (t) of hay per ha per year.

Production targets need to be realistic.

(i) Fodder (hay) production

As a guide a well-managed hay enterprise growing a warm season (C4) perennial grass like Rhodes grass has a potential yield of 30-35t dry matter (DM) per ha per annum. Variables with fodder production include:

- Nutrient status. Grasses are highly responsive to N fertiliser up to very high levels and increasing the fertiliser N will increase both overall production and the level of crude protein. Other nutrients such as phosphorus (P) and potassium (K) also need to be maintained (refer to Section 3.2 for nutrient guidelines).
- Quality versus quantity. There is a trade-off between feed quality and quantity. When producing bulk hay for station purposes expect high yields but lower feed quality. This hay is typically cut late to maximise yield and has a lower proportion of leaf to stem.
- Location. Allow for periods of no or slow growth due to cooler temperatures over winter – this varies with the location from a slow-down in growth over June to July in coastal zones to minimal production for 3-4 months in the Low rainfall – inland elevated zone (refer to Section 1.4 for a map of the agro-climatic zones).

(ii) Stand and graze

As a guide a well-managed perennial C4 grass pasture under direct grazing is likely to produce about 25-30t/ha DM and with rotational grazing 50% pasture utilisation is achievable. Therefore, assuming a feed conversion of 10:1 (typical of grass pastures) this would result in annual production of 1250-1500kg/ha beef.

Numerous grazing studies in both northern Australia and from other regions with a similar climate show that when cattle graze a well-managed tropical grass pasture the average liveweight gain in the medium-term is unlikely to exceed 0.7kg per head per day (Section 4.1).

Key skills for irrigation developments include:

- Mechanical skills; the remote location of many stations means that getting a mechanic to fix breakdowns is both time consuming and costly, particularly with specialist equipment.
- Grazing management skills for stand and graze operations.
- Irrigation management skills to ensure efficient use of resources.
- Agronomic and farming skills with experience in crop and pasture production is valuable.

Experienced irrigators suggest the development budget should allow for 20-30% lower productivity over the first two years, while the system is fine-tuned.

System design considerations

Table 1. System design considerations

Design consideration	Comments
Irrigation system	
Depth to groundwater	Apart from artesian water supplies, the cost of pumping water is a major operating cost and profitability is closely linked to the depth to groundwater.
System capacity	The recommendation is for a minimum system capacity of 13mm of irrigation per hectare in 24 hours, which requires a minimum flow rate off 1.5 litres of water per second per hectare (refer to Irrigation management, Section 2.2).
Power supply – diesel or solar	Solar-powered irrigation systems are limited to pumping during daylight hours, so may not satisfy the minimum system capacity during peak demand. Therefore a hybrid system of solar and diesel may be required to meet a minimum system capacity. Adequate protection against lightening is essential.
Fertigation	The fertigation tank must hold sufficient fertiliser and water to meet the required fertiliser rate of the crop. Fertilisers can be corrosive and reduce the operational life of a centre pivot. Consideration of materials used in the construction of the centre pivot during the design phase can reduce these effects. Not all fertilisers are soluble in water, so a tractor powered fertiliser spreader is recommended in most farming operations.
Infrastructure for stand and graze	
Number of cells within a centre pivot	There is a trend to reduce the number of cells a centre pivot is sub-divided into using permanent fencing to two or four – partly due to the high cost of fencing, but also the difficulty with operations like topdressing and cutting hay in narrow spaces.
Location of water troughs	With the first centre pivots established for direct grazing the troughs were placed in the centre of the pivot with access from each cell. However, some troughs are now being placed on the outside of the pivot.

Whether to include native vegetation within fenced area	A common practice is to include an area of native vegetation when fencing around a centre pivot. Stock will preferentially camp in these areas.
Ability to remove all stock off pivots	This is advantageous when faced with challenges such as locusts where it is preferable to spray the entire irrigated area. This would require access to a relatively small paddock of native vegetation adjacent to the irrigation area where stock could be held.
Laneways for movement of stock and machinery between centre pivots and to yards	Ensure the width of laneways is adequate for moving all machinery. All weather access is desirable.
Infrastructure for cut and carry	
Fencing	Keep fencing to a minimum to reduce costs and minimise obstruction to machinery operation. However a fence around the centre pivot allows for opportunistic grazing.
New or second-hand machinery	For smaller developments, desktop modelling has shown that profitability is sensitive to machinery costs (Section 1.2). Specialist equipment is required for silage and baleage at higher moisture contents in the wet season (e.g. plastic wrap).
Feeding facility	Shade if feeding over summer to reduce heat stress. Commercial experience has highlighted difficulty with feeding out on grazed pastures due to poor pasture utilisation. A tractor powered feed mix wagon is required. Need to be aware of regulatory requirements governing the construction of feeding facilities and feedlots.
Other points	Storage of fodder, a hay shed is recommended to prevent hay spoilage over the wet season. If making silage a pit is required, if making baleage a wrapper is required.

1.2 Economics of small-scale irrigation

Clinton Revell, Renata Tognelli, Chris Ham, Sam Crouch

Key Messages

- Small-scale irrigation developments (30-50ha) can be profitable, however, investment decisions should be made carefully given the high sensitivity to feed quality, sale price of steers, hay yield and discount rate.
- Modelling suggests one of the more profitable scenarios is early weaning of calves and feeding them in a cut and carry system with high quality irrigated hay. This allows breeders to recover body condition earlier and thereby improve conception rates and reduce mortality rates.
- An example single 40ha irrigation enterprise (centre pivot) in the Pilbara was estimated to cost in the order of $1M to become fully operational and the payback time ranged from 7 to 13 years depending on the cattle management scenario.
- Intensive management through high nitrogen and phosphorus inputs can substantially lift the productivity of Rhodes grass and improve financial returns, but variable costs are high and the system requires constant and consistent management with staff skilled in farming operations.
- Development and production costs will vary considerably according to the location, water source and scale of operation and it is important to work through these specifically for each individual business.
- While not considered in this analysis, direct grazing (stand and graze) of irrigated pastures is likely to involve larger scale developments of 80-160ha and with the pivot being a terminal location for finishing animals.

Irrigated forage production provides a significant opportunity to transform beef production systems of northern WA, but there are substantial development costs. This section describes the economic evaluation of small-scale pivot irrigation developments in the Pilbara region through the use of some economic models. This builds on earlier analysis by CSIRO at national and catchment scale levels using simulation modelling of plant growth and herd dynamics. A key feature of this analysis was to integrate the production of forage into the whole-of-station cattle operation.

Method

The modelling framework considered pivot irrigation investment, cost of pasture production, hay making and labour in a cut and carry system based on either a Rhodes grass perennial pasture or a rotation of annual forage sorghum and legume crops. Breedcow and Dynama herd budgeting software (Department of Agriculture and Fisheries Queensland, DAFQ) were then used to evaluate a series of beef cattle management scenarios.

The base model is built around a hypothetical beef cattle enterprise located in the low rainfall coastal zone of the Pilbara. It is a 350,000ha holding with a self-replacing herd (5070 Adult Equivalents, AE) of Brahman-cross breeding cows (3,333 breeders) grazing native pastures with an average stocking rate of 50ha/AE. Base assumptions were a weaning rate (weaners per total breeders mated) of 56%, 10% for average breeder mortality (7% for breeders 3-7yrs old) and a station hay requirement of 136t dry matter (DM) per year (152t hay @ 12% moisture).

The irrigation development costs for a single 40ha pivot pumping water with a total dynamic head of 60m are summarised in Table 1, while the production and feed quality assumptions are shown in Table 2. An existing feeding facility was assumed with no additional infrastructure costs.

Table 1. Indicative development costs for a 40ha pivot.

Operations	Description	Costs ($'000)
Site selection		2
Consultants	Hydrology, flora & fauna surveys etc.	100
Land clearing	45ha	68
Fencing		8
Irrigation	Production bore	90
	Monitoring bore	20
	Pump and head works	80
	Pivot (40ha)	150
	Pipes, fertigation & installation	35
Purchased machinery[1.]	Tractor	70
	Cultivator, seeder, sprayer, spreader	50
	Hay - mower, rake, baler	70
	Trailer, load-all	90
Other infrastructure	Shed, workshop, washdown pad	60
Capitalised interest[2.]	7% (bank interest + risk premium)	359
Total		**1,252**

[1.] Purchased machinery is second-hand
[2.] Interest repaid over 5 years, but capitalised as an upfront cost.

Cattle management scenarios included:

(i) early weaning, where 50% of weaners were intensively fed from 120kg liveweight to 200kg, with associated herd benefits of a 12% increase in conception rate and a 2% decline in average mortality of all breeders (the change in conception rate of breeders to 7yrs old was 70 to 82%, except for 3yr old animals, which was 43 to 55%).

(ii) heifer supplementation, where 50% of first and second year heifers were fed to increase liveweight by an average of 55kg, with an associated 12% and 25% increase in conception rates for first and second year heifers (70 to 82% and 43 to 68% respectively) and a 2% decline in their mortality (8 to 6% and 7 to 5% respectively).

(iii) rapid turn-off of steers, where 60% of steers were fed to reach sale weight (360kg) in 15 months instead of being held over until 24 months.

Table 2. Production and feed quality assumptions for each ‘cut and carry’ forage production system.

Parameters	Unit	Strategy 1	Strategy 2	Strategy 3[1]	
		Rhodes grass	High Production[2] Rhodes grass	Annual Sorghum	Tropical legume
Growing period		perennial	perennial	6-7 months	5 months
Annual dry matter produced	t/ha	33.6	44.4	20.4	8.4
Dry matter harvested	t/ha	28	37	17	7
Number of cuts/year		7	10	3	2
Irrigation required	ML/ha	16	18	9	7
Variable costs[3]	$/ha/yr	5,285	8,040	3,111	1,759
Metabolisable energy	MJ/kg DM	8.5	9	9.5	10.5
DM digestibility	%	56	62	64	70
Crude protein	%	10	11	14	20

1. Strategy is a rotation with annual sorghum over the wet season and a tropical legume (lablab) in the dry season. Alternatively, a more tropical legume such as centro could be grown in the wet season and sorghum (or maize) in the dry season.

2. High production package with additional N,P,K fertiliser

3. Seed and fertiliser, weed/pest control, hay-making, irrigation/water costs

The herd model endeavours to keep a constant total AE for the business over time. Farm enterprise budgets were developed to capture both cash inflows (benefits) and outflows (costs) in order to compute gross margins and net farm incomes. A discounted cash flow approach over 15 years was used to calculate net present value (NPV), internal rate of return (IRR) and benefit cost ratio (BCR) of each production scenario. Sensitivity analyses were conducted to test the robustness of the investment to variable factors such as liveweight sale price of steers, hay yield and discount rate.

Machinery costs are a key factor affecting the profitability of small-scale developments

Key outcomes

This analysis suggests that beef enterprises can benefit from an investment in irrigation but only if high yielding and high quality pastures are produced and if the investors are patient, since there is a substantial lag period to break-even. Maximum benefit to the overall business is achieved when the irrigation development is fully integrated into the cattle production system rather than operating solely for the purpose of selling hay. The most profitable scenario is early weaning of calves (Table 3) and feeding them with high quality irrigated pastures to allow breeders to recover body condition more rapidly. This leads to an improvement in conception rates and reduced mortality rates, resulting in a more efficient herd structure.

All irrigated forage strategies produced sufficient fodder to meet the requirements of the three cattle management scenarios, together with the station's hay requirement for mustering and sale cattle. Excess fodder for sale was also available in all strategies.

The forage options of sorghum plus legume and the high production package for Rhodes grass under the three cattle scenarios raised the profitability of the enterprise above that of the base case both in terms of annual gross margin and annual net profit (Table 3). In contrast, the standard Rhodes grass option only increased the profitability of the business when combined with the early weaning scenario.

Table 3. Simulation results for base case and three cattle management scenarios; early weaning, heifer supplementation and rapid turn-off of steers, under three irrigated pasture systems; standard Rhodes grass (RG), high production Rhodes grass package (HPRG) and forage sorghum and legume rotation (S+L).

Financial indicators	Base Case	Early weaning			Heifer Supplement			Rapid turn-off steers		
		RG	HPRG	S+L	RG	HPRG	S+L	RG	HPRG	S+L
Gross margin for herd ($'000)	822	883	961	965	778	887	902	783	888	901
Gross margin/AE	162	174	190	190	153	175	178	154	175	178
Net profit ($'000)	60	121	199	204	16	125	141	21	126	140
Meat produced (t)	513	579	579	579	551	551	551	558	558	558
Cost per kg meat	2.27	2.29	2.48	2.25	2.45	2.64	2.41	2.43	2.61	2.38
Net Present Value ($'000)	606	237	951	992	-1,012	-18	124	-951	2	126
Benefit Cost Ratio		1.02	1.07	1.08	0.93	1.00	1.01	0.93	1.00	1.01
Internal Rate of Return		9.7	17.0	17.4	-8.6	6.8	8.5	-7.4	7.0	8.5
LWG (kg/hd/d)		0.42	0.56	0.71	0.33	0.52	0.88	0.35	0.54	0.9
Intake (kg/hd/d)		4.0	4.2	4.0	6.2	6.7	7.6	5.9	6.4	7.3
Days on feed		190	144	113	165	110	66	226	149	89

The advantage of the sorghum plus legume strategy is the higher nutritional value of the feed, which leads to a lower amount of feed required for achieving the same animal weight gain objective relative to Rhodes grass (Table 3). The main advantage of the high production Rhodes grass package is the higher yield. Consequently, there was a higher quantity of excess forage sold off-station (alternatively, a larger herd size could be sustained).

The analyses highlight the importance of the capital cost of development and the long payback time required, between 6 to 14 years depending on the cattle management scenario (Figure 1). Investment decisions should be made carefully as the financial returns are highly sensitivity to feed quality, liveweight sale price of steers and hay yield. Management needs to optimise these key profit drivers and this is likely to require additional investment in skills development for irrigation scheduling and pasture agronomy.

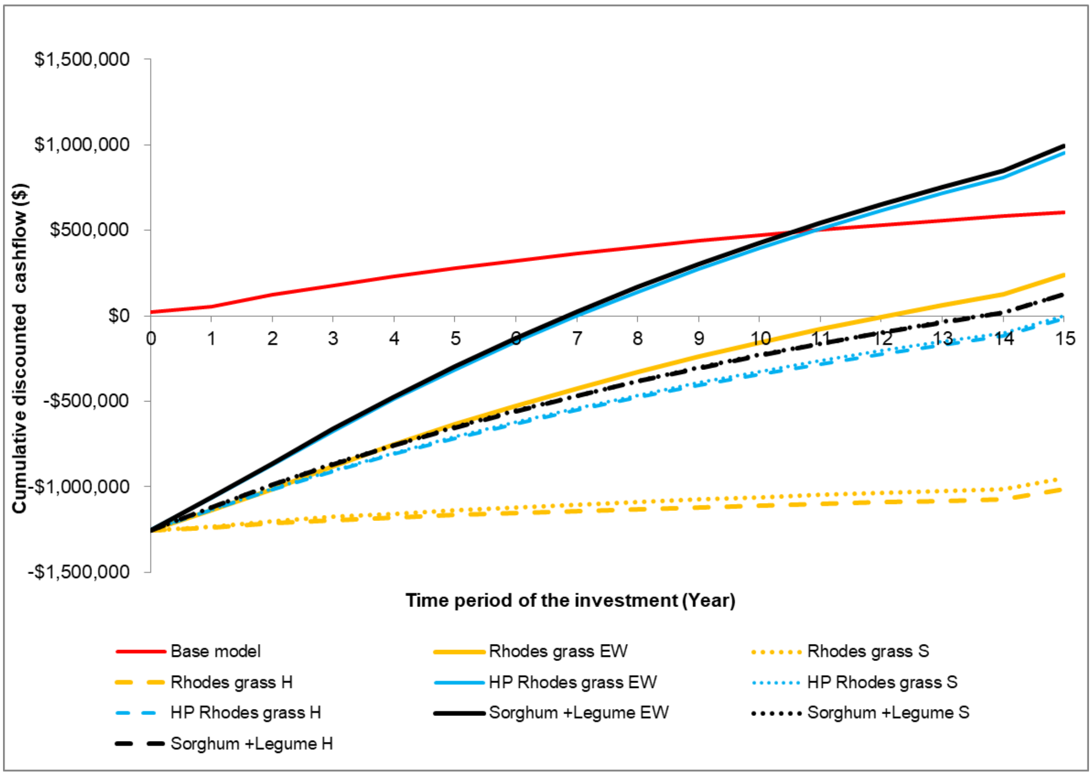


Figure 1. Cumulative discounted cash flow ($) for the base model (without irrigation) and irrigated forages: Rhodes grass, High production (HP) Rhodes grass package and sorghum plus legume under three cattle management scenarios; early weaning (EW), heifer supplementation (H) and rapid turn-off of steers (S) over the fifteen-year investment period. Discount rate = 7%.

This analysis was based on the assumption of purchasing second hand machinery to keep costs low, which reduced the initial development costs of the investment by approximately 25%. This runs the risk of higher maintenance costs and machinery break-down but the option of buying new machinery would likely require the irrigation investment to be scaled-up for effective utilisation of the machinery asset. Consider machinery costs carefully as accurate timing of cropping operations requires reliable machinery and skilled operators. While hay is the basic product for cut and carry systems, the production of plastic wrap baleage (at higher moisture content) and specialist silage crops (such as sorghum or maize) are options to produce a product with higher nutritional value. These options require specialist equipment and labour at additional cost and this may actually outweigh the benefit in feeding value. However, these systems provide flexibility, as they are better for fodder conservation during the wet season when hay can be difficult to dry.

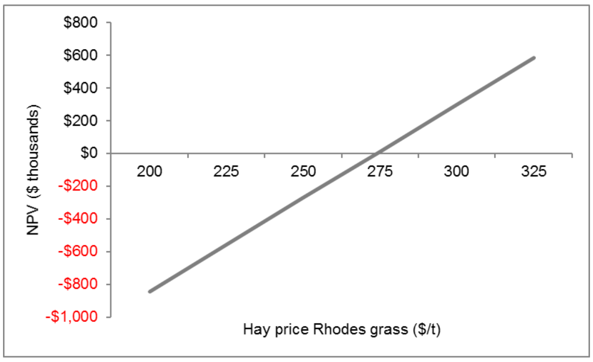
Sensitivity analysis and profit drivers

Hay yield and price

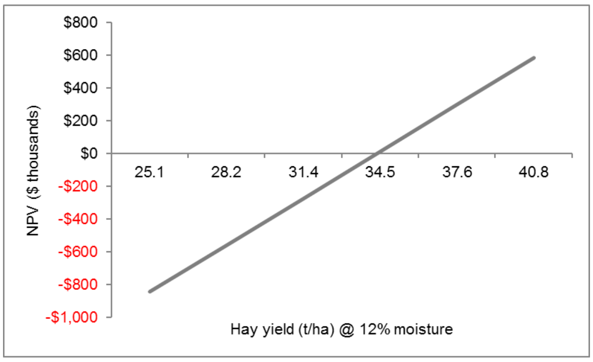
For a hay-only production scenario, sensitivity analysis (Figure 2) suggests that for the investment to be profitable, the hay price should be higher than $275/t for Rhodes grass (both production systems), $315/t for the legume and $294/t for sorghum.

Hay yield needs to be more than 30t DM/ha (35 t/ha @12% moisture) for the standard Rhodes grass system, 33t DM/ha (38t/ha @ 12% moisture) for the high production Rhodes grass package, 7.5t DM/ha for the legume and 18t DM/ha for sorghum (8t/ha and 20t/ha @ 12% moisture).

(i) Standard Rhodes grass

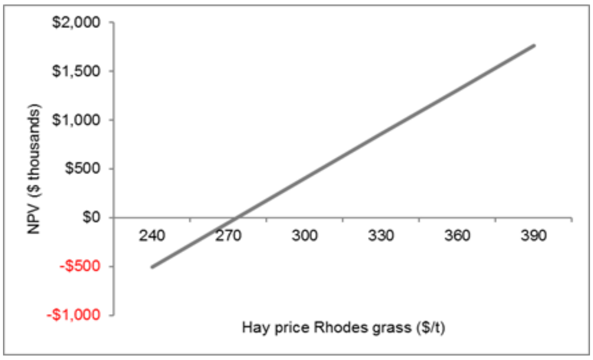


(a) Hay price

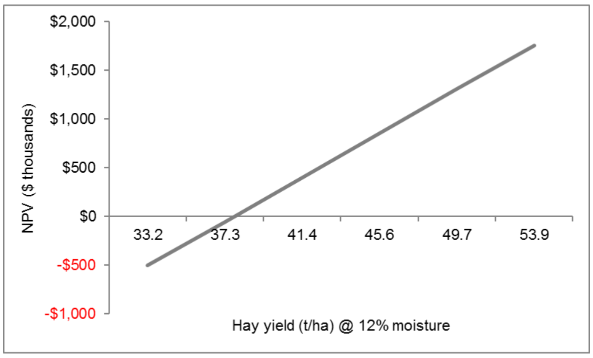


(b) Hay yield

(ii) High production Rhodes grass

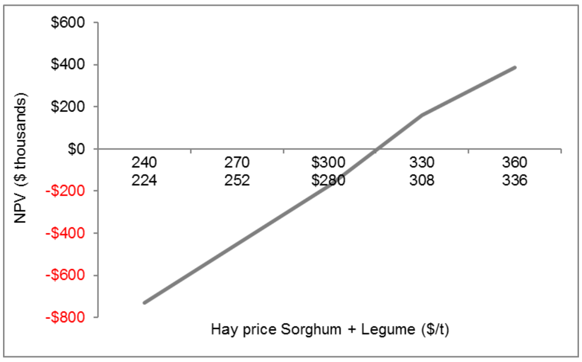


(a) Hay price

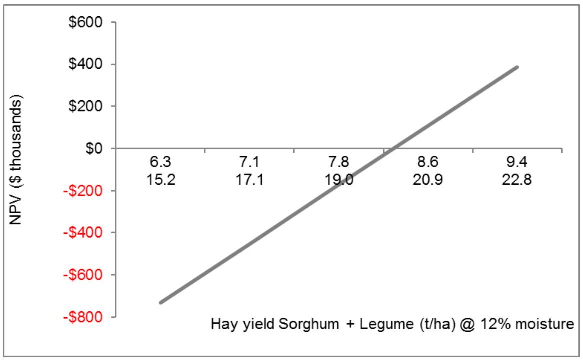


(b) Hay yield

(iii) Sorghum plus legume



(a) Hay price



(b) Hay yield

Figure 2. Sensitivity of Net Present Value (NPV $'000) with changes in (a) hay price and (b) hay yield (@ 12% moisture) for irrigated forage production all sold as hay for (i) standard Rhodes grass, (ii) high production Rhodes grass and (iii) sorghum plus legume systems.

For the cattle scenarios, early weaning is still profitable if production of the sorghum and legume option remains above 16t DM/ha (combined), but needs to be above 22t DM/ha (combined) for the heifer and steer scenarios to break-even.

Any reduction in yield in the high production Rhodes grass package makes the heifer and steer scenarios unprofitable, while the break-even yield for the early weaning scenario is 30t DM/ha (a decline of 20% from the base assumption of 37t DM/ha).

Liveweight sale price

The results suggest that the irrigation investment is very sensitive to changes in liveweight sale price. A 13% decrease in steer price from the standard $3/kg to $2.60/kg would make even the early weaning scenario unprofitable (Figure 3). The future pricing environment is a risk analysis producers must undertake but making a projection about the way in which beef cattle prices will fluctuate is very difficult since it depends on global production and substitution by other types of meat.

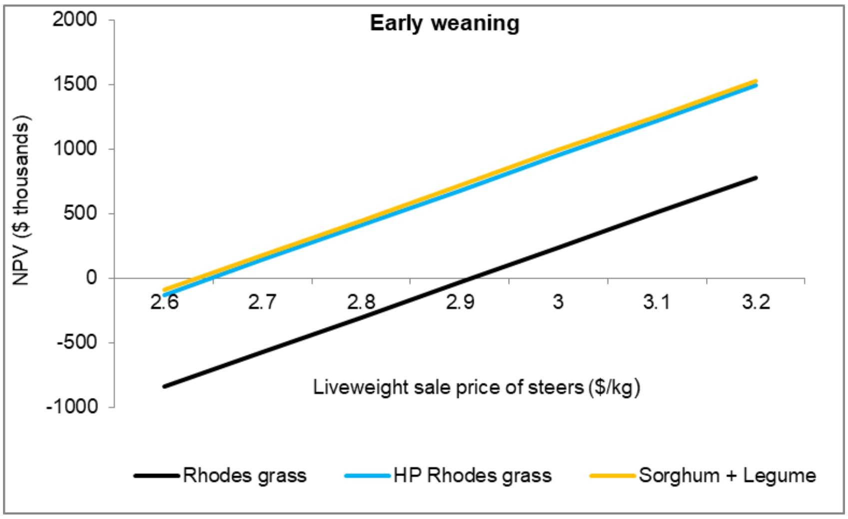


Figure 3. Sensitivity of Net Present Value (NPV $'000) with changes in liveweight sale price ($/kg) for early weaning cattle management with (i) standard Rhodes grass, (ii) high production Rhodes grass and (iii) sorghum plus legume systems.

Water costs

Water pumping cost is another key variable within the annual operating costs of an irrigation development that affects profitability. In this analysis, water was costed at $84/ML. If this cost was 33% lower (such as extraction from shallower depths or lower pumping heads) then heifer supplementation and steer turn-off scenarios become profitable for the high quality feed options, but not for the standard Rhodes grass package. Some parts of the Pilbara region have the advantage of pressurised artesian water, which has reduced, or incur no pumping costs, but this water is generally accessed from much greater depths and incurs higher development costs.

Select your site carefully to keep pumping costs to a minimum. As a guide, $100/ML is an upper threshold for fodder cropping.

Discount rate

The investment would break even with a discount rate of 4% for standard Rhodes grass, 5% for sorghum plus legume and 12% for the high production Rhodes grass package. The financial returns from the sale of hay in the high production Rhodes grass package appear quite favourable, but would increase the level of risk exposure to higher input costs and loss of production from extreme events such as cyclones, pest outbreaks (e.g. locusts) or untimely equipment/machinery breakdown.

Other considerations

The simulation of the base case model assumes average performance over time and does not take into account extreme climate events such as drought where producers may be forced to destock and then be faced with having to rebuild the herd over several years. If the irrigation enterprise can mitigate the effect of drought (at least in part) it becomes part of a risk management strategy and may effectively help to shorten the payback period of the investment.

Economies of scale are likely to apply that will improve the feasibility of the investment. Running an analysis with a 80ha irrigation development (2 pivots) and an 8500 AE herd size (10,900 head), with the same machinery costs reduces the payback period from 6-7 years to 4-5 years for the most profitable scenarios and lowers break-even targets for the liveweight sale price, hay yield and hay price. For example, a sale price of $2.30/kg would still be profitable for most livestock scenarios with sorghum/legume and high production Rhodes grass. Dry matter yields above 26t/ha with high production Rhodes grass would be profitable for heifer and steer scenarios and could be as low as 20t/ha for the early weaning scenario.

It is possible that high energy supplements such as molasses can be added to improve the feed quality of Rhodes grass hay and improve animal growth rates. This needs to be separately costed (Section 2.4).

While not considered in this analysis, direct grazing (stand and graze) of irrigated pastures is likely to involve larger scale developments of 80-160ha and with the pivot being a terminal location for finishing animals.

The value of irrigation also needs to be assessed against the opportunity costs of other proposed development strategies such as the adoption of grazing management strategies integrating additional fencing and water points and the development of an integrated supply chain involving cattle breeding in the rangelands and backgrounding and finishing in southern regions of WA.

It is important to recognise that development and production costs will vary considerably according to the location and scale of operation, so it is important to work through these specifically for each individual business. These intensive production systems also require access to skilled labour with agricultural knowledge all year-round.

Further information:

Holmes W, Chudleigh F and Simpson G. (2017) Breedcow and Dynama herd budgeting software package. A manual of budgeting procedures for extensive beef herds. Department of Agriculture and Fisheries, Brisbane, Qld.

MacLeod ND, Mayberry DE, Revell C, Bell LW and Prestwidge DB (2018) An exploratory analysis of the scope for dispersed small-scale irrigation developments to enhance the productivity of northern beef cattle enterprises. The Rangeland Journal. https://doi.org/10.1071/RJ18026 (published online 22 August 2018).

1.3 Pre-feasibility and project approvals

Christopher Ham

Key Messages

- Managing regulatory requirements can be complex, costly and time consuming.
- Preparation is critical before submitting development applications.
- Setting out a regulatory action plan can be helpful.
- Include a budget for approvals in the development budget.
- Guiding documents are available.
- Assistance is available through PLB, DPIRD and DWER.

Background

Land tenure in northern WA differs somewhat from other areas used for agriculture. As apart from the irrigation precincts at Carnarvon and on the Ord River near Kununurra the vast majority of the land used for agriculture is under pastoral lease, with small pockets of freehold and special lease. In addition, irrespective of land tenure there has been minimal land cleared for agricultural activities, with the land predominantly used for the grazing of native vegetation. This contrasts with the Northern Territory and north Queensland where there are extensive areas of improved dryland pastures.

As a result of land tenure and current land use – irrigated mosaic agriculture proposals in northern WA usually require both a diversification permit and a permit to clear native vegetation in addition to the approvals which are required across all forms of tenure.

Agricultural projects on pastoral leases are evolving in increasing scale and complexity and the regulatory environment is subject to change. We recommend that proponents conduct a thorough pre-feasibility assessment first, including consultation with government development officers and regulators. As each proposal is unique, the approval pathway will vary according to the circumstances. Feedback from pastoralists who have gone through the permit process is that the length of time and expense involved should not be under-estimated.

The purpose of this paper is to provide guidance on where to start and some useful references and contact points to seek further information. The information provided is a simplified description of the approval process. DPIRD has set up a web portal for proponents to access advice prior to submitting a proposal 'click on the link' http://www.waopenforbusiness.wa.gov.au/Contact-Us.

Managing regulation is a significant component of project cost and effort. It will take time, regardless of the scale, location or tenure of a project. Approvals typically take from 8 months to 2 years for straightforward proposals and can be much longer for more complex tenure changes. Based on recent projects, the cost can range from $200K to $1M+ for large-scale projects.

Presenting a sound proposal from the outset is most important, as there is little scope to amend applications midway through the assessment process. If amendments are required they often create confusion and are likely to substantially increase the complexity and cost.

The first step is to map out the steps involved in conducting a pre-feasibility assessment. Figure 1 provides an overview of the planning process and the typical issues faced by most proponents. The key message in this diagram is to begin with the end in mind and consider a range of issues that typically arise throughout the process.

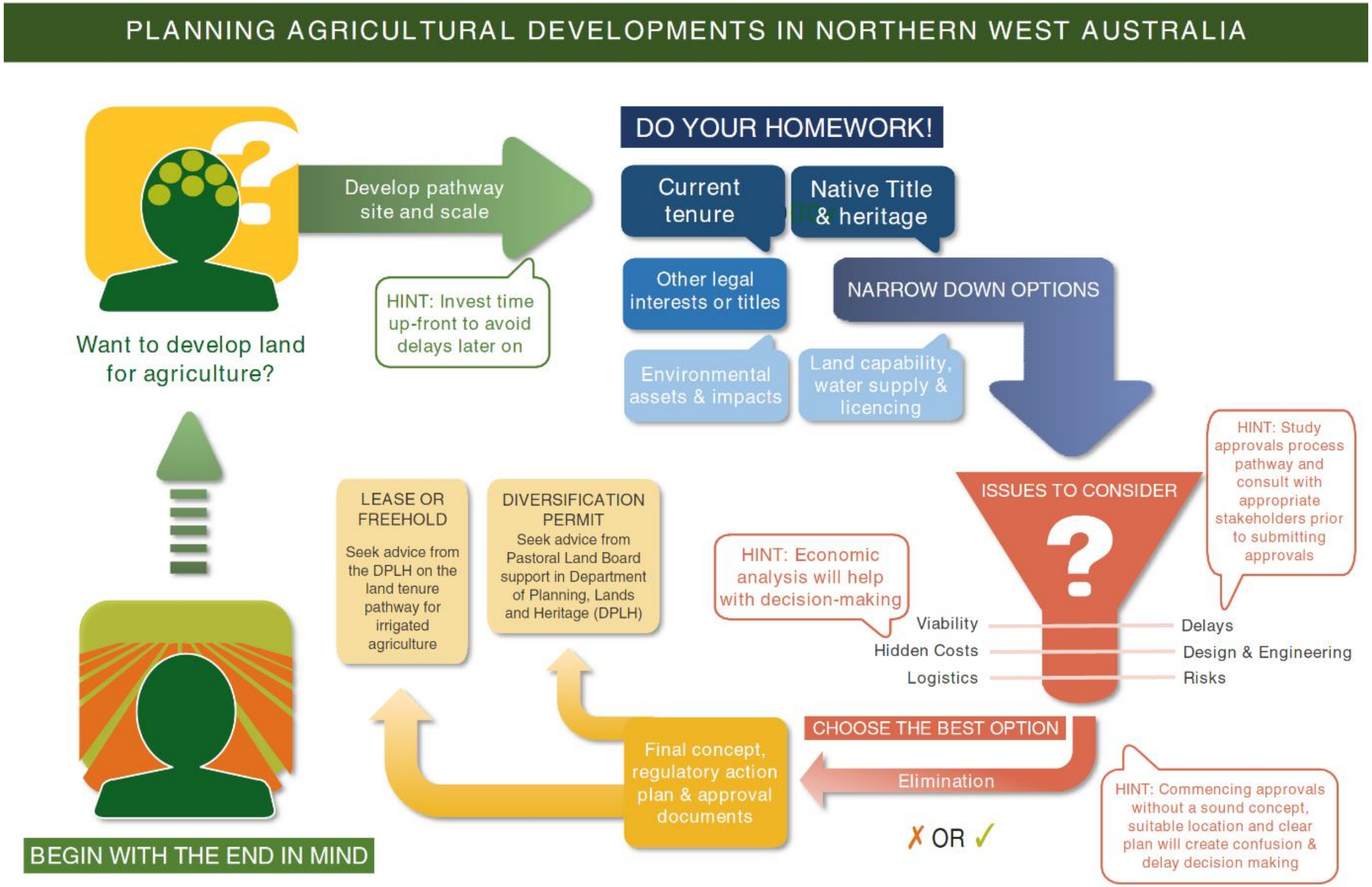


Figure 1. Prefeasibility flow chart.

Key steps prior to submitting a proposal include; assessing land capability, hydrogeological investigations, environmental requirements, mapping all legal interests in the area, and engaging with Traditional Owners, key stakeholders and local, state and federal regulators. Business planning, economic pre-feasibility and a regulatory action plan are strongly recommended, but not compulsory in most cases.

In most circumstances there are two possible approval pathways, pastoral diversification or a change of tenure, such as the land tenure pathway for irrigated agriculture. See Land Tenure Pathway for Irrigated Agriculture on page (X)

If the most appropriate pathway is pastoral diversification then several permits or licences are required under legislation; that is, at a bare minimum, the approval to diversify, clear land and use water for irrigated agriculture.

Pastoral Diversification

- The first step is to contact the Pastoral Lands Board (PLB) support staff and discuss your proposal to determine if you require a diversification permit under section 119 or 120 of the *Land Administration Act.* The PLB staff have set up an email address for this purpose proposals@dplh.wa.gov.au.
- The Non-Indigenous Plant (NIP) policy applies to all diversification permits and is an important aspect that proponents need to understand. Pastoral leases differ from other forms of tenure in that lessees may only sow or cultivate non-indigenous plants (i.e. plant species not native to WA) in accordance with a diversification permit issued by the PLB. Some plants permitted into Western Australia may not be approved for use on a pastoral diversification permit due to the application of the NIP policy guidelines.
- The PLB is not able to issue a general list of approved species because the *Land Administration Act* requires that the PLB approve non-indigenous plants on a case-by-case basis. Under the guidelines of the policy each permit is referred to DPIRD to provide an assessment of the risk of the species becoming a weed of the natural environment. The assessments are provided at a regional scale and can differ from region to region for the same species. The assessments are available online at: https://www.agric.wa.gov.au/rangelands/environmental-weed-risk-assessments
- Diversification permits cannot be amended to include additional species. Therefore, when applying for a diversification permit, the application should list all the species that may be considered in the future.

Water licences

- The Department of Water and Environmental Regulation (DWER) has a 'one stop shop' which can advise on clearing and water licencing requirements.
- Water licences are often staged to allow the knowledge of the water source to be developed. Licences are required for approval to drill, for hydrogeological modelling, pump testing and an operating strategy as well as annual monitoring. These will require the services of a qualified and experienced hydrogeologist.

Land clearing

A permit is required to clear more than 5ha of native vegetation, so will be required for any irrigation developments except where the land is already clear of native vegetation or was previously cleared within the last 20 years. The application will be assessed by DWER who will also request specialist advice from the Commissioner of Soil and Land Conservation (DPIRD) and Department of Biodiversity, Conservation and Attractions (DBCA).

Applications for clearing permits can include a wider area, which will allow some flexibility when selecting the final site to clear and develop. The best way to describe this is to nominate an amount of clearing within a broader envelope of land. It is likely that a flora and fauna survey will be requested before a clearing permit can be approved. This will require the services of a qualified and experienced environmental consultant. The survey will be assessed by the DBCA and needs to be carried out to their standards (http://www.epa.wa.gov.au/policies-guidance/technical-guidance-flora-and-vegetation-surveys-environmental-impact-assessment).

Other approvals

- Local government development approvals will most likely be required.
- The *Native Title Act* 1993 and *Aboriginal Heritage Act* 1972 obligations will apply, however the proponent will be responsible for managing their obligations under these acts, through formal and informal processes.

Permits apply only to the pastoral lessee. They are not registerable or transferable to a third party, nor are they automatically transferred to the new lessee on sale of the property, although the PLB does have discretion to allow a streamlined process to transfer the permit on sale of the property and thus allow the business to continue without disruption.

Useful references and contacts:

Pastoral purposes framework:

If your project is on pastoral land then the Pastoral Lands Board (PLB) should be the first point of contact. They have published the Pastoral Purposes Framework to guide proponents and pastoralists through a range of scenarios and commonly asked questions. The guide includes a table of typical developments and the approvals required from the PLB and other agencies.

URL: https://www.dplh.wa.gov.au/information-and-services/pastoral-land/diversification

Contact PLB support staff: https://www.dplh.wa.gov.au/contact-us

Investment Ready Regulation Pathways for Agricultural Projects:

This document describes the range of approvals that you might be required to obtain for an agricultural intensification project on various land tenures, under regulations as at January 2018. While the full suite of possible approvals required is considered, each project is different and not all approvals will be relevant for each project.

There are two sections to this document. The first describes the approvals pathways as specified in the relevant legislation. The second shows the approvals required and the procedural steps that are most likely to be followed.

URL: http://www.waopenforbusiness.wa.gov.au/How-can-we-help/Regulatory-Pathways-Guide

Contact DPIRD staff: http://www.waopenforbusiness.wa.gov.au/Contact-Us

Land Tenure Pathway for Irrigated Agriculture

The Land Tenure Pathway for Irrigated Agriculture (LTPIA) applies if the proposal is not suitable for pastoral diversification, or if the proponent is seeking a general lease or freehold title. The LTPIA also provides an opportunity for the private sector to apply to develop irrigated agricultural projects on Crown land (including portions of an existing Pastoral Lease, unallocated Crown land or unmanaged reserves) in locations where the State is not taking a lead role. Development of the LTPIA policy framework took into account of what is currently possible under the Land Administration Act 1997 and the Native Title Act 1993 (Cth). The intent of the LTPIA is to make the process clearer and streamline information, providing the tools to enable land tenure change and increase development opportunities to diversify land use.

URL: https://www.agric.wa.gov.au/waterforfood/land-tenure-pathway-irrigated-agriculture

Contact DPLH support staff: Department of Lands (need permissions)

DWER one stop shop: A co-ordinated approach to water and environmental approvals

The Department of Water and Environmental Regulation is responsible for environment and water regulation. It serves as a ‘one stop shop’ for industry and developers with the aim of streamlining and simplifying regulation while ensuring robustness of regulation to meet government and community expectations.

URL: https://dwer.wa.gov.au/one-stop-shop

Contact DWER support staff: https://dwer.wa.gov.au/1stop/webform-contact

1.4 Understanding the climate

Meredith Guthrie and Geoff Moore

Key messages

- The annual rainfall has increased significantly in the last 30 years over the Kimberley and most of the Pilbara.
- Seven agro-climatic zones have been identified across the Pilbara and Kimberley for the purpose of providing agronomic advice on crop, fodder and pasture options.
- High levels of solar radiation, year-round warm to hot temperatures and low frost risk enable production of high yielding crops and pastures.
- Tropical cyclones, periods of extreme temperatures from October to April, and high vapour deficit are some of the climate challenges facing irrigators in northern WA.
- The inland elevated zone has the potential to grow crops which have a requirement for vernalisation or 'chilling'.

The climate of north-western Australia ranges from tropical savannah in the north Kimberley to a hot desert in the east Pilbara ('Koppen' climate classification, BoM 2005). These regions experience a strong summer dominant rainfall pattern with hot to extreme temperatures from October to April and mild to warm conditions over the dry season.

The summer dominant rainfall pattern with very dry winters, mild to warm temperatures over winter, combined with year-round high levels of solar radiation results in irrigation being an attractive option to provide good quality green feed all-year round.

The low and highly variable rainfall means that dryland cropping in the low rainfall zones is high risk or at best an opportunistic activity following major episodic rainfall events. In the medium rainfall zone there is some potential for dryland cropping on soils with a good water holding capacity, but establishment is still risky as there are regular periods in January – February with no rainfall for >7 days. If combined with high to extreme temperatures this can result in failed or patchy establishment. In the high rainfall and very high rainfall zone the potential for dryland cropping improves, but is still limited by the comparatively short growing season.

Agro-climatic zones

For the purpose of differentiating areas with similar climates and potentials for growing various crops and pastures the Pilbara and Kimberley have been subdivided into 7 agro-climatic zones. These zones are based on rainfall isohyets and July minimum temperature isotherms (Table 1). The Pilbara includes three agro-climatic zones, while the Kimberley includes all seven zones (Figure 1). For the purposes of irrigation production the high (750-900mm) and very high rainfall (>900mm) zones have been combined (i.e. high to very high rainfall (>750mm) in this bulletin. The characteristic features of the agro-climatic zones are summarised in Table 2.

Table 1. The agro-climatic zones in the Pilbara and Kimberley

Agro-climatic zone	Description
1. Very high rainfall	AAR >900mm
2. High to very high rainfall	AAR 750 – 900mm
3. Medium rainfall – coastal	AAR 500 – 750mm and July minimum temperature >12°C
4. Medium rainfall – inland	AAR 500 – 750mm and July minimum temperature 8 to 12°C
5. Low rainfall – coastal	AAR <500mm and July minimum temperature >12°C
6. Low rainfall – inland	AAR <500mm and July minimum temperature 8 to 12°C
7. Low rainfall – inland elevated	AAR <500mm and July minimum temperature <8°C

*AAR – Average annual rainfall

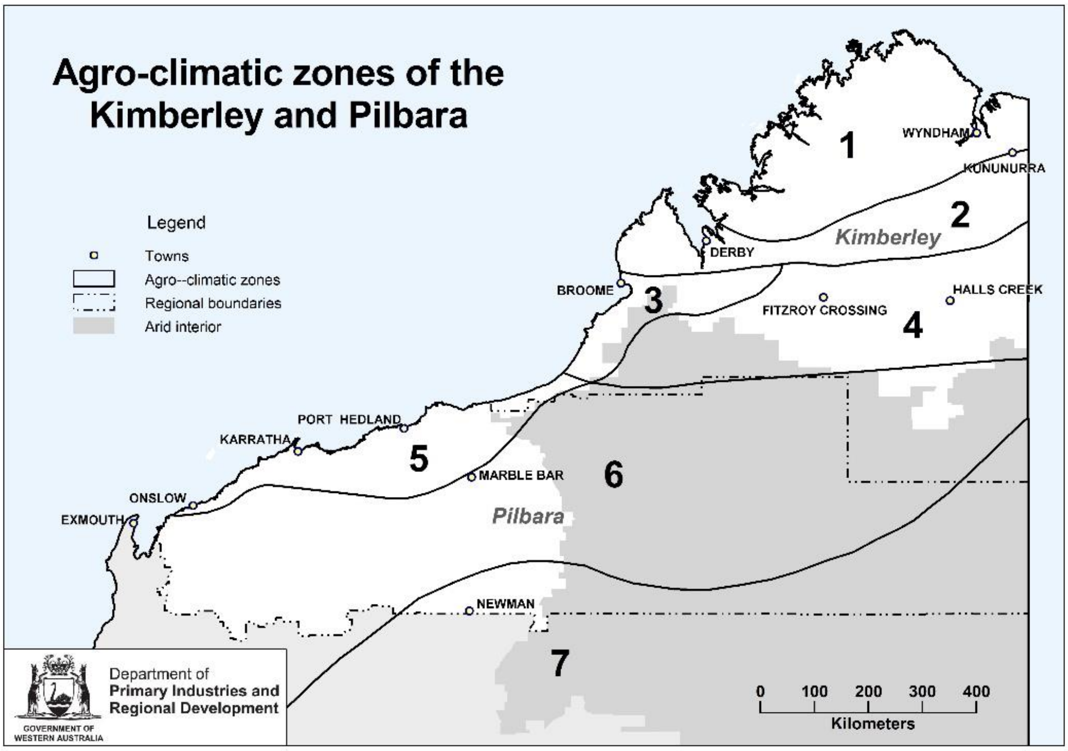


Figure 1. The agro-climatic zones in the Pilbara and Kimberley – refer to Table 1

Table 2. Characteristic features of the Agro-climate zones in Kimberley and Pilbara (source BoM)

Average annual rainfall	Agro-climatic zone	Rainfall variability over wet season	Maximum temperature December to February	Minimum temperature June to July	Likelihood of frosts	Annual evaporation (mm)	Potential challenges
Low rainfall (<500mm)	Coastal	Very high to extreme	36-39°C	12 to >15°C	Nil	2800 to >3200	Higher incidence of tropical cyclones
	Inland	High to very high	36 to >39°C	<9 to 15°C	Rare	3200 to >4000	Very high vapour pressure deficit (VPD) in October-November
	Inland - elevated	Very high to extreme	36 to 39°C	<6 to 9°C	Av. 2-5 per year	3200 to >3600	Cool temperatures and occasional frosts over winter
Medium rainfall (500-750mm)	Coastal	Moderate to high	33 to 36°C	12-18°C	Nil	2400 to >2800	
	Inland	Moderate to high	33 to 39°C	9 to 15°C	Rare	2800 – 3200	High to extreme temperatures from October to April
High to very high rainfall (>750mm)	–	Moderate	33 to 36°C	12 to 18°C	Nil	2400 – 2800	Reduced solar radiation over wet season due to cloud cover

Rainfall

The average annual rainfall (AAR) ranges from <300mm in the south-west Pilbara (Low rainfall zone) to more than 1,000mm in the north Kimberley. The AAR in the Kimberley and Pilbara (except for far-west corner) has increased significantly over the last 30 years by up to 26% (Figure 2). A recent study of tree growth in the Pilbara found that 5 of the 10 wettest years in the last 210 years occurred in the last two decades (DPIRD 2019).

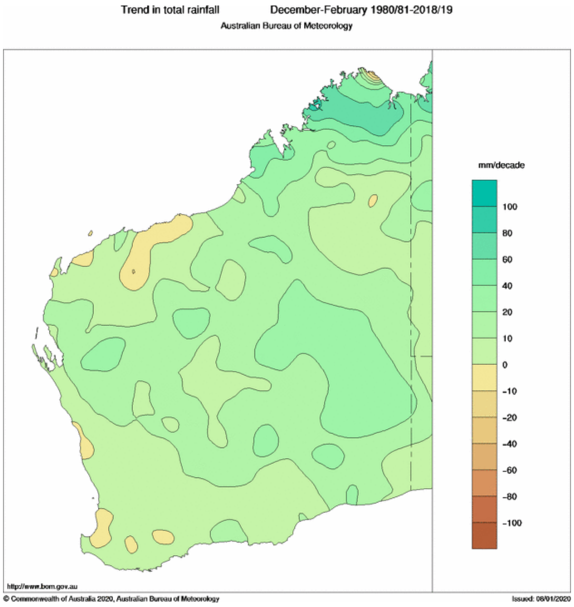


Figure 2. The summer rainfall trend (mm/decade) from 1980/81 to 2018/19 showing the increase in rainfall over most of north-western Australia (Source BoM).

Rainfall is strongly summer dominant and associated with north-west cloud bands monsoonal activity, thunderstorms and tropical cyclones. Tropical Cyclones are more likely to develop during active phases of the Madden-Julian Oscillation (MJO). The MJO has its greatest effect on the tropical areas of Australia during summer and is the major influence on tropical weather on a weekly to monthly timescale. The MJO can have an effect on the timing and intensity of 'active' monsoon periods in northern Australia.

Winter in northern WA is generally dry with western parts of the Pilbara region receiving a small amount of rainfall due to the influence of south-western frontal systems. The elevated Hamersley Ranges in the Pilbara receives slightly higher rainfall than surrounding areas at lower elevations. Rainfall variability is moderately high to extreme in the Pilbara, but becomes moderate to low in the north Kimberley.

Across the northern Rangelands the beginning of the wet season is defined as the date of accumulation of 50 mm of rainfall after the dry season. In the high rainfall and very high rainfall zone, wet season rainfall typically begins within the first week of November. For the medium rainfall zone the wet season usually begins by mid-December.

Early wet season rainfall is not always reliable. The region is known for false starts to the wet season, with extended dry periods following a break to the season. Over the last 30 years false starts have occurred 30% of the time across most of the high and very high rainfall zones (Bureau of Meteorology and CSIRO, 2019).

The relative importance of rainfall is much reduced in an irrigation context, however heavy rainfall events:

- provide a leaching factor to reduce the build-up of salt in the root zone, but also can result in the leaching of mobile nutrients like nitrogen,

- reduce trafficability and access over the wet season on soils which are imperfectly or poorly drained including texture-contrast and cracking clay soils,
- reduce the irrigation requirement, but on sandy soils with a low PAWC and high permeability the effect of even large rainfall events can be short-lived (refer to Irrigation management 2.2).

Tropical cyclones

Tropical cyclones (TC) are low pressure systems that form over warm tropical waters (sea-surface temperature >26.5°C). TC can continue for many days, even weeks, and may follow quite erratic paths. A cyclone will dissipate once it moves over land or over cooler oceans.

The northwest coastline between Broome and Exmouth is the most cyclone-prone region of Australia. On average about five TCs occur over the warm ocean waters off the north-west coast during each cyclone season (November to April) and about two cyclones cross the coast, one of which is severe.

At the start of the cyclone season, the most likely area to be affected by tropical cyclones is the Kimberley and Pilbara coastline. Later in the season, the area threatened extends further south including the west coast. The chance of experiencing an intense category 4 or 5 cyclone is highest in March and April (http://www.bom.gov.au/cyclone/climatology/wa.shtml).

Tropical cyclones are responsible for most of the extreme rainfall events across north-west WA and generate up to 30% of the total annual rainfall near the Pilbara coast. They make a valuable contribution to rainfall in the north-west, and inter-annual and spatial variability strongly affects the reliability of this rainfall as a source for water supplies. For example, in the Pilbara their contribution to summer rainfall ranges from 0 to 86% between years. Over the last 40 years, the frequency of TCs has not changed significantly in WA, but there is some evidence that the frequency of the most intense cyclones has increased (https://www.agric.wa.gov.au/climate-change/climate-trends-western-australia). However, even the threat of a TC is a disruption to irrigation operations as each centre pivot needs to be parked and tied down. When there is no or minimal rainfall from a potential TC it can result in moisture stress to the crop if there is an extended period between irrigations.

Temperature

Wet season temperatures – October to April

The north-west is the hottest area used for irrigation in Australia. The mean maximum temperature in the wet season is 38°C and mean minimum temperature 24°C. In the build-up to the wet season there are high to extreme temperatures across the region, but particularly in the inland zones.

Extreme temperatures are detrimental to plant growth and can be lethal for sensitive species or some phenological growth stages. The number of days exceeding 42°C varies considerably across the region and increases with distance from the coast. Marble Bar (Low rainfall – inland zone) has on average 37 days over 42°C between October and April, the medium rainfall inland location of Fitzroy Crossing has 26 days, while Kununurra (High rainfall zone) only experiences 6 days over 42°C during the wet season.

Dry season temperatures – May to September

The dry season temperatures are favourable for the growth of many species. The mean maximum temperatures are between 28-32°C and the mean minimum temperatures are between 13-17°C. In general there is a north-south temperature gradient with the north Kimberley having the highest temperatures.

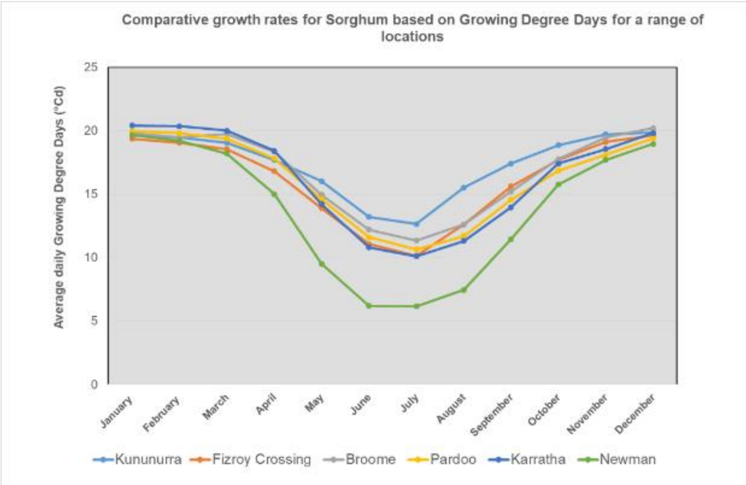
Night temperatures below critical thresholds reduce the growth of warm season species more than differences in the maximum temperature. The inland zones have average minimum July temperatures <12°C, while the coastal zones have milder winters.

The average temperatures over winter are around 20°C across the Pilbara. Coastal areas have a smaller annual temperature range compared to inland areas and winter temperatures rarely drop below 10°C. Except for the upland areas of the Hamersley Ranges and far south-eastern Pilbara (Low rainfall – inland elevated zone), there is minimal risk of frost.

Comparative growth rates between sites

Growing degree days (refer to 'box') can be used to compare the relative growth rates over 12 months and also between locations. Different plants have different minimum, optimum and maximum temperature requirements, but on the whole they respond to rising temperatures by growing or developing faster. However, at very high to extreme temperatures as experienced in northern Australia over the 'wet' season growth rates will plateau or decrease.

Figure 3 illustrates that there is a dip in biomass over the dry season, particularly from May to August for both Rhodes grass and sorghum across all the locations, while potential production over the wet season is comparable. Newman which is situated at an altitude of 540m ASL in the Low rainfall – inland elevated zone has the coolest winter and consequently the most marked decline in growth rates over the dry season. Newman is also susceptible to occasional frosts which would burn the top-growth of many sub-tropical and tropical species.



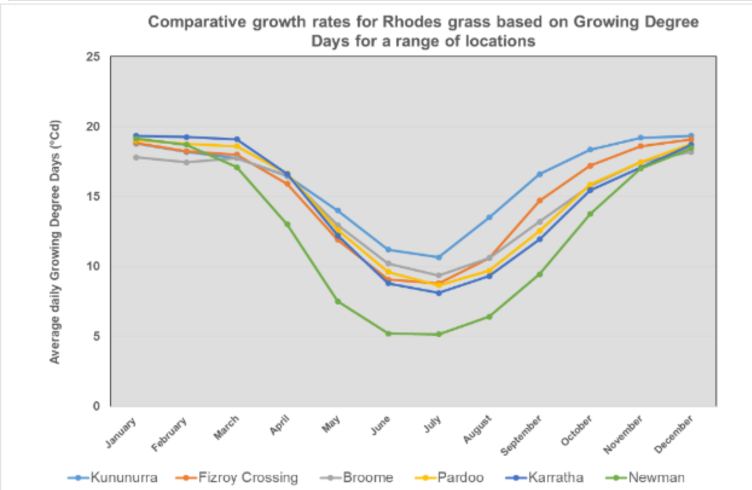


Figure 3. The comparative monthly growth rates for (a) forage sorghum and (b) Rhodes grass across a range of locations in the Kimberley and Pilbara based on growing degree days

Chilling hours

Some crops, particularly horticultural crops like stone fruit have a vernalisation requirement to break dormancy and ensure good flowering and fruit-set. This is normally measured in terms of 'chilling hours', which is the cumulative number of hours when temperatures are above 0°C and less than 7.2°C.

The unique climate characteristics of the inland and elevated parts of the Pilbara may provide enough chilling hours to enable the production of crops that have a low vernalisation requirement. There is minimal chilling hours across the other agro-climatic zones.

Growing degree days

Plant growth is strongly controlled by the ambient temperature and unless stressed by other environmental factors (e.g. moisture, nutrients) the development depends on the accumulation of specific quantities of heat units.

The term Growing Degree Days (GDD) is a widely used method to predict the growth and development of plants (and insects) during the growing season. GDD are also known as thermal time or heat units. The concept is that development will occur when the temperature exceeds some minimum threshold for growth, often called the base temperature (T_{base}). The base temperature varies between species and to a lesser extent between varieties.

GDD is calculated from the mean daily temperature (daily maximum (T_{max}) plus minimum (T_{min}) temperature divided by two) minus the base temperature (Equation 1) for each day and then summed over time.

Equation 1 $$GDD = \{ \frac{(Tmax+Tmin)}{2} \} - Tbase$$ (units are °Cd)

Refinements of GDD include a maximum temperature (T_{opt}) above which growth plateaus and lethal temperatures (T_l) which are either lethal for the whole plant or for that phenological stage. When either the daily minimum or maximum temperature are outside the T_{base} to T_{opt} range for a plant then the term 'modified' growing degree days is used. In this case, the T_{opt} or T_{base} values are substituted into equation 1 (e.g. If the daily minimum temperature is 5°C, then 12°C is substituted to calculate the GDD for Rhodes grass).

Plant development can be predicted from accumulated thermal time. For example, a mid-maturity hybrid maize requires 795 GDD for silking and 1520 GDD for physiological maturity (Maize Growth and Development NSW DPI p.12).

Table 3. Temperature thresholds for some key pasture and crop species used for calculating growing degree days

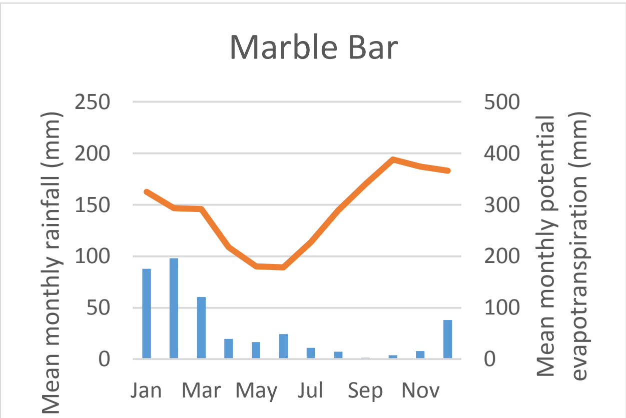
Species	T_{base} (°C)	T_{opt} (°C)		Failure point (°C)
		Vegetative	Reproductive	
Rhodes grass[gh]	10-12	37	-	>50
Panic grass[ei]	7-16 (variety)	30-36	-	
Forage sorghum[f]	8-10	32-35	-	
Maize (corn)[ac]	8-10	33-38	26-30	>37 T_l for anthesis
Wheat[bd]	0	20-30	15-25	>32 T_l for anthesis
Lucerne[h]	5	21-27	-	
Cotton[a]	14	38	28-30	
Soybean[ab]	6	26-30	23-26	
Grain sorghum[ab]	8	26-34	25-28	>35
Peanut[b]	10	29-30	24	>40

Source: a – Luo (2011); b — Hatfield *et al*. (2011); c — Sanchez *et al*. (2014); d — Porter and Gawith 1990; e — Moreno *et al.* (2014); f — Rai *et al*. (2013); g — Agnusdei *et al*. (2012); h — EcoCrop Database; i. — Sweeny and Hopkinson (1975).

Evaporation

For irrigated mosaic agriculture, 'point potential evaporation' (PPE) is the best estimate as it corresponds with the evaporation from small irrigated fields with an unlimited water supply surrounded by non-irrigated land. The PPE values in the north-west are predominantly 3,000 to 3,400mm per annum. The mean monthly PPE exceeds the average rainfall in every months at the high rainfall Kununurra location (Figure 4).

Hot, dry and sunny conditions mean the Pilbara is subject to very high evaporative demand, with the Low rainfall – inland zone having the highest annual pan evaporation in Australia. Over much of the Pilbara, point potential evaporation exceeds 3000mm per year. Potential evaporation is highest during the build-up to and over the wet season averaging 10-14mm per day and is lowest during winter averaging 4-7mm per day.



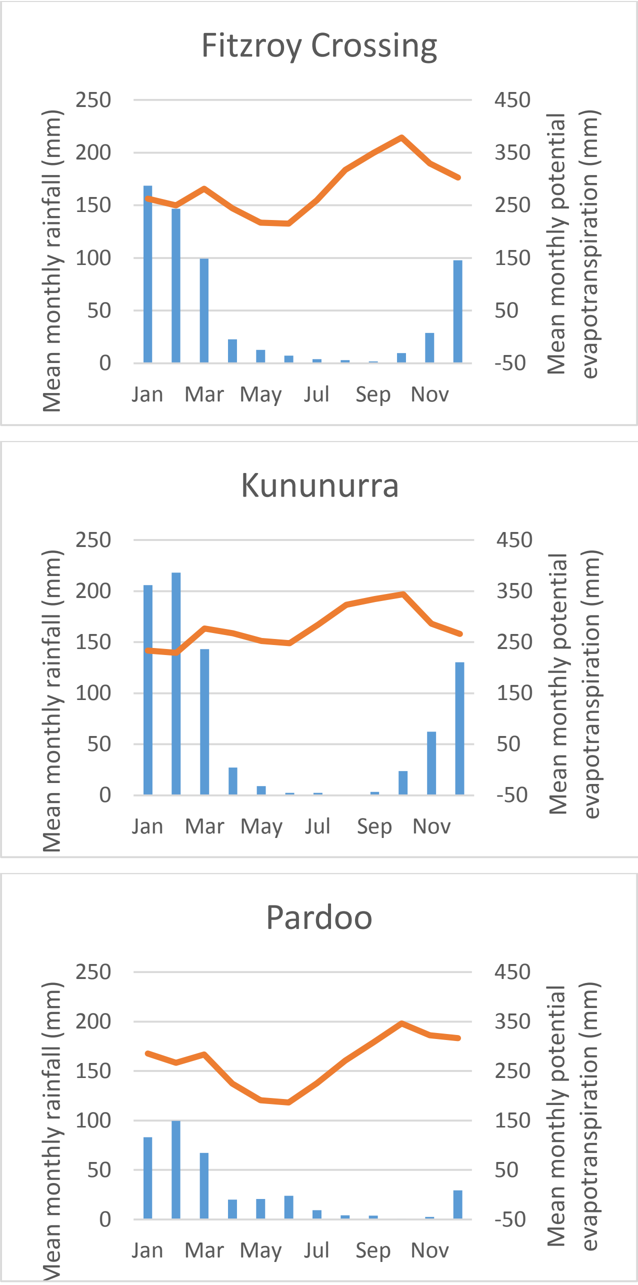


Figure 4. Comparison of monthly rainfall (blue bars) and point potential evapotranspiration (orange line) for Marble Bar, Fitzroy Crossing, Kununurra and Pardoo.
Using 1960 – 2019 records sourced from Bureau of Meteorology stations. Note the scale differences

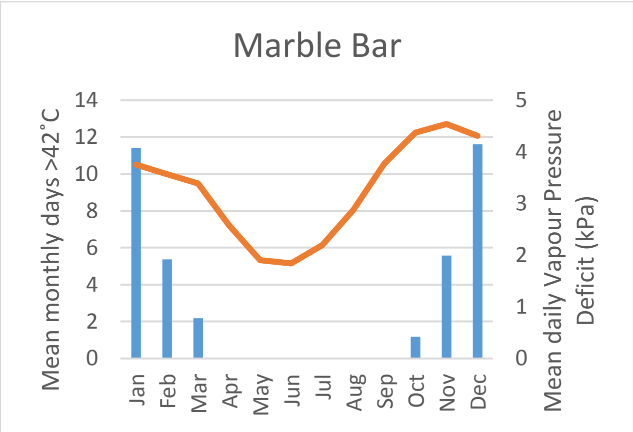
The climate regime of the Pilbara whereby potential evapotranspiration greatly exceeds rainfall (Figure 4 – Marble Bar comparison) means dryland cropping is likely to be unviable right across the region. Irrigation will be essential for commercial yields of fodder, grains, fibre or horticultural crops.

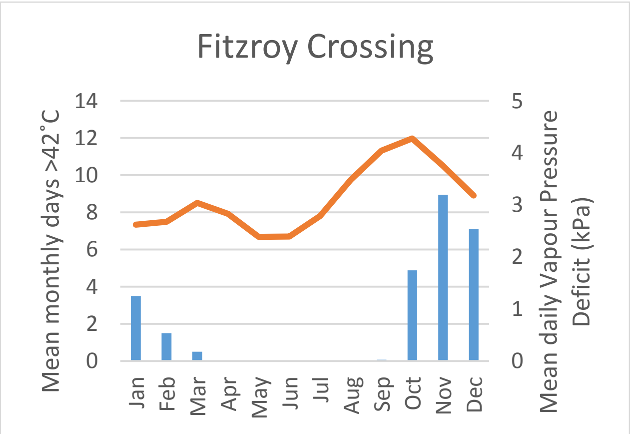
Vapour pressure deficit (VPD)

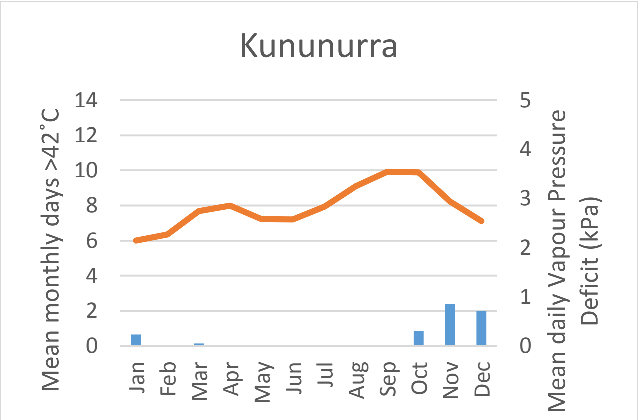
Vapour Pressure Deficit (VPD) is regarded a better estimate of how plants react to the temperature and humidity of the environment than either temperature or relative humidity (RH) alone. Essentially VPD is a combination of temperature and RH in a single value. From a plant's perspective the VPD is the difference between the vapour pressure inside the leaf compared to the vapour pressure of the air.

VPD is defined as the difference between the theoretical pressure exerted by water vapour held in saturated air (100% RH at a given temperature) and the pressure exerted by the water vapour that is actually held in the air being measured at the same given temperature. VPD values run in the opposite direction to RH values, so when RH is high VPD is low. VPD is measured in pressure units, usually kilopascals (kPa), and values above 2.3 or below 0.7 can cause significant plant stress and reduced growth.

High to extreme temperatures combined with low relative humidity equate to a high VPD, and given these conditions many crops struggle, there is a high water demand, comparatively low water use efficiency (WUE) and higher pumping costs. For example, when the temperature is 38°C, the VPD is 1.3 at 75% RH, but at 25% RH the VPD increases to 4.6.







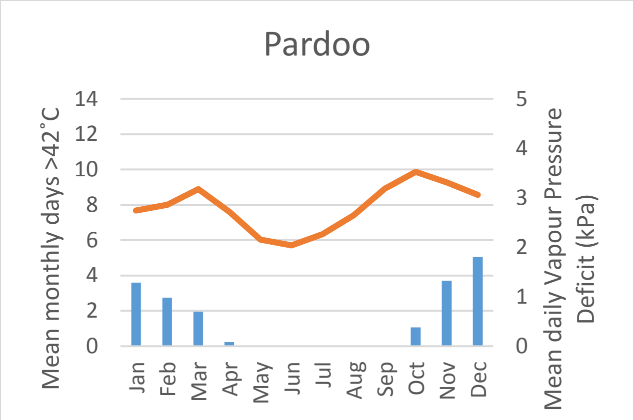


Figure 5. Mean monthly days greater than 42˚C and mean daily Vapour Pressure Deficit (kPa) for Marble Bar, Fitzroy Crossing, Kununurra and Pardoo using 1960 – 2019 record from Bureau of Meteorology stations. Note the scale differences

Commercial horticultural crops are untested in the Pilbara region, however it is likely that horticulturalists would need to consider strategies for certain crops to mitigate high temperature and low humidity extremes.

Solar radiation

The Pilbara and Kimberley overall have high rates of solar radiation with annual average >20MJ/m^2 indicating the potential for high rates of plant growth under irrigation. Cloud cover in the north Kimberley from January to March may constrain growth, while in the Pilbara there is reduced solar radiation over winter (15-18 MJ/m^2) (BoM). The mean monthly solar radiation is highest in October as there is less cloud cover over the region (Figure 5).

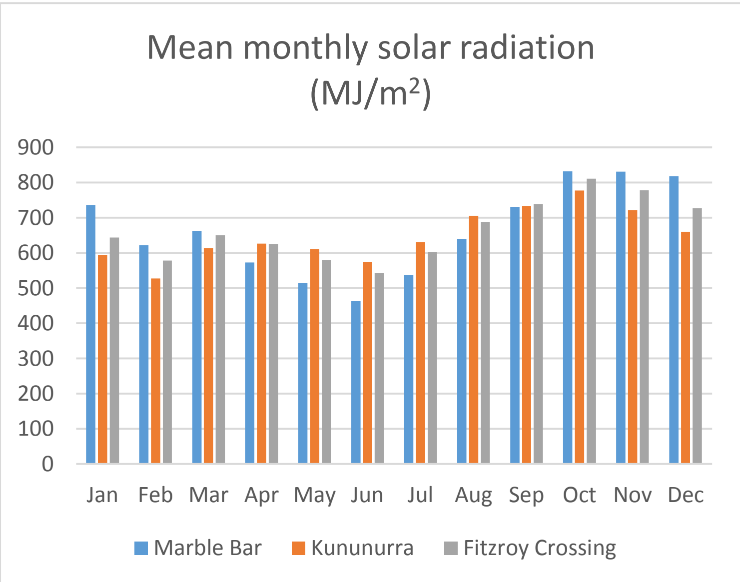


Figure 6. The mean monthly solar radiation for Marble Bar, Kununurra and Fitzroy Crossing

Further reading

‘Climate in the Pilbara’, Sudmeyer, R., 2016. Department of Agriculture and Food, Western Australia, Bulletin 4873, Perth.

1.5 Understanding the soils of the Kimberley and Pilbara

Henry Smolinski

Key Messages

The location of a suitable water resource for irrigation will be the primary factor determining the general location of an irrigation development rather than soil type *per se*. However, an understanding of the soils and site selection can improve the efficiency and production potential of the development.

Imagery such as Google Earth can be used to identify uniform patterns of soils, vegetation and grade by using the Tools/Ruler/Path/Elevation profile applications.

Checklist for site selection

- Does the site have year-round trafficability? (As this has implications for the crops and pastures that can be grown over the wet season)
- Is the site well drained? Well drained soils are preferable and can grow the widest range of crops, while crops grown on rapidly (or excessively) drained soils are prone to moisture stress (Avoid poorly drained soils)
- Is the soil profile >1m deep and preferably >1.5m?
- Are there any chemical (pH, salinity, sodicity) or physical properties in the subsoil that restrict root growth?
- Is the topsoil free of rocks and large stones? (Rock and stones will interfere with seeding and hay making operations and need to be cleared)
- Avoid natural flow lines and drainage depressions as water erosion can occur on the break of slope even under natural vegetation
- Avoid areas of undulating terrain
- Ensure there are uncleared buffer areas (>100m) along drainage lines and other wetlands to minimise the risk of inundation, flooding and eutrophication.
- Avoid slopes greater than 2% as they are more prone to water erosion.

Introduction

The soils of north–western Australia have formed on very old and sometimes weathered geologies under hot sub-tropical to arid climatic conditions. The rainfall ranges from 300 to 1000mm and total annual evaporation is very high and greatly exceeds rainfall. As a result, the soils are strongly weathered, contain very low soil organic carbon and are generally nutrient poor. With appropriate fertiliser and irrigation systems, irrigated agriculture can however be highly productive on some of these soils.

Soils sharing similar qualities that can be managed together under a similar land use are assigned to a soil generic group. In WA these are referred to as WA soil groups. The main soil groups in the Pilbara and Kimberley are summarised in Appendix Table A1. The soils with the most potential for irrigated agriculture are summarised in Table 1 and then described in more detail.

Table 1. Potential for irrigated agriculture

Soil group	Deep red sands	Red loamy earths	Yellow-Brown and Grey loamy earths	Cracking Clays
Land capability for irrigated agriculture	Moderate (Low; if coarse grained)	Moderate to high	Moderate (Low; if inundated in wet season)	Generally high (unless saline)
Key limitations	Wind and Water erosion where slopes >2%	Water erosion when slopes >2%	Waterlogging, inundation also erosion when slopes >2%	Drainage, sodicity and salinity

Terminology and interpreting the soil chemical and physical data

Key criteria for describing soil properties are explained below. Low, moderate and high ranking values for each of these criteria are provided in Table 2.

Bulk density (BD) is a measure of the oven dry (105°C) soil mass per unit volume. High values can indicate soil compaction which is likely to impede root growth.

Cation exchange capacity (CEC) is a measure of the ability of the soil to hold cations (i.e. positively charged ions) such as calcium, magnesium, potassium and sodium. It mainly depends on the amount and type of clay and organic matter present.

Electrical conductivity (EC) is a measure of the soluble salt content. High levels of soluble salts in the root zone can affect water and nutrient uptake and adversely affect plant growth. Plants are more susceptible to salinity in their germination and seedling stage than in later stages of growth.

Mottles are yellow and red patches in the clay subsoil due to a concentration of iron oxides which form under waterlogged conditions.

Organic carbon % (OC) is a measure of the organic matter present in soil. Soil organic carbon assists in maintaining soil structure and the supply and retention of nutrients, air and water.

Plant available water capacity (PAWC) is the maximum amount of water available for a given crop within a given depth of soil ($PAWC_{100}$ is the available water in the top 100cm of the soil profile). It is the soil moisture at the upper storage limit (field capacity) minus the soil moisture at the lower storage limit (or wilting point).

Permeability is the infiltration rate of the topsoil measured in mm per hour.

pH_w is a measure of the alkalinity or acidity of the soil, where a pH value of 7 is neutral (pH_w is measured in a mix of one part soil to five parts distilled water). A low pH indicates strongly acid soils that may be unsuitable for some plants with potential problems including aluminium toxicity, the reduced availability of some nutrients and nodulation failure in legumes. High values indicate alkaline soils which are often calcareous and potential issues with nutrient imbalance.

Saline soils have sufficient soluble salt to adversely affect the growth of crops.

Sodic soils have a high proportion of sodium on cation exchange sites associated with the clay fraction. Exchangeable sodium percentage (ESP) is the exchangeable sodium divided by the measured CEC expressed as a percentage. A soil is regarded as sodic if the ESP >6 and highly sodic if the ESP>15. Sodic soils are more susceptible to dispersion and soil structural decline. Sands and clayey sands have a low clay content, so any clay that does disperse is less likely to affect soil structure.

Soil texture is a measure of the particle size distribution, specifically the proportion of sand, silt and clay sized particles in the soil where: sands have less than 5% clay, clayey sands 5-10%, sandy loams 10-20%, loams ~25%, clay loams 30-35% clay and medium clays more than 45% clay.

(Terminology adapted from Purdie (1998) and Agriculture Victoria (2011)

Table 2. Low, moderate and high rankings for the various soil properties with the 'ideal' range highlighted in green (Adapted from Moore (1998) unless annotated).

Soil property	Low	Moderate	High
pH_w (1:5 H_2O)	<5.5	5.5-8.0	>8.0
Organic Carbon (OC) % Topsoil	<1%	1-2%	>2%
Subsoil	<0.1%	0.1-0.5%	>0.5%
Cation Exchange Capacity (CEC) (mEq/100g)	<12	12-25	>25
Electrical conductivity (ECe) (mS/m)	<400	400-1600	>1600
Phosphorus (P HCO_3) sands	<14	14-20	>20
Phosphorus (P HCO_3) loams	<16	16-30	>30
Phosphorus (P HCO_3) clays	<30	30-80	>80
Potassium (K HCO_3))[a] sands	<50	50-150	>150
Potassium (K HCO_3))[a] sandy loams	<80	80-200	>200
Potassium (K HCO_3))[a] clay loams	<110	110-250	>250
Potassium (K HCO_3))[a] clays	<120	120-300	>300
Bulk Density (g/cm^3)[b]	<1.2	1.2-1.6	>1.6
Plant available water capacity $PAWC_{100}$ (mm)	<50mm	50–100mm	>100mm
Permeability (mm/h)	<5	5-130	>130

[a] adapted from Agriculture Victoria (2011)

[b] adapted from Hunt and Gilkes (1992)

Main soils suitable for irrigation

The following four soil groups have the most potential for irrigated agriculture in the Pilbara and Kimberley.

Red sandy and loamy earths

Locally known as 'Pindan' (Smolinski *et al.* 2016); also a loamy variant of Cockatoo sands (Burvill 1991)

WA soil group: Red Sandy Earth or Red Loamy Earth;

Australian soil classification: Haplic Eutrophic Red Kandosol; Haplic Hypocalcic Red Kandosol

The red sandy earths and red loamy earths share similar characteristics apart from topsoils having either a sand or loam texture. The clay content increases gradually with depth with clay loam or clay usually occurring within 60-150cm.

Red earths are generally associated with level to gently undulating plains and are formed on Quaternary colluvium and alluvium. Within narrow valleys and lower slopes of hills the red earths contain common to abundant gravels and usually have a surface lag. Also, ironstone gravels are residual weathering products that are commonly found in the deeper subsoil over basement rocks.

Soil profiles are more often deep to very deep, well drained and have moderate to high soil water storage, which is often dependent on the thickness of the upper sand or loam horizon.

These soils are strongly weathered and usually nutrient deficient; therefore, irrigated cropping requires very high fertiliser inputs of NPK when soils are initially developed. Also, micro-nutrients, particularly magnesium and zinc require addition and monitoring particularly on alkaline soils. After the initial application, fertiliser rates follow recommended crop requirements.

Irrigation potential is limited to spray and drip irrigated crops.

Red loamy earth (loam grading to clay loam) formed on colluvium from the Mt Newman area.

Soil chemistry: Inherently very low soil fertility with very low levels of macro-nutrients (NPK) and organic carbon. The clay content is almost solely kaolin with iron oxide coatings (haematite, goethite) on the sand grains.

'New land' requires a large basal application of P, K, trace elements and thereafter on-going applications of NPK to replace the nutrients removed in produce.

Soil physical properties: These soils are highly permeable, although degraded topsoils often develop a surface crust that can reduce infiltration and exacerbates runoff especially during intense storms. They are susceptible to subsoil compaction and very high bulk densities (1.8–2.0 kg/dm^3) have been measured under wheel tracks on soils used for horticulture.

However, there are no chemical or major physical limitations that prevent their use for irrigated agriculture, providing a balanced water and nutrient regime is maintained.

Table 4. Red sandy and loamy earths – Typical values for soil chemical and physical properties (Smolinski *et al.* 2016 and TAP project data)

Soil property	0-10cm	Subsoil
pH_w (1:5 H_2O)	5.5-6.5	7.0-8.5
Organic Carbon (OC) %	0.2 – 0.3	0.1
Cation Exchange Capacity (CEC) (mEq/100g)	1-2	3-10
Electrical conductivity (EC) (mS/m)	<2	<2
Phosphorus (P)	<2	<2
Potassium (K)	30-50	<200
Bulk Density (g/cm^3)	1.5-1.6	1.5-1.8
Plant available water capacity $PAWC_{100}$ (mm)	80-150mm to a depth of 100cm	
Permeability (mm/h)	40-80mm/h (cleared) to 200->500mm/h (uncleared)	
Site drainage	Well drained to rapidly drained	

Potential soil management issues: Year-round trafficability is fine, however these soils are susceptible to subsoil compaction from when moist cultivation. Machinery traffic should be limited to when the soil is dry while cultivation is best at or below field capacity.

Periodic deep ripping may be required especially under ‘stand and graze’ irrigated pasture systems. Red loamy earths are susceptible to topsoil crusting and hardsetting after clearing, the impact can be reduced, with minimum or zero tillage combined with the incorporation of plant residues and cover crops.

Continued product removal (alkaline nutrients) may result in topsoil or subsoil acidification because of the low pH buffering capacity however the development of soil acidification is dependent on the alkalinity of the irrigation water.

Changes in soil chemistry under irrigation are likely to be minor with a slight increase or decrease in pH_w and organic carbon, together with an increase in available P from fertiliser applications. There may be an increase in soil sodicity if the chemistry of the water is dominated by sodium although sodicity can be ameliorated with gypsum.

Key points when selecting a site:

Choose level areas with similar vegetation i.e. the loamy soils carry woodlands or shrublands with an understorey of tussock grasses, Shrubs may include bauhinia, snake wood, lemonwood or beefwood. Termites are usually more common where subsoils are loamier especially if the soils are seasonally wet.

Soil erosion can be minimised by choosing areas with grades of <3% and preferably <1%.

Red deep sands

Locally known as 'Pindan'; also as Cockatoo sands (Speck *et al*. 1960)

Australian soil classification: Basic Regolithic or Arenic Red-Orthic-Tenosol

Red deep sands are generally associated with level to gently undulating sandplains developed on deeply weathered sedimentary rocks and variably reworked by the wind. Topsoils are loose to weakly coherent sand to clayey sand texture that usually extend to 100cm or more although sandy loam may be encountered within 150cm. Dune sands usually have a uniform fine to medium sand texture for several metres.

Red deep sands are usually deep to very deep although rock, hardpans or gravel layers may be encountered within 100cm.

These soils are rapidly drained and have very low to low soil water storage in the upper metre of the soil profile. Maintaining adequate soil moisture conditions can be a major challenge under an arid climate particularly for shallow rooted crops.

These soil profiles contain less clay compared to the red earths and are usually more nutrient deficient; therefore, irrigated cropping requires very high fertiliser inputs. Phosphorus can be retained within the iron-oxide/ clay coatings on the sand however potassium and nitrogen are more likely to leach due to the low clay content and excessive drainage.

Red deep sands are rapidly drained and have low water storage

Soil chemistry – inherently very low soil fertility with very low levels of macro-nutrients (NPK) and organic carbon. The clay content is almost solely kaolin with iron oxide coatings (haematite, goethite) on the sand grains. Nutrient retention and cation exchange capacity is very low as a result of the low organic carbon and clay content.

Sandy soils are not hardsetting and less prone to compaction and crusting problems when compared with clay or loamy soils.

'New land' requires a large basal application of P, K trace elements and thereafter on-going applications of NPK to replace the nutrients removed in produce. Phosphorus and trace elements are generally applied as a topsoil dressing while nitrogen and potassium are more efficiently applied through fertigation.

Soil physical properties: These soils are highly permeable, although intense storms will result in runoff. They are susceptible to subsoil compaction and very high bulk densities (1.8–2.0 kg/dm^3) have been measured under wheel tracks on soils used for horticulture.

However, there are no chemical or major physical limitations that prevent their use for irrigated agriculture, providing a balanced water and nutrient regime is maintained.

Table 5. Red deep sands – Typical values for soil chemical and physical properties (Smolinski *et al.* 2016)

Soil property	0-10cm	Subsoil
pH_w (1:5 H_2O)	5.5-6.5	6.0–7.0
Organic Carbon (OC) %	0.1-0.2	0.1
Cation Exchange Capacity (CEC) (mEq/100g)	1-2	2-5
Electrical conductivity (EC) (mS/m)	<2	<2
Phosphorus (P)	<2	<2
Potassium (K)	30-50	<15-30
Bulk Density (g/cm^3)	1.5-1.8	1.5-1.8
Plant available water capacity $PAWC_{100}$ (mm)	50–80mm to a depth of 100cm	
Permeability (mm/h)	80mm/h (cleared) to >300mm/h (uncleared)	
Site drainage	Rapidly drained	

Potential soil management issues: These soils can be worked all year-round although it is essential to retain stubble and reduce traffic particularly during fallow. Sandy soils associated with sand dunes are not recommended for development due to more exposure to wind and the sloping terrain have a risk of water erosion

Continued product removal (alkaline) may result in topsoil or subsoil acidification because of the low pH buffering capacity however, acidification can be offset to some degree by the alkalinity of the irrigation water.

Key points when selecting a site:

Choose level areas with similar vegetation i.e. the red sandy soils carry acacia shrublands (Pindan wattles) with an understorey of curly spinifex. Native sorghum can be locally common, lower in the landscape. *Grevillea* and *Hakea* species usually occur in the mid-storey.

Avoid –Scattered paperbarks or tea trees (*Melaleuca* spp.) indicate flow lines and wet depressions.

Soil erosion can be minimised by choosing areas with grades of <3% and preferably <1%.

Brown yellow and grey loamy earths

Locally known as Wet 'Pindan'; Pago, and Elliot soils (Speck *et al*. 1960)

Australian soil classification: Brown and Yellow and Grey Kandosols and Hydrosols

Brown, yellow and grey earths are not common in semi- arid to arid regions and are mainly restricted to drainage lines, open depressions and other water gaining sites where annual rainfall is >400mm.

The soil colour sequence from red to grey is indicative of soil profile drainage i.e. Red soils are well drained while brown-yellow soils are moderate to imperfectly drained and subject to seasonal subsoil waterlogging. Grey soils are poorly drained, seasonally inundated and usually remain wet for several months. These wetter soils are usually classified as Hydrosols.

Soil permeability and drainage is dependent on three main factors: topography; depth of soil and permeability of the underlying rock or substrate. Brown yellow and grey soils generally have a drainage restriction layer such as hardpan, clay or rock within a depth of 3m while red soils are deeper and or the substrate is more permeable.

The brown and yellow earths contain few to common iron-manganese gravels and mottling in the subsoil which indicates periodic waterlogging. Grey soils are more compact, may have powdery topsoils and are often pale below the surface and strongly mottled in the subsoil. As a result of the poor drainage, grey soils are more likely to be sodic and may also be saline.

Yellow loamy earth of the Bonaparte Plains, East Kimberley are subject to periodic waterlogging

Soil chemistry – Soil chemistry is comparable with the Red loamy and sandy earths although these seasonally moist to wet soils contain slightly more organic carbon within the topsoil. Yellow to grey soils generally have a higher ratio of magnesium and sodium to calcium and may accumulate more salts.

Soil physical properties: Soils that are seasonally wet are generally more compact and prone to hardsetting, crusting and compactionwhen developed for agriculture. The wetter yellow and grey soils usually have a pale or bleached horizon below the topsoil that is strongly leached and contains fine silicates that act as a cement. When dry it is brittle, compact and powdery when cultivated. Once wet, these layers are sticky and prone to pugging. Soil bulk density can be as high as 1.8–2.0 kg/dm^3, which restricts root growth and exacerbates waterlogging.

Table 6. Brown, yellow and grey loamy earths – Typical values for soil chemical and physical properties (Smolinski *et al.* 2016)

Soil property	0-10cm	Subsoil
pH_w (1:5 H_2O)	5.5-6.5	6.0-7.5
Organic Carbon (OC) %	0.2-0.8	0.1-0.2
Cation Exchange Capacity (CEC) (mEq/100g)	1-2	2-10
Electrical conductivity (EC) (mS/m)	<5-10	<50
Phosphorus (P)	<2	<2
Potassium (K)	30-50	<150-200
Bulk Density (g/cm^3)	1.5-1.8	1.5-1.8
Plant available water capacity $PAWC_{100}$ (mm)	50–150mm to a depth of 100cm	
Permeability (mm/h)	10-80mm/h (cleared) to >250mm/h (uncleared)	
Site drainage	Moderately well to poorly drained	

Potential soil management issues: Subsoil waterlogging and inundation limits traffic on these soils during the wet season. Topsoil structure is destroyed if worked or grazed when wet. Periodic deep ripping may be required. Loamy earths are susceptible to topsoil crusting and hardsetting after clearing, the impact can be reduced, with minimum or zero tillage

Changes in soil chemistry under irrigation are likely to be minor although sodium salts can build up on imperfect to poorly drained soils. These soils have the advantage of retaining more soil moisture after the wet season so that irrigation can be delayed for several weeks on commencement of the dry season.

As these soils occur low in the landscape or within drainage systems they are more prone to flooding and water erosion. It is essential to establish a cover crop or retain stubble before the wet season to reduce the loss of soil and nutrients.

Key points when selecting a site:

The brown and yellow soils are usually indicated by riparian vegetation such as paperbarks (*Melaleuca* spp.), *Pandanus* and ferns. The loamy soils carry Darwin Box *Eucalyptus tectifica* with understorey of ribbon grass (*Dicanthium fecundum*). Choose level areas that are not seasonally inundated. In general, grey soils are not recommended for fodder cropping.

Avoid natural flow lines and drainage depressions as rill and gully erosion can occur on the break of slope even under natural vegetation or areas of undulating terrain. Maintain uncleared buffer areas (>100m) along drainage lines and other wetlands to minimise the risk of eutrophication.

Cracking clays

Locally known as Cununurra, Aquitaine (Aldrick *et al*. 1990)

Australian soil classification: Red, Brown, Black or Grey Vertosols

The cracking clays are found on the alluvial plains of the Ord, Fitzroy, Lennard, De-Grey, Fortescue Rivers. Extensive uniform areas of cracking clays locally known as the 'Roebourne Plains' are found between Karratha and Port Hedland associated with the Horseflat Land System.

The cracking clays of the Kimberley are commonly brown grey or black, while within the semi-arid to arid regions of the Pilbara the cracking clays are usually dark-red.

Cracking clays are formed from alluvium derived from basic igneous and metamorphic rocks including dolerites and basalts. They develop in backwater and swampy plains where there is a natural accumulation of basic minerals such as calcium, magnesium and organic matter. Cracking clays also form over marls and limestone that can also form under wet or swampy environments.

Gypsum and lime are often encountered in the soil profile. Cracking clays that contain appreciable amounts of gypsum are usually saline.

Red cracking clay of the Roebourne Plains near Karratha

Table 7. Cracking clays – Typical values for soil chemical and physical properties.

Soil property	0-10cm	Subsoil
pH_w (1:5 H_2O)	6.5-7.5	8.0-9.5
Organic Carbon (OC) %	0.2–1.0	0.1-0.4
Cation Exchange Capacity (CEC) (mEq/100g)	30-50	30-50
Electrical conductivity (EC) (mS/m)	<50	20-600
Phosphorus (P)	2-10	<2-10
Potassium (K)	150-500	150-500
Bulk Density (g/cm³)	n/a	n/a
Plant available water capacity $PAWC_{100}$ (mm)	120-150mm to a depth of 100cm	
Permeability (mm/h)	<1 to 20mm/h	
Site drainage	Moderately well to poorly drained	

Soil chemistry – The cracking clays are poor in nitrogen and phosphorus but generally have adequate levels of potassium. The trace elements: iron, copper and zinc are usually less available due to high subsoil pH, resulting from the presence of highly alkaline sodium and carbonate salts. Boron is commonly encountered at moderate to high levels within subsoils and there is a risk of boron toxicity for susceptible crops.

The cracking clays of the Pilbara and Kimberley usually have a salt bulge in the subsoil that occurs between 60 to 120cm. This layer contains sodium salts, and gypsum crystals are usually evident. Soil EC_w is in the range of 2-6 dS/m. Salt concentrations usually decline with depth although this may not be apparent in soils with medium to heavy clay subsoils.

Subsoil salinity and sodicity is a common feature of the cracking clays particularly if gypsum is encountered at shallow depth. Gypsum is usually encountered at the base of the cracking clay layer where drainage is impeded once the clays swell. In general, cracking clays with calcic horizons that contain negligible gypsum are less likely to be sodic or saline.

Non saline cracking clays can be encountered on active flood plains, overlie fractured calcretes or alluvial sand and gravel lenses that are associated with paleo-drainage lines.

Soil physical properties: Cracking clays have shrink–swell properties that may exhibit a granular self-mulching surface condition and deep vertical cracks, characterised by gilgaied, ‘crab hole’ micro-relief consisting of surface cracks, sinkholes, linear and or circular depressions with a vertical depth ranging from 10 to 60cm. The soils are freely drained when dry, as water bypasses the soil matrix and instead flows down the deep cracks, but infiltration is restricted once the clay subsoil swells.

Cracking clays with self-mulching (strong finely structured topsoils) are highly versatile horticulture soils. These soils have the advantage of retaining more soil moisture and moderately well drained within the upper soil horizons.

Potential soil management issues: Subsoil waterlogging and inundation limits traffic on these soils during the wet season. Topsoils of self-mulching clays are more resilient to degradation however, soil structure can be destroyed if worked or grazed when wet and irrigated with high sodium water. Periodic deep ripping and gypsum amelioration may be required especially where topsoils are degraded or not self-mulching.

Changes in soil chemistry under irrigation are likely to be minor although sodium salts can build-up in the subsoil on imperfect to poorly drained soils.

As cracking clays occur low in the landscape or within drainage systems it is essential to establish a cover crop or retain crop residues before the wet season to reduce soil erosion and nutrient loss.

Key points when selecting a site:

Surface drainage, flooding and the extent and severity of gilgai micro-relief are key factors to consider. Choose near level areas with grades of less than 0.5% if flood irrigation is considered. Slopes >0.5% are best avoided particularly adjacent to river banks where concentrated overland flow can cause back-cutting and gully erosion.

Areas where the microrelief is greater than 20–30cm are difficult to develop. Land grading is a possible solution, although the gilgai micro-relief will reform in time and the grading can expose more sodic or saline subsoils.

Avoid areas subject to frequent erosive floods and preferably with an Annual Return Interval of more than 1 in 20 years.

Further information:

Hazleton, PA and Murphy, BW 2007 *Interpreting soil test results: what do the numbers mean?* CSIRO Publishing, Victoria.

Smolinski, H, Laycock, J, and Dixon, J. (2011) *Soil assessment of the Weaber Plain (Goomig) farmlands*. Department of Agriculture and Food, Western Australia, Perth. *Resource Management Technical Report* 369.

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Nawra Explorer

https://www.csiro.au/en/Research/Major-initiatives/Northern-Australia/Current-work/NAWRA/Web-based-applications

2.1 Water requirements for irrigation

Chris Schelfhout

Key Messages

- A reliable supply of good quality water is the cornerstone to any irrigation development.
- Reliability of supply and water quality are more likely to influence the location and scale of an irrigation development than the availability of suitable soil or proximity to existing business infrastructure.
- Water quality analysis will identify potential risks to crops or soils prior to commencement of irrigation.
- The use of irrigation water above 180mS/m (i.e. 1000mg/L TDS) is not recommended in northern WA.
- Professional services may be required to collate the necessary water quality and yield information often requested by DWER as part of the licencing process.

Water Quality

Four key factors are often used to determine suitability of water for irrigation. These factors are; salinity, rate of water infiltration into the soil, specific ion toxicity, or other miscellaneous effects (Ayers and Westcot 1985). Soil type, crop species and method of irrigation are additional factors that must be considered when appraising the suitability of a water resource for irrigation.

Salinity

Low salinity irrigation water is essential to avoid crop yield penalties and long-term salt accumulation in the soil. The salinity of irrigation water is commonly reported in terms of electrical conductivity (EC) in milliseimens per meter (mS/m) or as parts per million, total dissolved salts (ppm TDS).

Water salinity: Converting units of measure
Total Dissolved Salts (ppm TDS) = 5.5 x EC (mS/m)
ppm is approximately equal to milligrams per litre (mg/L) when water density is 1kg/L

Irrigation water is considered fresh if it has a salinity value less than 90mS/m. Above 90mS/m water is classed as marginal and at 270mS/m or above, brackish. There is a low risk to crops or soil when using irrigation water of less than 90mS/m.

As the salinity of irrigation water increases, crops increasingly suffer yield penalties as a result of the increased stress of managing water and nutrient balance within the plant. Irrigation management strategies must be deployed to prevent accumulation of salts in the soil. Soil type, drainage and the frequency, method and duration of irrigation are factors that will affect the influence dissolved salts have on crops and pastures.

Some crop and pasture species grown in northern WA exhibit good tolerance to marginally saline or brackish irrigation water. Table 1 details the approximate irrigation water EC at which no yield loss is expected and also higher EC values at which 10% and 25% yield loss may be expected.

Table 1. Irrigation water salinity (mS/m) at which point yield loss is expected (adapted from Ayers and Westcot (1994)).

	Proportion of yield loss		
	0%	10%	25%
Grasses			
Barley	530	670	870
Panic grass	200	290	440
Maize	110	170	250
Oats	330	360	410
Rhodes Grass	460	670	980
Sorghum	450	490	550
Sudan grass	180	340	570
Legumes			
Cowpea	90	130	200
Faba bean	110	170	280
Lucerne	130	220	360
Vetch	200	260	350

Despite many crops having good tolerance to irrigation water salinity, caution must be taken if choosing to irrigate with brackish water. The result may be impacts on other species used in the cropping rotation and the long term accumulation of salts in the soil profile.

Due to soil and climatic factors the use of irrigation water above 180mS/m (i.e. 1000ppm TDS) is not recommended in northern WA.

Salinity levels in groundwater and surface water are influenced by geological, hydrological and climatic processes and vary considerably across northern WA. Table 2 lists the salinity values for a selection of the main water resources across northern WA.

Table 2. Salinity of water resources in northern WA (adapted from DoW 2014, Bennett 2019 and DPIRD field sampling)

Water resource	Typical salinity range (mS/m)
Surface water	
Ord River Irrigation Area - Lake Argyle	32
Fitzroy River (wet season – dry season)	35 – 160
DeGrey River	80 –180
North West Pilbara rivers (Maitland, Harding, Jones, George, Sherlock, Yule)	25 – 80
Upper Fortescue River (Newman)	80 – 180
Lower Fortescue River	180 – 470
Robe River, Cane River, Ashburton River	80 – 470
Yannarie River	25 – 80
Groundwater	
East Kimberley (Bonaparte) – Point Spring Sandstone	5 – 40
Fitzroy Valley alluvial aquifers	35 – 180+
LaGrange area - Broome sandstone aquifer	35 - 130
Pardoo to Mandora – Canning - Broome sandstone aquifer	180 – 540
Pardoo to Mandora – Canning - Wallal sandstone aquifer	50 – 125+
Lower DeGrey River - alluvial aquifer	50 – 180+
Shaw River - alluvial aquifer	50 – 180+
Woodie Woodie - Carawine dolomite aquifer	65 – 155
Newman - Fortescue River and surrounding aquifer	50 – 180+
North West Pilbara rivers - Coastal alluvial aquifers	70 – 300+

Infiltration

Irrigation water must be able to infiltrate to the root zone in a timely manner to enable unconstrained plant growth, especially in hot, dry conditions when crop water demand is high. Soil physical and chemical properties affect infiltration but water quality also plays an influential role.

Low salinity water (less than 50mS/m and especially below 20mS/m) is corrosive and tends to leach surface soils free of soluble minerals and salts, especially calcium, reducing their strong stabilizing influence on soil aggregates and soil structure (Ayers and Westcot 1994). Without calcium and other salts, the soil surface disperses when wet filling small pores in the soil matrix. As the soil dries problems often arise with surface crusting and crop emergence. Soil structure changes reduce the amount of water entering the soil in a given amount of time and ultimately causes crop water stress between irrigation events.

Sodium adsorption ratio and sodicity

Sodium is a common chemical element found in water. High sodium levels in irrigation water can damage plants and soil structure. Sodium adsorption ratio (SAR) is a measure used to determine the propensity of sodium delivered in irrigation water to displace calcium and magnesium adsorbed in the soil. Displacement of calcium and magnesium results in breakdown of soil aggregates and loss of soil structure, leading to compaction and surface-sealing issues. When this occurs, soils are termed ‘sodic’.

Irrigation water SAR formula; $SAR = Na^{+} / \sqrt{(Ca + Mg)^{++} / 2}$

(Sodium, calcium, and magnesium concentrations are expressed in milliequivalents/litre)

As a guide, SAR <3 poses no risk, SAR from 3 to 6 poses a moderate risk to clay soils only, a SAR >6 will have an increasingly detrimental effect on soils and crops and at a SAR >9 there will be a high risk of causing soil structure decline and considerable reduction in crop yield potential (NSW DPI, 2016).

The SAR of irrigation water should be considered in the context of both the EC of the water and the characteristics of the soil. High SAR values are of most concern when irrigating clay soils as the ability to leach sodium beyond the root zone is more challenging than on sandy soils.

If marginal or brackish irrigation water is used, regardless of the SAR reading it will introduce a large quantity of sodium to the soil profile. Increased sodicity of the soil creates further risk if fresh irrigation water is subsequently used at a later date. Fresh irrigation water with low calcium and magnesium content will be unable to balance out resident sodium in the soil leading to soil structure decline.

Specific ion toxicity

An ion is the charged particle of a chemical element or molecule. In the soil water solution ions interact by attracting or repelling one another depending on their charge. Plants can regulate movement of ions into their roots but this can become difficult to control when the concentration of ions of a specific chemical is very high. Some chemical elements supplied through irrigation water provide a positive contribution to crop nutrient requirements however at high levels, some elements become toxic to plants. Crop species vary in their susceptibility to ion toxicities. Table 3 lists the threshold water quality values for a selection of elements known to cause toxicity in crops or lead to long-term issues due to accumulation in the soil.

Table 3. Short and long term threshold values for chemical elements known to cause plant toxicity or soil accumulation risk.

Element	Long-term Threshold Value (mg/L)	Short-term Threshold Value (mg/L)	Suggested Soil Contaminant Loading Limit (kg/ha)
Aluminium	5	20	ND
Arsenic	0.1	2	20
Beryllium	0.1	0.5	ND
Boron	0.5	See Table	ND
Cadmium	0.01	0.05	2
Chromium	0.1	1	ND
Cobalt	0.05	0.1	ND
Copper	0.2	5	140
Fluoride	1	2	ND
Iron	0.2	10	ND
Lead	2	5	ND
Lithium	2.5	2.5	ND
Lithium (Citrus)	0.075	0.075	ND
Manganese	0.2	10	ND
Mercury	0.002	0.002	2
Molybdenum	0.01	0.05	ND
Nickel	0.2	2	85
Nitrogen	5	12-125	ND
Phosphorus	0.05	0.8-12	ND
Selenium	0.02	0.05	10
Uranium	0.01	0.1	ND
Vanadium	0.1	0.5	ND
Zinc	2	5	300

High concentration of detrimental elements such as fluorine and arsenic, have been found in groundwater samples in parts of the Pilbara highlighting the importance of obtaining a full chemical analysis before using water for irrigation.

High sodium irrigation water can lead to soils with a high exchangeable sodium percentage (ESP). High ESP soils make it difficult for the crop to absorb other nutrients such as potassium, leading to reduction in crop yield potential.

Maize and many annual legumes species (field pea, mung bean, cowpea) are more sensitive to sodium than most temperate and tropical grasses. Rhodes grass and lucerne tolerate higher sodium levels in the soil solution.

Chloride ions easily move through the soil solution into plants. High chloride irrigation water can lead to accumulation of toxic levels of chloride in leaves, often presenting as burning on leaf tips. Horticultural crops and legumes tend to be more sensitive to chloride than cereals and other forage crops.

Irrigation water with high sodium or chloride, if applied by sprinkler can cause leaf scorching and leaf drop in more sensitive crops (Table 4). Sprinkler irrigation in hot, windy conditions is not only inefficient but is unfavourable for sprinkler irrigation with high sodium or chloride water as it leads to rapid precipitation of salts on the leaf surface.

Table 4. Irrigation water chloride and sodium concentration and crop sensitivity to leaf damage.

Sensitivity	Chloride (mg/L)	Sodium (mg/L)	Affected crop
Sensitive	<178	<114	Almond, apricot, citrus, plum
Moderately sensitive	178–355	114–229	Capsicum, grape, potato, tomato
Moderately tolerant	355–710	229–458	Barley, cucumber, maize
Tolerant	>710	>458	Cauliflower, cotton, safflower, sesame, sorghum, sunflower

Boron toxicity symptoms normally show first on older leaves as a yellowing, spotting, or drying of leaf tissue at the tips and edges. Many horticultural crops, temperate cereals and legumes are sensitive to high boron levels. Maize, sorghum and lucence exhibit higher tolerance to elevated boron.

'Hardness' is used to describe the level of calcium and carbonate in irrigation water. Hard water may have high calcium (Ca^{2+}) and carbonate (CO_3^-) or high calcium and high sulphate (SO_4^{2+}) and can lead to precipitation of lime ($CaCO_3$) and gypsum ($CaSO_4$) or on plants or to fouling of irrigation equipment.

The pH scale represents the acidity or alkalinity of water. The ideal pH range for irrigation water is 6 to 8.4. Irrigation water with a pH below 6 and above 8.5 may be corrosive to irrigation equipment.

Water quality analysis

In the first instance a handheld EC meter will provide a reasonably accurate reading of water salinity. If the salinity reading is within an acceptable range, a correctly prepared sample from the prospective irrigation water supply should be submitted to a laboratory for full chemical analysis prior to use. A chemical analysis will indicate not only the overall salinity of the water but also the relative proportions of a range of chemical elements. There are several laboratories in WA that provide comprehensive water quality analysis.

Yield and reliability of water supply

Reliability of an irrigation water supply is paramount to the viability of the enterprise. Brief periods of water deficiency can significantly reduce crop and pasture yields. Reliability of supply is influenced by the scale of the resource and the rate and processes by which it is replenished.

It is essential to understand the supply capability of the water resource when planning an irrigation development, to ensure it can meet the requirements of the proposed area of irrigated crop or pasture. Failing to do so can result in production losses or the development of an inefficient and/or unreliable irrigation system.

The capability of the water supply should be appraised in terms of the instantaneous supply rate and the long term reliability of the resource. DWER may request information on long-term reliability of the water supply when assessing the sustainability of the resource during their water allocation and licencing process.

An understanding of the instantaneous supply rate from the water resource is very important for irrigation system design and efficiency. Professional hydrogeological services may be required to assist with this assessment.

An irrigation water resource must be capable of an instantaneous supply rate that meets crop water demand in the hottest and driest times of the year. In most areas of northern WA crop water demand peaks in November prior the start of the wet season and can exceed 13mm/day. High levels of evaporative demand can persist for longer in inland areas of the Pilbara where humidity tends to be lower and wet season rainfall is more variable.

Estimated seasonal water demands for several crop types at locations in the Kimberley and Pilbara are summarised in Table 5.

Table 5. Estimated seasonal crop water requirement and daily requirements at peak crop demand for a selection of crops and pastures at several locations in northern WA.

Crop or pasture	Season	Total water requirement for cropping season (or year for perennial crops) (ML/ha)
Fitzroy Crossing		
Rhodes grass hay	Perennial	18
Sorghum hay	Sept. - April	25
LaGrange and East Pilbara coast		
Rhodes grass hay	Perennial	18
Sorghum hay	Sept. - April	24
Maize silage	May – Aug	6
Karratha		
Rhodes grass hay	Perennial	19
Maize silage	May – Sept.	7
Sorghum hay	Sept. - April	24
Oaten hay	May-Sept.	7
Newman		
Rhodes grass hay	Perennial	15
Maize silage	May – Sept.	6
Oaten hay	May –Sept.	5
Lucerne hay	Perennial	24

Groundwater resources

Expansive, deep aquifers often constitute the most reliable water supplies due to their lower response to seasonal fluctuation. The West Canning Basin is an example of such a resource. Higher development costs of commissioning deep artesian bores in the Wallal Sandstone aquifer are offset by a high yielding and reliable resource.

Many other shallower aquifers in northern WA are capable of yielding good water supplies. These local aquifers are generally reliant on local rainfall and, or stream flow events for recharge. Preferably, an aquifer targeted for irrigation supply will have a relatively shallow watertable but has good depth of saturated material that permits the storage of a significant volume of water.

Shallow aquifers may require more expansive bore development to meet supply requirements. Irrigation operating cost increases with depth to water, and if abstraction must also be spread over a wide area, developments from these types of aquifers may have to be constrained to small scale ventures.

Thorough hydrogeological investigation will provide understanding as to the suitability of these aquifers. Table 6 highlights the variation in groundwater bore yields from various aquifers found in northern WA.

Table 6. Groundwater bore yields from a selection of northern WA aquifers (sourced from Haig 2009, Harrington and Harington 2015, Paul *et al* 2019 and DPIRD field sampling).

Locality	Aquifer	Potential yields from production bore (ML/day)
Bonaparte	Point Spring Sandstone	
LaGrange	Broome sandstone	1.7 – 6.0
Fitzroy Valley	Lower Fitzroy River alluvial	0.3 – 0.4
Yule River	Coastal alluvial	2.0+
Lower DeGrey	Alluvial, Paleochannel	1.0 – 2.0
Shaw River	Fractured rock	1.0+
Karratha	Maitland River alluvial	0.5 – 1.0
Woodie Woodie	Carawine dolomite aquifer	10+
West Canning Basin	Wallal sandstone aquifer	10+

Surface water resources

The use of surface water in northern WA is limited to the Ord River scheme and much smaller developments at Liveringa and GoGo on the Fitzroy River. Most river flows in the Kimberley and Pilbara have low salinity levels (Table 2). Occasionally, the extreme tail end flow of some Pilbara rivers may experience elevated salinity readings. When abstracting surface water for irrigation, the principles of supply reliability is equally as relevant as it is for groundwater.

In most catchments stream flow is highest in the months from January to March, coinciding with the northern monsoon. The higher variability of rainfall in the Pilbara means that some rivers and streams do not flow every year. The narrow window of opportunity to abstract free flowing surface water means that water must be banked for later use. Construction of in-stream dams are limited in site opportunity and often prohibitively expensive for mosaic style irrigation developments at the pastoral property scale.

Off-stream storage as used at Liveringa, and GoGo or managed aquifer recharge are possible options to harness stream flow for later use. Dowsley *et al*. (2018) completed preliminary investigation into the potential for managed aquifer recharge (MAR) in the Pilbara. An example of MAR is the system on the Ashburton River at Minderoo Station. A low weir has been constructed to impound water below major flood level and assist recharging a paleo-channel below the present river bed. Shallow bores adjacent to the river abstract water for irrigation. Storing water via MAR mitigates evaporative losses that would otherwise be experienced in surface storages. The practicality and location of aquifer recharge and off-stream storage schemes for irrigation supply are the subject of current investigations by DPIRD at other locations in northern WA.

Other water resource information

Thorough investigations have been undertaken in what DWER terms ‘target aquifers’, resources from which they allocate public and industrial water supply. Many aquifers adjacent to major mining operations in the Pilbara have also been thoroughly investigated. For all aquifers the onus is on the developer to undertake the necessary investigations to demonstrate the water resource capability prior to DWER issuing a licence.

DPIRD, DWER and non-government proponents have conducted numerous groundwater investigations across northern WA (Table 7). Availability and abundance of water resource information varies from site to site, however much information is available to assist in targeting prospective locations and water resources for irrigation agriculture.

Prospective irrigators are encouraged to contact DWER in the first instance to understand what resource information is available and what further information may be needed to satisfy licence requirements. DPIRD can also provide comprehensive information in those areas of the Kimberley and Pilbara where they have conducted investigations with a particular focus on identifying water resources for prospective irrigation development.

Table 7. Investigations into groundwater resources with potential to support irrigated agriculture in northern WA.

Locality	Water resource	Proponent and date of investigation
Kimberley		
Ord Irrigation Expansion (Goomig Farmlands, Cockatoo Sands and Bonaparte)	Alluvial aquifer and paleochannels	DPIRD (2010-2017)
Fitzroy Valley	Fitzroy River alluvial	CSIRO (2016-2018)
LaGrange	Broome sandstone	DPIRD (2012-2016)
West Canning Basin	Wallal Sandstone	DWER (2012-16)
Pilbara		
Lower DeGrey	DeGrey River alluvial aquifer and paleochannel	Various contractors for Water Corporation (2005-2011), DPIRD (2019)
Karratha Hinterland	Coastal alluvial aquifers	DPIRD (2018-2020)
Robe River	Lower Robe alluvial	DWER (2010)
Newman	Upper Fortescue alluvial aquifer	DPRID (2019-2020)
Woodie Woodie	Carrawine dolomite	DPIRD (2016)
Oakover Valley	Oakover, Nullagine and DeGrey River alluvial	GHD (2017)

For further information:

Contact DWER at Karratha, Broome or Kununurra for information on the water resources and the water licencing process.

Visit DPIRD website and search for:

- ‘land and water assessment’ for information on DPIRD resource assessments in northern WA.
- ‘water salinity and irrigation’ for more information on irrigation water quality

Visit the National Association of Testing Authorities website to search for laboratories that can provide water analysis services; https://www.nata.com.au/

2.2 Irrigation management

Christopher Ham

Key Messages

- Understanding and learning about irrigation management is a valuable skill that can save money and ensure sustainable use of water resources.
- Regardless of the type of irrigation system chosen, the system capacity is a very important factor to consider when designing an irrigation system.
- Irrigation management becomes easier with practice. It requires good record keeping, weather data, basic maths and preferably soil moisture monitoring.

Irrigation is a significant investment; so maximising efficiency of costly inputs is one way to improve the financial return. In most self-supplied irrigation systems, a major variable cost is the energy required to move and pressurise water, using electricity, diesel or solar generated power. While artesian pressurised aquifers minimise the energy required to supply water, the capital cost is higher and water use efficiency is still important. Irrigation management contributes to efficient use of energy, maximising crop inputs, reducing offsite impacts and demonstrating sustainable use of our natural resources.

There are three basic types of irrigation system:

- sprinkler systems; either set sprinklers, a centre pivot or lateral move systems
- surface furrow irrigation systems
- sub-surface or surface drip systems.

Each system has their merits and limitations and their suitability is dependent on many variables. It is not within the scope of this paper to explore each option in detail. Regardless of the system type, the irrigation engineers will need to calculate the:

- minimum supply rate (desired system capacity)
- managed system capacity

- evaporative losses
- energy source and requirements.

The challenge is to reduce cost, maximise efficiency, flexibility and security of supply to the irrigation operation, with there being constant tension between these factors. Reducing the cost of infrastructure per unit area typically requires distributing less water over more land. Under-engineering the system will increase the risk of inadequate supply during periods of peak demand. Over-engineering the system could unnecessarily increase the capital cost. Appropriately engineering the system will ensure adequate supply of water at all times and provide for maximum flexibility in irrigation management on a daily basis.

Irrigation management involves:

- estimating individual crop demand
- developing a total annual water budget
- applying specific water applications in a manner that meets crop demand without wasting energy, water or nutrients.

Irrigation management becomes easier with experience supported by field observations, weather data and record keeping. Soil moisture monitoring also provides valuable feedback for irrigation managers (refer to section 2.3).

System capacity

System capacity refers to the sustainable supply of water available to the irrigation system can apply in 24 hours. The system must be able to meet peak periods of demand. Under-designed systems will be unable to supply enough water to manage periods of sustained hot weather, or provide additional water to catch up after delays caused by maintenance, harvest or breakdowns.

Rule of thumb ─ system capacity

For the semi-arid tropics, DPIRD recommends a minimum constant water supply of 1.5L of water per second per hectare of irrigated land.

For example, a bore that produces 60L per second is capable of irrigating a maximum of 40ha, assuming 100% efficiency.

Expanding on the example above, if a centre pivot was installed with a supply of 60L per second then this system will have the capacity to apply up to 13mm of irrigation per ha in 24 hours over the whole 40ha (at 100% efficiency). Therefore, measurement of the system capacity is in mm/day.

System capacity is a key design criteria. Over-design can result in unnecessary capital costs, while under-design can result in losses of production during periods of peak demand

Irrigation management requires varied rates of application. If the supply rate is constant, then varying the application depth per pass (millimetres of water applied per irrigation) requires changing the speed of the irrigator and therefore the time required to complete a full revolution. This is an important aspect to understand when calculating irrigable area based on supply volumes. Table 1 provides an example, based on typical design parameters, a range of varied application rates against the time taken to complete a full revolution with a constant supply rate.

Table 1. Typical application rates and time taken to complete a full circle for a 40ha centre pivot with a constant supply of 1.5L per second per ha.

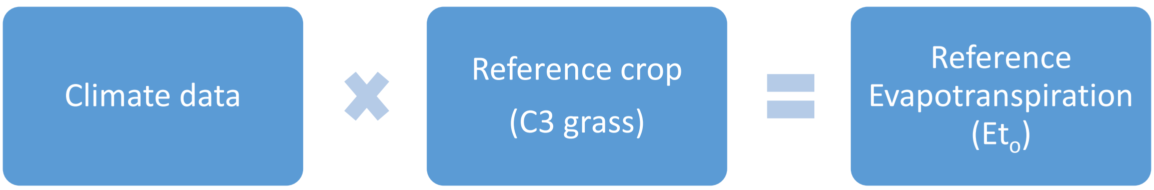
Application amount per full revolution (mm)	Revolution time in hours (hours)
7.5	13.9
9.3	17.3
12.5	23.1
13	24
18.7	34.7
22	40.8
22.6	41.8

Based on the example above, an irrigation of 25mm would take approximately 48 hours to apply as one full revolution over the 40ha. Presuming the soil type can absorb 25mm in a single irrigation then this will adequately meet crop demand for several days during mild weather. This will allow one or more days of not watering for maintenance and field operations. This supply rate can also cope with periods of peak demand in very hot weather as evapotranspiration rarely exceeds 13mm per day for an extended period and will allow for periodic maintenance.

How much water will a crop require?

The simplest method to predict the estimated water demand is to use reference evapotranspiration (Et_o) data from the Bureau of Meteorology (BoM). The BoM can estimate reference Et_o for any location using climate data from the nearest weather stations. The BoM base the calculation on the water demand from a reference crop, which is defined as a C3 grass crop, 15cm tall with 100% groundcover that is never short of water. Evapotranspiration units are mm on a daily, monthly or annual basis.

The BoM reference evapotranspiration formula is:



For a more accurate estimate of an actual crop, calculations need to include a crop factor (K_c). The crop factor takes into account the specific crop type, the growth stage and the groundcover at different growth stages, which will differ from a standard reference crop. Long-term average values of Et_o are useful predictive tools, however for irrigation scheduling it is important to use the actual daily Et_o in the calculations.

Crop evapotranspiration formula is:

Reference Evapotranspiration (BOM Et_o) × Crop Factor (K_c) = Crop Evapotranspiration (Et_c)

Understanding and varying the crop factor is the key to calculating actual crop evapotranspiration. A soil moisture monitoring system is an extremely useful tool to assist irrigation managers to track soil moisture levels to cross-reference with irrigation amounts and help refine crop factors under local conditions (Refer to Soil Moisture Monitoring section 2.3).

For annual crops, the crop factors will typically increase with the crop height and groundcover, peak at maturity and then reduced to nil water applied prior to drying out grain in preparation for harvest. Table 2 provides an example of the crop factors for a typical annual crop such as grain sorghum.

Table 2. Typical crop factors for an annual crop matched to growth stages

Annual crop	Crop stage					
	Seedling	40cm high	1m high	Seed formation and maturity	Pre harvest	Harvest
Groundcover (%)	10%	40%	80%	100%	100%	100%
Crop factor (K_c)	0.5	0.7	0.9	1.1	0.9	0

The crop factors for a perennial C4 grass like Rhodes grass will require a cyclic pattern that will vary according to the cutting cycle. When grazed perennial C4 grasses tend to require a more constant crop factor. Perennial and annual C4 grasses use water more efficiently than C3 grasses; hence, the crop factors tend to be lower. The reference evapotranspiration will increase with high temperatures and low humidity; however, the crop factor is more reliant on the stage of the crop than the climate. Table 3 provides an example of typical crop factors for a perennial grass such as Rhodes Grass.

Table 3. Typical crop factors for a perennial C4 grass matched to harvest cycles

Perennial C4 grass	Crop stage				
	First week after cutting	4 leaf stage (pre-harvest)	First week after cutting	4 leaf stage (pre-harvest)	Stand and graze
Groundcover (%)	70-100%	100%	70-100%	100%	100%
Crop factor (K_c)	0.5	0.7	0.5	0.7	0.7

The Food and Agriculture Organisation of the United Nations has an extensive database of information on the crop factors of a wide range of annual crops, click here to access the database http://www.fao.org/land-water/databases-and-software/crop-information/en/.

No irrigation system is 100% efficient and the efficiency (or losses) must be included in the next stage of calculations. The definition of irrigation efficiency is the amount of water used by the crop compared with the total amount of irrigation applied as a percentage. As an example, if the crop uses 95% of the water applied then the irrigation efficiency is 0.95.

Losses can occur through leaks, poor sprinkler placement or design and evaporation from the soil or sprinkler droplets and vary with the type of irrigation system (Table 4). Irrigation engineers are very aware of the potential losses, highlighting the importance of engaging expertise in the design phase.

Crop Evapotranspiration (Et_c) ÷ Irrigation efficiency = Irrigation requirement (mm)

Isolated rain events or extended periods of wet weather will contribute to the soil moisture and irrigation may not be necessary. High temperatures often follows rain events, particularly in the wet season. Irrigation managers must judge how much of the rain is effectively stored in the soil profile and when to begin irrigation again. Much of the excess rainfall will drain quickly, particularly on deep sands and irrigation may be required within 7 to 10 days.

Example of calculating a daily irrigation requirement using the methods explained in this paper:

If BoM Reference Evapotranspiration (Et_o) = 9mm

Crop factor (K_c) = 0.7

Crop Evapotranspiration (Et_c) = Et_o x K_c = 9 x 0.7 = 6.3mm

Irrigation efficiency = 0.85 (85%)

Irrigation requirement = Et_c ÷ 0.85 = 6.3/0.85 = **7.4mm**

Table 4. Comparison of irrigation system types and typical irrigation efficiencies

Irrigation system type	Typical efficiency	Range
Centre pivot/Lateral move	85% (0.85)	±5%
Sub-surface drip system	90% (0.90	±5%
Solid set sprinklers	65% (0.65)	±15%
Furrow (surface) irrigation	65% (0.65)	±20%

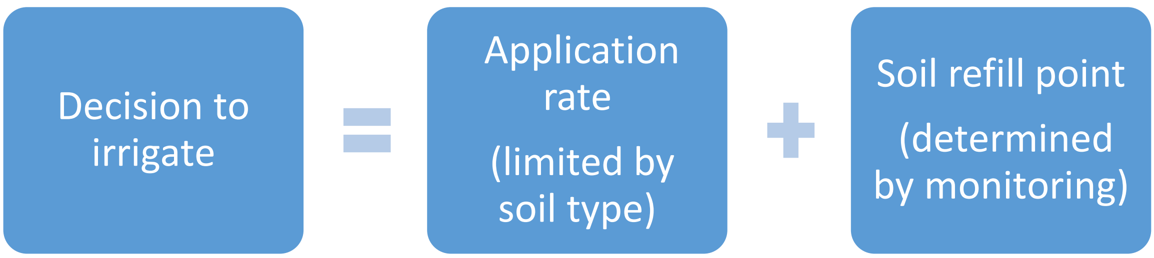
In order to calculate irrigation efficiency a field test is required. The Department of Primary Industries, New South Wales has published a thorough method, click on the link to access this https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/317478/Evaluating-a-centre-pivot-irrigation-system.pdf

How much water do I need to apply per irrigation?

The irrigation required in mm per day provides a guide to the crop demand; however, in most situations, with the exception of drip systems, it is usually not practical or efficient to irrigate every day. As shown in Table 1 applying larger amounts of water will take more than 24 hours in many cases. Learning when to apply and how much to apply requires the ability to understand the hydrology of the soil type and the interrelationship with crop growth and root uptake. These decisions become easier with experience. The ideal irrigation cycle will fill the root zone and allow the plants to deplete this water to a predetermined refill point and then fill the profile back up again. This cycle will maintain the soil moisture present in the whole root zone so that there is no physical stress on the crop.

The first step in judging when to irrigate requires the ability to know when the soil has reached the refill point, before water stress starts to limit crop growth. Water stress can occur several days before the plant shows signs of wilting. The amount of irrigation required relates to the evapotranspiration rate and crop phase and demand. The most efficient irrigation cycle will provide the right amount of water to fill the root zone, without causing run-off or deep drainage below the root zone

There will be occasions where this does not go to plan. Good system design is important to be able to compensate for breakdowns, extreme weather events and catching up after periods when it is not possible to irrigate. This additional or spare capacity may only be required occasionally, but will be critical when required.



The soil type will determine the maximum application rate, which can be applied in a single irrigation. If the irrigation exceeds the infiltration capacity of the surface soil it can cause puddling, wheel rutting or run-off. Water moves through the soil profile to deeper layers when the pores in the upper layer are full of water and the gravitational forces exceed the water holding tension of the soil pores. This will happen more quickly in a sandy soil than in a loam or clay soil. Therefore, clay and sandy soils have different irrigation strategies.

Sprinkler irrigation on deep sands

DPIRD recommends that three standard applications will suit most purposes when irrigating sandy soils using a centre pivot.

- 6-8mm – a small application, most suitable for fertiliser applications, post-herbicide applications, is likely to penetrate to a depth of 10-15cm.
- 12-15mm – a medium application is likely to penetrate to a depth of 20-25cm.
- 20-25mm – is the maximum single application, without causing run-off, and is likely to penetrate to 40-50cm.

The simplest way to manage irrigation is to select pick three applications that suit most situations, for example 8mm, 15mm and 25mm and use them most of the time. Then adjust the time interval between the applications to reflect the prevailing weather conditions or once the soil has reached the refill point. This is preferable to constantly adjusting the system to apply different amounts based on daily changes in evapotranspiration.

If the deeper root zone is dry (up to 1m), then application of two to three large (20-25mm) consecutive irrigations will be required to wet the deeper subsoil.

Producer experience ─ drip irrigation on deep red sands

David Stoate from Anna Plains Station manages a drip irrigation system to water his Rhodes grass crop. Drip systems apply water daily, typically around 5 to 9mm per day to match crop evapotranspiration.

David installed a sub-surface drip system because it has:

- high water use efficiency
- the ability to deliver fertiliser directly to the root zone
- in addition, is protected from cyclonic winds.

Challenges have included patchy establishment in sandy soils due to limited capillary rise, uneven wetting due to limited lateral flow and roots blocking emitters.

Producer experience - sprinkler irrigation on clay soils

Jake O'Dell from Liveringa Station manages centre pivot systems on the black cracking clay soils of the Fitzroy Valley. Jake recommends applying a maximum of 12 to 14mm is applied in any single irrigation on clay soils, while he prefers to apply~9mm . He also recommends maintaining subsoil moisture after the wet season or any significant rainfall to ensure the deeper subsoil remains moist all year. Unlike sandy soils, it is quite difficult to re-wet a clay soil profile, as large irrigations will create boggy conditions on the surface.

Further reading:

Irrigation Australia conducts training courses on how to manage and maintain irrigation systems; they also have a great range of publications and links to expert consultants. Further information is available on their website https://www.irrigationaustralia.com.au/.

Irrigation Association 2011, *Irrigation,* 6th edn, Irrigation Association of America Falls Church, VA 22042

Smith, P. *et al,* 2014, *A review of the Centre Pivot and Lateral Move irrigation installations in the Australian Cotton Industry,* Department of Primary Industries, New South Wales

Harvey, A. *et al* 2016 Irrigation Glove Box Guide, Government of South Australia

Cotton Research and Development Corporation 2012 *Waterpak – a guide for irrigation management in cotton and grain farming systems,* Cotton Research and Development Corporation

2.3 Soil moisture monitoring

Sam Crouch

Key messages

- Soil moisture monitoring technology vary in cost, complexity and precision.
- Soil moisture monitoring can be used as the basis for irrigation scheduling, or simply as a check to ensure that irrigation scheduling based on weather data is working in practice.
- Irrigation scheduling involves setting a full point and a refill point and using a monitoring tool to tell you where you sit between these limits.
- Soil moisture monitoring technology helps maximise water use efficiency and profitability.
- Water content sensors are the most precise and most useful tool for irrigation scheduling, however extensive data is generated and to new users this can be overwhelming
- Over-watering can result in onsite and offsite impacts. Improving irrigation efficiency can prevent these issues.

Irrigation in northern WA requires a high degree of management due to the combination of episodic rainfall, the low water-holding capacity of coarse-textured soils and high to very high evapotranspiration rates. Minimising crop stress and maintaining soil moisture status requires attention 365 days of the year. Watering decisions need to be precise and made daily to maintain the soil moisture status between field capacity and the refill point. Soil moisture monitoring makes these decisions simpler, faster and more accurate.

Moisture stress adversely affects the quality and yield of crops and pastures. Over-watering wastes water and can result in the leaching of mobile nutrients like nitrogen. Soil moisture monitoring helps avoid over- or under-watering and improves the efficiency of water use.

Soil moisture probes provide real-time data on the relative amount of soil moisture in the profile. Combining this information with evapotranspiration and crop factors ensures well-informed irrigation decisions (Section 2.2).

Soil moisture terminology

To effectively and efficiently meet crop water requirements, it is important to understand some key terms.

Readily Available Water (RAW) is water that a plant can easily extract from the soil (Figure 1). As soil starts to dry out plant roots must work harder to extract water as the water is bound more tightly to the soil particles. Onset of moisture stress and reduced plant growth starts as soon as the crop depletes the RAW.

Field Capacity (also called the Full point or **Upper Storage Limit**) is the amount of soil moisture or water a soil can hold after downward movement caused by gravity has ceased. This takes about 24 hours in coarse-textured soils and 48 hours in medium- and fine-textured soils. Field capacity can be measured in the field or the laboratory.

Wilting Point (or **Lower Storage Limit**) is the soil moisture content below which roots cannot extract any more water from the soil.

Refill Point is the soil moisture content when the plant has used all the readily available water and lies between field capacity and wilting point.

Setting a refill point will be determined by the soil type, the monitoring technology and the irrigation system. As a rule of thumb: the refill point can be first set at 50% depletion of field capacity. This figure can then be refined with the data produced and the response of the crop. Irrigation system design will impact how an irrigation program can be scheduled. It is necessary to know how much water can be applied efficiently to the crop and the time required to apply a specific amount of water. A refill point will be set where a single irrigation can be applied to fill the root zone after it has depleted the RAW.

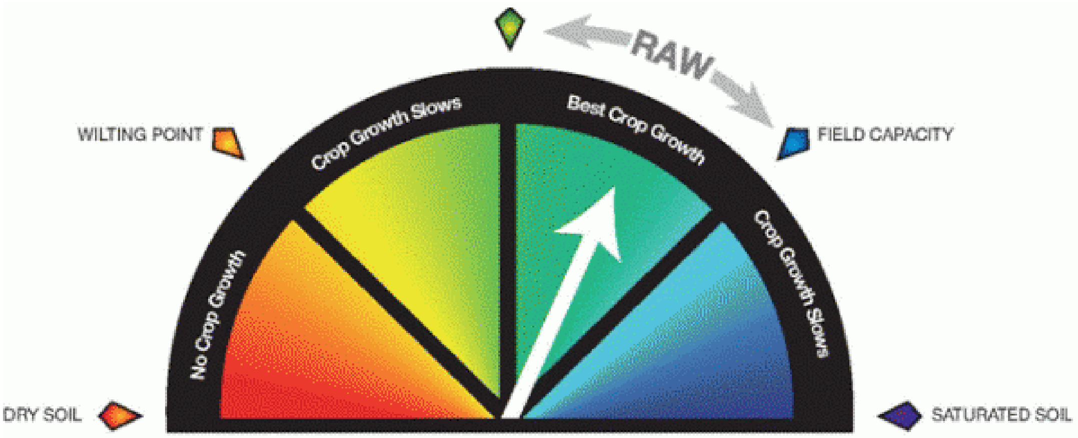


Figure 1. Relationship between readily available water and crop stress (Source DPIRD)

Scheduling a wetting – drying cycle

DPIRD soil moisture monitoring program indicates that irrigating to a scheduled wetting and drying cycle improves the water use efficiency of the crop. This refers to irrigation scheduling that fills the whole root zone and then allows the soil to dry to a set refill point before watering again (Figure 1). Staying within the RAW zone with small frequent irrigations is both an inefficient strategy and encourages shallow root activity. Losses from sprinklers and evaporation from the soil and plant canopy occur with each irrigation. A clear wetting-drying cycle with larger, less frequent irrigation applications reduces these losses and encourages deeper root activity.

Soil moisture monitoring is knowing the moisture status at any point in time (Figure 2). Irrigation scheduling using this information can maximise water use efficiency.

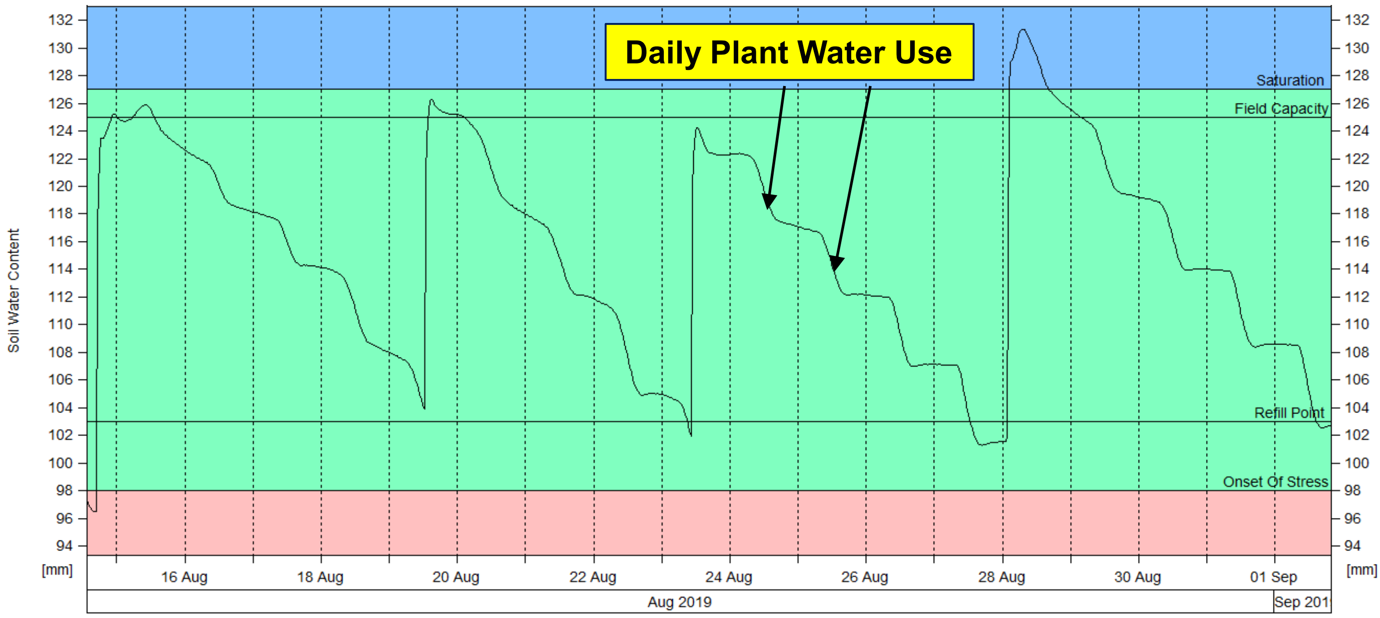


Figure 2. Total soil moisture over a depth of 150cm at Mowanjum Station showing regular irrigation applications, together with the field capacity, refill and stress lines (using the IrriMAX^{TM} software). Irrigation cycles ensure soil moisture status remains within the refill zone. Daily plant water use is observed by the daily downward steps and reduced water use at night.

What monitoring technology is available?

Methods for irrigation monitoring vary in complexity and precision from checking the soil moisture status in the field to continuous monitoring using a range of technologies. The strengths and limitations of the three main options: gypsum blocks (granular matrix), tensiometers and water content sensors are compared in Table 1 and discussed below.

Table 1. A comparison of soil water monitoring technology

Soil water monitoring technology	Suitability for sandy soils	Suitability for loams and clays	Maintenance requirements	Data reliability	Data complexity	Cost	Ease of installation
Gypsum blocks	√	√√√	Low - Monthly	Low	Low	$	√√√
Tensiometers	√√√	√√	High - weekly	Low-moderate	Low – moderate	$$	√√
Water content sensors	√√√	√√√	Low-monthly	High*	Medium – High	$$$	√

* If installed correctly

Gypsum blocks are the lowest cost, but they provide the least reliable data and are not suitable for coarse-textured soils. The accuracy can vary between 10-25% of the actual soil moisture status. They are slower to respond to changes in soil moisture than the other methods, which makes them unsuitable for use in crops sensitive to water stress. The calibrations are for generic soil types and may not be suitable for all soils. The blocks have a limited lifespan of 1-2 years due to gypsum dissipating.

Tensiometers require weekly maintenance to ensure the results are reliable.

- All soil moisture monitoring technology requires close contact between the probe and the soil, however the regular maintenance requirement of tensiometers can disturb this contact.
- Regular calibration is also required.
- The pressure values may not be accurate for specific soil types.
- Root growth into the porous tip can adversely affect readings.

Tensiometers only measure a specific point in the soil, so multiple tensiometers are required to measure the whole root zone. Tensiometers are available in lengths ranging from 15cm to 182cm, allowing installation in the soil at various depths.

Water content sensors are the most accurate and the most expensive option. In addition to the cost of the probe, a yearly subscription for a program to analyse the data is required. There are a range of programs available which differ in the way the data is presented and user friendliness.

Water content sensors produce extensive data, which for first time users can be overwhelming. However, once the initial setup is complete, the system becomes increasingly easier to use and proves to be very efficient when it comes to making irrigation decisions.

Installation of the probes requires the use of special tools and can take some time and care to install. If not installed with a good contact between the soil and probe false data is provided. Users in the Kimberley and Pilbara have found that probe placement is critical. Anything that results in a poor probe-soil contact, such as ant hills, rocky soil etc. will provide false data.

Caution when mowing the paddock – as a number of probes have been damaged which becomes expensive to fix. Grass that is left uncut around the probe after mowing needs to be cut to the same height as the rest of the paddock to ensure it is representative of water use across the rest of the paddock.

DPIRD research scientist Chris Ham setting up automated soil moisture monitoring

Description of options

Stainless steel push probe

A steel push probe is the simplest method for determining soil moisture status and is a handy tool to have in the back of the ute. The probe should push easily into moist soil, but conversely, will be difficult to push through dry soil. They are useful for:

- determining the depth of soil moisture – The depth to which the probe can be easily pushed corresponds to the depth of readily available water.
- detecting subsoil compaction (traffic pans) in coarse-textured soils. Suspect a traffic pan when it is comparatively difficult to push the probe through soil 15-30cm deep which is near field capacity.

This method only indicates the depth of soil moisture at the time of the measurement. Soil moisture sensors are essential to measure the soil moisture status and changes over time.

Water potential sensors

Water potential sensors measure how hard it is to remove water from the soil, providing a reasonable indication of available water for plants. Soil type and water content influence the suction pressure required to remove water from the soil, but a monitored sensor, which is recorded and graphed, will show the sharp fall that indicates water has become hard for a plant to access. They are a relatively low cost, easy way to measure the available soil moisture. The data is straightforward to understand and specialty installation equipment is not required.

The most common water potential sensors are gypsum blocks (granular matrix sensors) and tensiometers.

Gypsum blocks (Granular matrix)

Gypsum blocks consist of two electrodes embedded into a block of gypsum and work by measuring the electrical resistance between the electrodes. The resistance varies with the moisture content in the block, which depends directly on the soil water tension. The higher the soil water content, the lower the electrical resistance, because the electrical current passes more easily through water than gypsum. After the electrical resistance is measured, the water tension is calculated using calibrations to determine the plant available soil moisture.

Gypsum blocks are suitable for use on medium-textured soils and provide a 'ballpark' figure on the soil moisture. They are the cheapest and easiest technology to install, and the results are easy to understand.

Tensiometers

Tensiometers consist of a closed tube with a porous ceramic tip on the end. There are two types of tips one suitable for coarse-textured soils and the other for use in medium- to fine-textured soils. A vacuum gauge at the top measures the moisture status. The probe is filled with water and installed into the soil and the ceramic tip allows water to move freely in or out of the tube. As the soil dries out water is drawn through the tip creating a partial vacuum in the tube which is read on the vacuum gauge. When irrigation is applied water is drawn back into the tube, decreasing the vacuum resulting in lower reading on the gauge (Table 2).

Tensiometers have the potential to be a useful moisture monitoring tool for irrigators who want easy to read data that anyone working within the operation can understand (Table 2). The data is more accurate than gypsum blocks.

They are used extensively in horticulture in southern WA, however they have not been used in northern WA on a pastoral operation, so it is unclear how effective they would be and any specific issues there may be.

Table 2. Pressure readings and their relationship to moisture status in coarse-textured (sandy) soils and fine-textured (clay) soils.

Reading (kPa)	Interpretation for coarse-textured soils	Reading (kPa)	Interpretation for fine-textured soils
0-8	Soil is saturated and draining	0-10	Soil is saturated and draining
8-10	Field capacity	10-30	Field capacity
10-25	Good conditions – soil moisture and aeration	30-60	Good conditions – soil moisture and aeration
25-35	Refill point	60-100	Refill point
35-50	Onset of moisture stress in well-drained soils	100-150	Onset of moisture stress in well-drained soils
50+	Soil is very dry, possibly at or near wilting point	150+	Soil is very dry, possibly at or near wilting point

*Table is a guide only, every soil will differ, contact local dealer for detailed charts.

Water content sensors

These probes measure the water content of soil by measuring the time of a pulse travelling and returning to electrodes on a capacitance sensor. Sensors are positioned at depth intervals of 10-20cm in a sealed plastic rod which can be up to 2m long. Most sensors are accurate within 2-3% of the actual soil moisture content. Multiple depth measurements on the one probe provides information on water movement through the soil profile and the soil moisture content at different depths. These sensors are currently the only moisture probes used commercially in the Pilbara and Kimberley.

The data is uploaded to a program on a phone or computer remotely via mobile network or can be uploaded manually. The data can be complex and difficult to interpret, which has caused some irrigators not to prioritise water monitoring. However, once the data has been analysed, and the field capacity and refill points have been established, irrigation scheduling becomes straightforward (Figure 2).

Further information:

DPIRD website: https://www.agric.wa.gov.au/horticulture/soil-moisture-monitoring-selection-guide

Charlesworth, P. and Currey, A., 2005. *Soil Water Monitoring*. Canberra, A.C.T: Land & Water Australia on behalf of the National Program for Sustainable Irrigation.

3.1 Pasture and crop options – Summary

Geoff Moore

Key Messages

- Temperate crops and pastures are poorly adapted to the high to extreme temperatures from October to April. Conversely, many warm season (C4) grasses are relatively well adapted to these conditions.
- Temperatures during the dry season, in particular night-time temperatures vary significantly between locations having a major impact on the dry season options for an area. Most tropical legumes may stay green, but will produce little if any biomass over the dry season even when irrigated.
- Temperate annual crops and pastures have a role over the dry season, but need to be harvested before the onset of high temperatures.
- There are a large number of species which can be grown in northern WA at some time of the year, however many do not produce sufficient biomass (or grain) to be viable economic options.
- Ensure your crop selections are 'Fit for purpose' – select species well adapted to your location and have the required nutritional (feed quality) and productive potential (yield) to meet your needs.
- Application of N fertiliser can increase the crude protein of the grass, but has little effect on the digestibility (energy).
- Close attention is required to ensure crops and pasture production is optimised to achieve high biomass yield and sufficient energy to maintain high animal growth rates.

1. Work with the environment (climate, soils)

It is important to work with the environment opportunities (climate, soils) by growing crops and pastures which are well adapted to local conditions.

The combination of high levels of solar radiation, year round warm to high-extreme temperatures in many areas when combined with irrigation and adequate fertiliser result in very high biomass potential. Annual biomass yields of 35t DM/ha are readily achievable and up to 50t DM/ha may be possible with high applications of N fertiliser. There is however a trade-off between high biomass production and feed quality (Section 3.4).

Forage sorghum at Kilto Station highlights the trade-off between biomass and feed quality. The tall growth on the left has impressive biomass production, but is only suitable as a maintenance diet (DMD 55%, CP 8% and ME 7.8MJ ME/kg DM), while the regrowth on the right would be suitable for the moderate growth of cattle (DMD 65%, CP 11%, ME 9.6MJ ME/kg DM) at 0.7kg LWG per day.

Temperatures during the dry season vary significantly between locations and impact on dry season options. The growth of tropical species is sensitive to night-time temperatures and low night-time temperatures can dramatically reduce growth rates even when daily maximum temperatures are mild to warm. As a general rule, night-time temperatures below 16-18°C adversely affect the growth of 'tropical' species, while temperatures below 10-12°C greatly reduce the growth of species from sub-tropical environments.

In contrast from October to April northern WA is characterised by sustained high to extreme temperatures, with maximum regularly above 40°C, especially through the inland zones. The warm season (C4) grasses are better adapted to these conditions than both tropical legumes and temperate species. Even some tropical species are not well adapted to the extreme temperatures regularly encountered in the build-up to and over the 'wet season'. For an understanding of the climate and its impact on plant growth refer to Section 1.3.

Most soils in northern WA have a very low inherent fertility with deficiencies in the both the macro- and micro-elements. High levels of fertiliser are essential to initially build the soil reserves and secondly to replace nutrients removed off-site in hay, silage or livestock. Due to inherent low soil fertility, applying a generic compound fertiliser (NPK) may not fully meet the requirements of high nutrient demanding crops like maize.

For an understanding of the soils in northern WA refer to Section 1.4 and for pasture/crop nutritional requirements – Section 3.2.

2. Well adapted pasture, fodder and crop options

There are a relatively few pasture, fodder and crop options which are well adapted to the northern WA environment (climate, soils) that produce sufficient biomass or yield to be considered viable economic options. The main options are summarised in Table 1 and described more fully in later Sections.

Well adapted options include:

- Warm season (C4) annual grasses including hybrid sorghum, sweet sorghum, pearl millet and maize (Section 3.3);
- Sub-tropical or warm season (C4) perennial grasses including Rhodes grass and panic grass (Section 3.4);
- Tropical legumes like cavalcade centro, lablab (Section 3.6)
- Temperate crops for hay or grain over the dry season including oats, forage barley, triticale and cereal rye (Section 3.7);
- Temperate pastures including lucerne, annual clovers and grasses like Italian ryegrass are marginally suitable at best except for the 'low rainfall – elevated inland zone' where lucerne can be grown.

Factors to consider:

- Adaptation of crop/pasture to your climate zone
- Seasonal influence on crop/pasture growth in your climate zone
- Adaptation of crop/pasture to the local soil type (texture, site drainage, pH, fertility)
- Crop / pasture nutrient requirements in relation to the fertility of the soil and fertiliser type?
- Nutrient removal and replacement (Section 3.2)
- Susceptibility of the crop/pasture to stress or pests:
  - unseasonal hot weather,
  - moisture stress if there was a breakdown with the irrigation system,
  - locusts,
  - bird damage for grain crops.
- For annual crops; a rotation to ensure year round production and minimise build-up of soil pathogens and crop residue borne diseases.

3. 'Fit for purpose'

A 'fit for purpose' system is the crop or pasture together with the proposed livestock management/feeding system that delivers: the expected daily animal growth rates and carrying capacity to meet the target annual beef production or; the hay quality and yield for a fodder enterprise.

A key question is the pasture/crop 'fit for purpose'? In other words will it provide the required feed quality (energy, protein) and quantity (biomass) for the intended use and to meet the production target? An associated question is, are the production targets realistic?

The most common uses for irrigated production in the Pilbara and west Kimberley are 'stand and graze' pastures and fodder crops for hay or bailage. 'Stand and graze' systems routinely involve the rotational grazing of perennial grasses. While this system has perceived advantage of reduced reliance on crop husbandry and machinery movements it does present the challenge of trying to optimise two dynamic biological systems; pasture growth and livestock feed demand. Maintaining enterprise efficiency by keeping these two systems in equilibrium requires close attention.

Table 1. Seasonal adaptation and typical feed quality for a range of pasture, fodder and crop options.

Species	Wet season production		Dry season production			Feed quality	
	Well drained soils (All weather access)	Moderately well to imperfectly drained soils (limited access during wet season)	Coastal	Inland	Inland – elevated	Typical metabolisable energy* (MJ)	Typical crude protein (%)**
Hybrid annual sorghum	√√√	√–√√	√√√	√√	√	7.5–9.5	5–12
Pearl millet	√√√	√–√√	√√√	√√	√	7–10	5–12
Sweet sorghum (Sweet x Sweet)	√√√	√√–√√√	√√√	√√	√	8.5–10	5–12
Maize	**X**	**X**	√√–√√√	√√–√√√	√√√	9.5–11.5	5-10
Rhodes grass	√√√	√–√√	√√	√–√√	√***	7.5–9.5	<7–18
Panic grass	√√√	√√	√√	√	(√)	8–10	<7–16
Temperate cereals (oats, forage barley)	**X**	**X**	√√	√√-√√√	√√√	8.5–11	7–12
Centro	√√√	√√	**X**	**X**	**X**	7.5–10.5	10–17
Lablab, cowpea	√√	√	√–√√	√	**X**	8.5–10.5	11–19
Lucerne	(√)	(√)	√–√√	√√	√√–√√√	8.5–11	15–20

***** Metabolisable energy varies with the management and stage of growth

** Assumes adequate nitrogen nutrition. For grasses the crude protein (CP) varies with the stage of growth, soil fertility, nitrogen fertiliser application rate and biomass (high biomass dilutes CP); while for legumes CP varies with the stage of growth and assumes effective nodulation.

***a pronounced shut down in growth of Rhodes grass occurs from approximately mid-May to mid-August in most of this zone

Key:

√√√	Highly suitable
√√	Moderately suitable
√	Marginally suitable, consider other options
X	Not suitable

Confidence level for particular species

(light yellow)	Low – limited testing or grower experience
(light green)	Moderate – some testing or grower experience
(green)	High – extensively grown or tested

There is increasing interest in ‘cut and carry’ systems which operate on the principle of producing fodder and feeding livestock independently of each other. Hay, silage or other fodder products are grown to optimal yield and quality and conserved onsite. Livestock are then fed this product directly or as part of a ration in confined or semi-confined feedlot arrangements. Pastoral tenure regulations enables the establishment of feedlots or stock depots, to a maximum of 500 head of livestock, as long as the stock being fed are from that pastoral lease (PLB, 2018).

Cut and carry systems open up the opportunity for ensiling crops and pastures or green chop and feeding out as part of a ration to ensure the animals are supplied with the required nutrition for the target growth rates. Refer to Table 3 for the suitability of a range of pasture, fodder and crops for various uses.

Growing animals

Key cattle feed quality requirements are energy and protein. The generalised relationship between cattle growth rates and feed quality are outlined in Table 2. Refer to Section 2.4 for more specific information for different classes of cattle.

Table 2. Generalised feed requirements for different cattle growth rates in kilograms of liveweight gain per day (kg LWG/day).

Nutrient	Maintenance	Low growth (0.2–0.4kg LWG/day)	Moderate growth (0.5–0.7kg LWG/day)	High growth (~1kg LWG/day)
Energy (MJ)	7.5	8–8.5	9–9.5	10–11
Crude protein (%)	8	8–10	10–12	10–12

Well managed warm season (C4) grasses are adequate for moderate growth expectations (0.7kg LWG per day) as a benchmark average. At times the pasture may be more productive and at times it will be less productive due to age of the stand, seasonal variations, pests and diseases, management and other factors. It is unusual for good quality tropical pastures to give liveweight gains in excess of 0.7kg per day for any sustained period (Humphreys 1981).

Select fodder crops and pastures that are capable of meeting the nutritional requirements of the cattle for the required weight gain or maintenance or to meet the requirements of the buyers if producing hay for sale. For instance, hay for yard feed and for use during mustering does not need to be of a high quality. A maintenance diet with a high fibre component to provide ‘gut-fill’ is satisfactory. Feeding a high quality hay to cattle coming off dry feed on the rangelands could be deleterious and result in scouring.

Fodder production

If producing fodder for sale, ensure the product meets the buyers’ requirements;

- hay for maintenance diet and for gut fill; 7.5MJ, 8% CP,
- good quality hay for growing animals; 8.5–9MJ, 10-12% CP.

Cut and bale fodder crops at the right growth stage to optimise the balance between yield and feed quality to achieve the desired outcome.

Mixed pastures and a companion legume

The concept of combining a legume as a companion species to a warm season (C4) grass is an attractive option. A tropical legume growing with a warm season grass could improve the feed quality of the mixture compared with a grass monoculture as well as offset some fertiliser N with that fixed from the atmosphere.

Forage sorghum with cowpea as a companion legume – in practice it is difficult to maintain a mixed pasture with a balanced composition

In practice it is extremely difficult to maintain a mixed pasture with a balanced composition between the grass and legume components. Regrowth of a perennial grass like Rhodes grass after cutting or grazing is very rapid and usually much faster than the companion legume which is subsequently shaded and quickly becomes a minor component of the mix (<10%).

- Competition for light, nutrients, water, combined with the complexity of grazing pressure and preferential selection heavily influences the composition of mixed pastures under irrigation;
- In practice, the regrowth of grass after cutting/grazing is usually much faster than the companion legume so the mixture quickly becomes grass dominant;
- A low legume component in the pasture only makes a small contribution to the overall feed quality and the N contribution as the N-fixation is commensurate with the legume biomass (low legume biomass = low N input);
- Conditions in northern WA are favourable for extremely high growth rates of the grasses, but the prevailing temperatures from October to April are frequently well above the optimum for the tropical legumes which for many species are in the range of 25-32°C (FAO Ecocrop database);
- When grown separately the average growth rates of warm season (C4) grasses are almost twice that of the tropical legumes and as the cutting or grazing regime becomes more intensive this difference may be exacerbated;
- It is difficult to maintain a mixed tropical grass-legume pasture under dryland conditions and if anything the challenge is more difficult under an irrigation scenario as the grass density is likely to be higher under irrigation and with adequate nutrition the growth rates of the perennial grass can be very high (150-200kg DM/ha per day).

Not-withstanding the above comments some possible combinations include:

Twining legumes could possibly be grown with annual warm season grasses on a wide row spacing, but this could compromise the total biomass production (untested in northern WA)

Panic grass (bunch grass) with centro, or panic grass with butterfly pea (both untested in northern WA) are possible companion species.

What hasn't worked

Rhodes grass – lucerne mix in La Grange area (Low rainfall – coastal) quickly became dominated by Rhodes grass and the lucerne component disappeared over summer.

Table 3. 'Fit for purpose' – the suitability of a range of pasture, fodder and crops for various uses. The ratings take into account the environment (soils, climate), relative yields and likely utilisation efficiency if grazed

Species	Stand and graze	Bulk hay (Yard feed)	Good quality hay	Round bale silage	Pit silage	Grain
Hybrid annual sorghum	√–√√	√√√	√√	√√	√–√√√	**X (**√√√***)**
Pearl millet	√√	√√	√–√√	√	√	√–√√
Sweet sorghum (Sweet X Sweet)	√√	**X**	**X**	**X**	√√√	**X**
Maize	√√	√	√	√√	√√√	√√√
Rhodes grass	√√–√√√	√√√	√√–√√√	√√	√–√√	**X**
Panic grass	√√√	√√	√√	√√	√–√√	**X**
Oats (dry season)	√-√√	√√√	√√	√	√–√√	√√√
Barley (dry season)	√	√√	√√	√	√–√√	√√√
Centro (wet season)	√-√√	√-√√	√√	√	**(**√**)**	**X**
Lablab, cowpea	√–√√	√	√–√√	**(**√**)**	√√	√–√√
Lucerne	√√	√	√√–√√√	√√	√√	**X**

Key:

√√√	Highly suitable
√√	Moderately suitable
√	Marginally suitable
X	Not suitable

*Rating for Grain sorghum

C3 and C4 plants

Photosynthesis is the process by which plants take in CO_2 from the atmosphere through open pores (stomata) in the leaves (and stems) and which is then combined with water (H_2O) to produce sugar and oxygen (O_2) using the sun's energy. The terms C3 and C4 are simply derived from the number of carbon atoms in the first stable product of photosynthesis (C3 – 3 carbon compound, C4 – 4 carbon compound).

Most plant species (>85%) assimilate CO_2 via the 'C3 photosynthetic pathway', also called the Calvin cycle. In C4 plants there is an additional step whereby the CO_2 is first converted into a 4-carbon molecule before undergoing the Calvin cycle. The warm season or tropical annual grasses like sugarcane, sorghum and maize and perennial grasses like Rhodes grass and panic grass use the 'C4 photosynthetic pathway'. In contrast, cereal crops like wheat, rice and oats are C3 plants. The vast majority of tree species are C3 species as well.

Pasture and fodder crops can be placed in 3 categories:

- Temperate C3 pastures and crops which includes the cereals, pulses, annual legumes, perennial legumes like lucerne, annual and perennial grasses like ryegrass,
- Warm season C3 tropical legumes which includes species like lablab, centro, butterfly pea and cowpea,
- Warm season C4 grasses which includes annual and perennial grasses from both sub-tropical and tropical regions.

The C4 plants have some important advantages over C3 plants in hot, dry conditions. They are more water and nitrogen efficient, but require more energy (light) as there is an additional step in the photosynthetic pathway. The C4 plants only need to keep their stomata open for short periods, so they lose much less water (transpiration) for the same amount of CO_2 fixed by photosynthesis. This is a significant advantage under hot, high light intensity, moisture-limiting conditions, which describes the conditions in northern WA from September to May.

The C3 plants have their stomata open for longer periods, so transpire more water. When it is hot and dry, the stomata close to conserve water, but this slows down photosynthesis and plant growth. At temperatures above 30°C, C3 plants can undergo the energy wasteful process of photorespiration whereby previously fixed CO_2 is released instead of O_2. Consequently, under hot, moisture-limiting conditions the C3 plants revert to other drought survival mechanisms like leaf senescence and dormancy well before the C4 grasses use these adaptations.

On the other hand, under cool, moist conditions and at lower light intensities C3 plants are more efficient than C4 plants. Temperate pasture and crop species are all C3 plants and they grow actively in cool to mild conditions when the C4 plants are dormant or only able to grow slowly.

Tropical legumes are warm season C3 plants which come from tropical environments. They tolerate high temperatures better than the temperate legumes and crops, but have poor growth at cool to mild temperatures.

There is also a third type of photosynthesis called Crassulacean acid metabolism (CAM) used in highly drought tolerant plants like cacti. CAM plants use a variant of the C4 pathway where the timing of photosynthesis is changed. The CO_2 is taken up at night when the stomata are open and is fixed into a 4 carbon molecule. This is stored until daylight before being broken down to release CO_2 for the Calvin cycle.

3.2 Plant nutrition

Geoff Moore, Chris Schelfhout

Fodder production results in the export of large quantities of nutrients, especially nitrogen and potassium which need to be replaced to ensure continued productivity.

Key Messages

- Fertiliser is usually the major variable cost in irrigated fodder production, so it is essential to ensure the nutrients are utilised efficiently. A crop nutrient budget combined with regular soil testing and tissue testing will help to ensure their efficient use.
- When growing conditions are favourable, the warm season perennial grasses are highly responsive to fertiliser nitrogen to very high levels (3 units of N per day), but ensure that the other elements including P are non-limiting.
- There are useful additions of sulphur and potassium in the irrigation water, while calcium and magnesium may be in overall surplus (Note: varies with the aquifer and bore)
- With grazed pastures 70-90% of the nutrients consumed by cattle are returned to the soil via excreta (dung, urine), however recycled nutrients are returned unevenly within a paddock and are concentrated in stock camps and where stock congregate.

Fertiliser is usually the major variable cost in irrigated fodder production, so it is important for multiple reasons to have checks and balances in place to ensure the efficient use of the applied fertilisers. Nutrient deficiencies of N, P and Fe have been observed in commercial crops. This section covers:

- Nutrient losses and sorption
- Crop nutrient budget
    - Nutrients in irrigation water
- Assessing nutrient status
    - Plant symptoms
    - Regular soil testing
    - Tissue testing
    - Fertilise strips
- Fertiliser application
    - Fertiliser requirements for ‘new land’

Nutrient losses and sorption

There are nutrients required by crops and pastures that are not accounted for in a simple nutrient balance accounting for kg applied and kg exported in grain or fodder. This is due to a number of factors including:

- Loss of mobile nutrients like N and S through leaching. Dissolved nitrate (NO_3^-) can move freely through the soil profile with water. If rainfall or irrigation exceeds evapotranspiration then nitrate can be leached below the root zone, possibly ending up in the groundwater. This is more likely in sandy soils with low organic matter.
- Loss of N through volatilisation − gaseous loss of ammonia (NH_3) to the atmosphere, primarily following the hydrolysis of urea either from fertiliser or urine.
- There may be a low plant availability of applied nutrients due to sorption by soil and organic matter particles (P, trace elements).
- Erosion or runoff – Nutrients attached to soil particles and in solution are carried by erosion to lower lying areas or into waterways.
- Soil applied nutrients may be spatially unavailable due to dry conditions and nutrients being concentrated in topsoil which has dried out (less important with irrigation)
- Nutrient concentrations in the final product can vary greatly (Table 2).
- Soil pH – affects the availability of nutrients for plant growth (Figure 1). Most of the soils in northern WA are slightly acid to slightly alkaline (section 1.4).

The properties of macro- and micro-nutrients are summarised in Table 1.

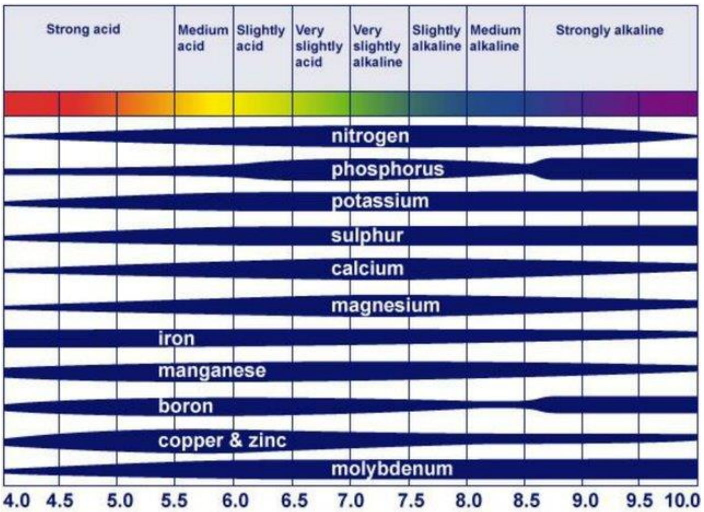


Figure 1. The effect of soil pH on nutrient availability
(source: Roques *et al*. 2013)

Table 1. A summary of the properties of macro- and micro-nutrients

	Macro-nutrients						Micro-nutrients				
	N	P	K	S	Ca	Mg	Fe	Mn	Cu	Zn	Mo
Key soil properties*	OM	Fe, Clay	Clay, OM	OM, Fe	Clay, OM	Clay, OM	Fe, pH_{alk}	pH_{alk}, OM	Clay, Fe, OM	pH_{alk}, OM, Clay	pH_{acid}, OM, Fe
Mobile in soil	Yes (nitrate)	Usually No	Yes (sandy soils)	Yes	No	No	No	No	No	No	No
Losses and reduced availability to plants	L, V	S, (E)	L (sandy soils)	L (sulphate S)	S	L	S	S	S	S	S
Residual value of applied fertiliser	Low (except from legumes)	High	Medium	Medium	High	High	High	Variable (lower in alkaline soils)	High	High	High (except highly acid soils)
Soil test (useful)	(limited value)	Yes	Yes	Yes	No	No	No	No	No	No (?)	No
Tissue test to detect deficiency	Yes	Yes	Yes (also for luxury levels)	Yes (Also N:S ratio)	Yes	Yes	Yes	Variable	Yes	Yes	Yes
Mobile in plant	Yes	Yes	Yes	Relatively immobile	No	Somewhat mobile	No	No	No	No	Yes
Deficiency symptoms	Yellowing of older leaves	Stunted early growth, small leaves	Yellowing and tips of old leaves	Pale or yellow young tissue	Young tissue – structural breakdown	Interveinal chlorosis	Interveinal chlorosis on young leaves	Interveinal chlorosis on young leaves	Varies with species	Stunted growth, interveinal chlorosis	Legumes same as N deficiency; Non-specific
Fertiliser application***	DB, F, TD	DB	TD	DB, TD	Usually applied incidentally in fertilisers	TD	TD, F	DS, F	F, SD, DS	DB, F	F, SD, TD

KEY: *Key soil properties affecting availability: OM – soil organic matter; Fe – iron (haematite, goethite) and aluminium oxides; Clay – clay fraction (cation exchange capacity); pH_{alk} – reduced availability in soils with alkaline pH; pH_{acid} – reduced availability in acidic soils (low pH).

**Losses (reduced availability) apart from removal in produce: L – leaching; S – sorption (tied up by soils which limits availability); V – volatilisation (loss through gas to atmosphere); E – loss through erosion.

***Fertilise application (preferred method): DB – Deep banded at seeding; F – foliar application (fertigation); DS – drilled with seed; TD – topdressing (broadcasting); SD – seed-dressing.

Source: ‘Soilguide’, Chapter 6 – Plant nutrition (Moore 1998)

Crop nutrient budget

A crop nutrient budget and fertiliser application schedule will ensure crops and pastures perform to a high standard and produce good quality products. High growth rates particularly over summer drive crop nutrient demand, especially of N. Significant fertiliser inputs are required to ensure that high yielding crops and pastures meet quality and yield targets and for on-going productivity.

The indicative nutrient removal in harvested fodder for a warm season C4 grass are summarised in Table 2. Harvesting hay or silage removes these nutrients from the soil, so the basis of a good nutrition program will be to replace these nutrients. The nutrient removal for a range of crops and pastures are summarised in Table 3. Fodder production for hay or silage removes large quantities of nutrients, particularly N and K. For example, 20t DM/ha of Rhodes grass hay (24t hay @12%) removes 320kg N, 340kg K and 50kg P.

Table 2. Typical nutrient removal in harvested fodder (kg per tonne dry matter) for a warm season grass

Crop	Nutrient removal (kg per tonne DM)					
	Nitrogen (N)	Phosphorus (P)	Potassium (K)	Sulphur (S)	Calcium (Ca)	Magnesium (Mg)
Warm season grass	16-24	2.5	15-20	4	3	1.5-3

Grazed pastures

The nutrient removal in stand and graze is an order of magnitude lower than with fodder production; for example, in 1000kg beef the nutrient removal is 27kg N, 7.2kg P and 0.2kg K (Impact fertilisers). With grazed pastures 70 to 90% of the nutrients ingested by grazing animals are returned to the soil in excreta (dung, urine). In general, ruminants retain only 5 to 25% of the N, 25 to 35% of the P and 8 to 12% of the K they ingest, with the balance returned to the pasture. However, there is a spatial re-distribution of the nutrients by the grazing stock through urine and dung patches which are concentrated in stock camps and where stock congregate, like around watering points. When the fenced paddock includes an area of native vegetation then stock will frequently camp in the native vegetation rather than on the irrigated pasture leading to a re-distribution of nutrients.

Phosphorus and K are excreted primarily in dung, while between 55 and 75% of N excreted is in the urine. The N in the urine is rapidly hydrolysed to NH_3 (ammonia), which is subject to volatilization. In the presence of moisture and oxygen, soil microbes convert NH_4^+ to nitrate (NO_3^-), which is not volatile but is highly soluble and mobile in the soil. If irrigation is excessive then nitrate (NO_3^-) can be leached below the root zone and eventually end up in the groundwater.

- Intensive short-duration grazing with a high stocking density results in rapid, uniform forage utilization and manure deposition. In turn, a lot of nutrients become available for pasture regrowth in a short period.
- Trampling mixes plant residues and manure into the soil, speeding up their breakdown and decomposition.

Table 2. Nutrient removal (kg) in one tonne of hay, silage, pasture or grain for a range of warm season annual and perennial grasses, tropical legumes and temperate species — removal is on a dry matter basis (mean ±standard deviation).

Fodder, pasture	Nutrient removal (kg per tonne DM)					
	Nitrogen (N)	Phosphorus (P)	Potassium (K)	Sulphur (S)	Calcium (Ca)	Magnesium (Mg)
Warm season C4 annual grasses						
Hybrid forage sorghum[a]	24	3	20	2	3	3
Pearl millet[a]	25	3	20	2.5	3	3
Maize silage[a,b,e]	11.5±1.3	1.8±0.3	10.9±1.9	1-1.5	2.0±0.5	1.7-2.5
Maize grain[b]	17.6	3.2	4.1	1.7	–	3.5
Sweet sorghum silage[a,e]	13.0±2.9	2-4	15-20	1.2-2.5	3	3.2±0.5
Warm season C4 perennial grasses						
Rhodes grass pasture[e]	14.4±4.5	2.9±0.9	18.7±5.6	NA**	3.8±1.0	1.9±0.5
Rhodes grass hay[e]	16.2±4.8	2.6±0.6	16.9±5.3	NA	3.1±0.7	1.4±0.3
Panic grass pasture[e]	17.9±6.9	2.4±0.9	23.1±9.3	NA	4.9±1.7	3.4±1.3
Tropical legumes						
Butterfly pea pasture[e]	34.1±6.9*	2.9±1.1	16.9±7.3	NA	12.7±6.7	4.2±1.6
Centro hay[f]	18*	1.2	21	1.7	15	2.1
Cowpea hay[a,e]	23.7±5.3*	3.9±1.6	33.2±10	3	13.1±3.1	6.6±1.6
Lablab hay[a,e]	26.1±3.8*	2.9±1.7	21.6±11.7	3	14.3±4.9	2.5±0.7
Temperate crops and pastures						
Whole crop cereal[a]	24	3	20	2.5	3	3
Wheat grain[c,d]	23	3	4	1.4-1.5	0.33-0.4	0.93-1.2
Lucerne hay[a,d]	33-35*	3-3.3	25-28	2.4-3.0	1.3-1.5	2.1-4.0
Oaten hay[d,e]	20	2	18	1.4	0.6-4.7	2.0

Source: a — Kaiser *et al*. (2004); b — Growth Potential – Corn Gowers Workshop, Pioneer Seeds; c — Summit fertilizers; d — Impact fertilisers; e — FAO Feedipedia; f — Thiagalingam *et al*. (1997).

*Nitrogen requirement met by legume N fixation; **NA — data not available

Table 4. An example of a nutrient balance for Rhodes grass hay at two levels of production 20t and 35t dry matter per ha including the nutrient input in 18ML of irrigation (assuming average nutrient concentration from Broome Sandstone − Table 5)

Nutrient	N	P	K	S	Ca	Mg
%	2.0%	0.25%	2%	0.4%	0.4%	0.3%
Nutrient composition %	1.6-2.4%	0.26-0.29%	1.5-2.0%	0.4%	0.3-0.4%	0.14-0.3%
Removal per tonne (kg)	16-24	2.6-2.9	15-20	4	3-4	1.4-3
Nutrient removal in 20t DM/ha matter	320-480	52-58	300-400	80	60-80	28-60
Nutrient Removal in 35t DM/ha	560-840	91-102	525-700	140	105-140	49-105
Nutrient input in irrigation @18ML per ha	90	0.5	135	125	275	180
Nutrient budget for 35t DM production	-(470 to 750)	-(91 to 101)	-(390 to 565)	-15	+135 to 170	+75 to 131
Fertiliser input required at 80% effectiveness (kg/ha)	590 to 940	114 to 126	490 to 705	0	0	0

KEY:

surplus

supplied through other fertilisers

deficit to be supplied through fertiliser

Nutrient addition through irrigation water

Bob Paul (Hydrologist, DPIRD)

The irrigation water applied contains some elements apart from salts, so this effectively becomes a low level of fertigation. Due to the large amount of irrigation water applied over a year this can be a significant source of nutrient application for some elements depending on the water source. Some typical values are provided in Table 5, or specific values can be readily calculated using equation 1 below. The high sodium input highlights the necessity for a leaching factor to move the 'salt' beneath the root zone. The sulphur content in groundwater from Broome Sandstone can vary by a factor of 10 between different bores. The input of trace elements like copper, zinc and molybdenum is negligible.

Equation 1: $N_T = N_C \times I$ = where,

N_T is the annual application of that element through the irrigation water (kg/ha)

N_c is the concentration of a specific nutrient (mg/L) in the irrigation water,

I is the amount of irrigation water applied in Mega litres per ha (ML/ha)

Table 5. Average and range of pH and nutrient concentrations in aquifers and the annual application of nutrients when irrigating from Broome Sandstone.

Nutrient	Typical concentration in aquifer (mg/L)*		Irrigation water applied (ML/ha/year)		
	Wallal Sandstone	Broome Sandstone	12	15	18
No. of bores	1	13			
pH (field)**	6.6	6.5 (5.7–7.0)			
Potassium (K)	8.5	7.5 (2–14)	90	110	135
Sulphur (S)	42	6.9 (2–23)	80	105	125
Calcium (Ca)	29	15 (8–31)	185	230	275
Magnesium (Mg)	17	10 (4–18)	120	150	180
Nitrogen (N)	<0.01	4.9 (1.1–9)	60	70	90
Phosphorus (P)	0.01	0.0 (0.01–0.1)	0.3	0.4	0.5
Iron (Fe)	0.7	0.1 (0.02–0.2)	1.3	1.6	2
Sodium (Na)	215	84 (43–172)	1000	1250	1500

*Note: To convert units 1mg/L = 1ppm (parts per million)

**Note: Field pH is usually lower than pH measured in the laboratory (e.g. Broome Sandstone – 12 samples analysed in the laboratory mean pH 7.3 (range 6.6–7.7), however analysis of the pH was outside the holding time of six hours, so the results should be used as a reference only.

A regular crop nutrition monitoring program will ensure that nutrient applications are on target and not limiting crop performance. Commercial service providers can also provide tailored advice to irrigators on the development and monitoring of crop nutrition.

There are a number of fertiliser suppliers and some have numerous fertiliser formulations for different applications and each formulation has a different nutrient content so comparisons can be time consuming. A 'Fertiliser calculator' is available on-line from DPIRD which compares the nutrient content of more than 1500 commercially-available fertilisers. DPIRD website. Link: https://www.agric.wa.gov.au/fertiliser-calculator

Assessing nutrient status

Soil and tissue testing, plant symptoms and fertiliser test strips can be used to help identify nutrient deficiencies and fertiliser requirements.

Plant symptoms

Plant symptoms can be useful as the deficiency of some nutrients results in specific plant symptoms. However, the plant symptoms are usually confirmed with soil and or tissue tests.

In many cases, by the time a crop is showing nutrient deficiency symptoms, yield potential has already been compromised.

Regular soil testing

Soil tests are useful for assessing the status of the macro-nutrients: P (Colwell P), K (Colwell) and S (extractable S) and in some situations for zinc. Soil tests vary due to spatial variation even when the soil appears quite uniform, this is due to natural variations in physical and chemical properties and the uneven distribution of applied fertiliser. Therefore adequate replication is necessary when soil sampling to ensure the results are representative.

A bulked sample from 20-30 individual soil samples is recommended, with sample cores taken in a zig-zag or W-pattern. The standard depth for nutrient testing is 10cm (0-10cm) which can be sampled with a pogo stick.

Tissue testing

Tissue testing provides an indication of the status of nutrients at the time of sampling. Nutrient levels in tissue vary with the age (from establishment or after grazing) of the tissue, stage of growth of the plant and of course, the availability of the nutrient in the soil.

Figure 2 illustrates a common relationship between yield and nutrient concentration in plant tissue showing the three zones of deficiency, adequacy (sufficiency) and toxicity. The critical level or concentration is usually defined in plant analysis as the level that results in 90% of maximum yield or growth (Figure 2).

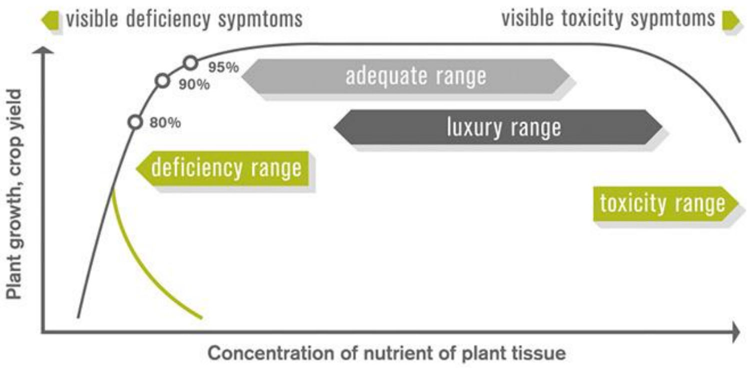


Figure 2. The relationship between nutrient concentration in plant tissue and yield or growth (Source: Mosaic webpage https://www.cropnutrition.com/nutrient-management/plant-analysis)

For nutrients which are immobile in the plant like Cu, Zn then samples of the youngest mature leaf are preferred to whole tops.

Tissue testing 'critical values' vary with the stage of growth and decline as annual plants age and mature.

Some of the critical levels for tissue testing for sub-tropical species are not all that well established. Results from sampling perennial pastures on and off fertiliser strips in the northern agricultural area suggest that the critical levels from the literature (Reuter and Robinson, 1997) may be too high for many elements (Table 6). The high frequency of deficiencies on the supposedly adequate, plus nutrient strips (plus Fert in Table 6) suggested the 'robust critical levels' from the literature are too high. There was a higher % of samples below the critical levels for Rhodes grass versus panic grass. This may be a species difference, however panic grass was usually well grazed, so young, fresh leaf tissue was usually available for sampling. On the other hand, the Rhodes grass was grazed less and as a result the leaf tissue was often older and there was less young regrowth to sample.

Table 6. Tissue test critical values for warm season perennial grasses on sandy soils in the northern agricultural area and the % of samples from fertilised strips (plus Fert) below the critical levels (source: Bowden *et al*. 2014).

Nutrient	'Critical' level	Panic grass plus Fert.	Rhodes grass* plus Fert
		% of analyses below 'critical' level	
N	2.0%	32	71
P	0.2%	19	42
K	1.5%	10	21
S	0.15%	13	8
Cu	5mg/kg	52	83
Zn	13mg/kg	19	50
Mn	40mg/kg	45	42
Mg	0.15%	0	33
Ca	0.2%	0	0
B	5mg/kg	13	25

As is the case for soil testing, use of tissue testing as a reliable diagnostic tool requires field research to correlate nutrient concentrations with crop yield response.

Testing your pasture using fertiliser strips

A fertiliser strip using a high fertiliser rate can be used to diagnose possible nutrient deficiencies in your pastures. Firstly peg out a strip, say 20m long x 5m wide and apply high levels of the essential nutrients evenly across the strip (some horticultural fertilisers provide the whole suite of elements).

An example of a fertiliser blend is 200kg/ha of DAPSZC plus 100kg/ha of MOP which equates to 34kg N/ha, 36kg P/ha, 50kg K/ha, 17kg S/ha, 100g Cu/ha, 300g Zn/ha, 2g Mo/ha and 40g Mn/ha.

If you notice a visual response to the fertiliser then for each species of interest in the pasture, carefully sample the young tissue and send off paired samples (**plus, minus fertiliser**) for a complete elemental analysis.

As a guide: usually a dry matter response of at least 15% is required before it can be visually detected.

Other tests – Greenseeker

A hand-held instrument like a Greenseeker can be used to identify N deficiency. It takes continuous readings of normalized difference vegetation index (NDVI) which are averaged over a transect when holding the instrument at a set height (recommended 80-120cm above the canopy). The sensor displays the measured value in terms of a NDVI reading, ranging from 0.00 to 0.99, with the higher the reading the healthier the plant.

As a guide: readings of a perennial grass pasture can be categorised as follows: deficient (<0.5); marginally deficient (0.5-0.6) and sufficient (>0.6), while readings >0.75 may indicate luxury levels. Note: the readings are confounded by patches of bare ground (best to have 100% groundcover) and seed heads. The Greenseeker is not reliable for assessing the biomass (i.e. feed-on-offer) of perennial grasses.

Fertiliser application

Nutrient inputs constitute a significant component to the cropping budget and with the additional costs of transporting fertilisers to northern WA consideration must be given to ensure that the most effective form of nutrient is being applied to the crop.

This may mean the use of a combination of granular products that are drilled into the soil at seeding or topdressed as the crop is developing. It may be more cost effective to deliver some nutrients, particularly micro-nutrients by fertigation whereby soluble fertilisers are injected into the irrigation water to be distributed to the crop.

Fertiliser requirements for new land

Most of the soils in the Pilbara and Kimberley are inherently low in the essential macro- and micro-nutrients (Section 1.4). With newly developed land (i.e. greenfield sites) it is essential to build-up the soil fertility with large basal fertiliser applications of P and K plus trace elements in the first year. The basal applications need to align with the expected level of production.

Example: A newly cleared site with red-brown clayey sand and pre-clearing soil test results of ??P and ?? K?? A typical fertiliser plan for year one assuming the expected level of production is 25t DM/ha (28t hay @12% moisture) is described below.

Fertiliser plan:

- At seeding 200kg/ha (super Cu Zn Mo), 40kg/ha (potash) plus nitrogen for grasses (20N).
- Then every three months: 200kg/ha of superphosphate (18.2P, 21S, 40Ca) and 200kg muriate of potash (100K).
- Plus for grasses N on a monthly basis or after cutting of at least 1N per day and up to 2N per day.

Further information:

3.3 Warm season annual grasses

Geoff Moore, Clinton Revell and Sam Crouch

Key Messages

- High potential growth rates (>150kg DM/ha per day) under favourable conditions
- A significant trade-off between biomass and feed quality, especially for the hybrid forage sorghums and pearl millet
- Maize is a high input – high quality crop which is grown around the world for feeding cattle. In northern WA maize is essentially a dry season crop as some growth stages are adversely affected by high to extreme temperature.
- Sweet sorghum (sweet x sweet) varieties have produced high biomass yields and the sugar levels (metabolisable energy) typically increase with maturity. Only suitable for pit silage and to a lesser extent direct grazing and carryover feed (untested in northern WA).
- Sudan grass hybrids are preferred for the production of hay and round bale silage (baleage) due to their finer stems.

The three warm season (C4) annual grasses of particular interest are:

(i) Hybrid sorghum (*Sorghum* spp. – there are many hybrid combinations of Sudan grass, sorghum and sweet sorghum available with different attributes)

(ii) Pearl millet, hybrid Pennisetum (*Pennisetum americanum*)

(iii) Maize, corn (*Zea mays*)

Their strengths, weaknesses and potential are described below.

(i) Hybrid forage sorghum

Sweet x sweet sorghum Sugargraze

Features

- Well adapted to most soils and most environments in northern WA
- Easy to establish with good seedling vigour
- There are a range of hybrid forage sorghums with different attributes which can be used for grazing, hay, round bale silage or pit silage – select a type/cultivar suitable for the end use
- Rapid growth over wet season and good growth over dry season, except in the 'low rainfall – elevated inland' agro-climatic zone
- Good regrowth potential and multiple cuts are possible, but varies with type. Forage sorghum can grow through to a second year but is not recommended as plant density declines over time and this negatively impacts on biomass production.
- Trade-off between biomass production and feed quality except for the sweet x sweet sorghum hybrids
    - Forage sorghum hybrids with 2m+ growth looks impressive, but feed quality is reduced. Depends on the planned end use (i.e. Fit for purpose):

      For higher quality hay then cut at 1.2−1.5m foliage height (ME 8.5-9MJ)

      For high biomass, but lower feed quality for yard feed then grow for a further 2-3 weeks which under favourable growing conditions could result in the biomass (DM) doubling; then cut at foliage height 1.8-2.2m (ME 7.5-8.5MJ).
    - Thin stemmed cultivars (typically Sudan grass hybrids) are preferred for hay making as they dry more rapidly and uniformly. They are also preferred for round bale silage (baleage) as they are less likely to puncture the plastic wrap.
    - Sweet sorghums behave quite differently as the sugar content increases with maturity, so combine good biomass and energy (ME 9.5-10MJ). They tend to

have thicker stems and nodes and are more difficult to dry. They are best suited as specialist silage crops.

- Specialised planting equipment is not required
- Caution – all forage sorghums contain prussic acid, so avoid grazing new regrowth and stressed plants – see 'Box'.

Hybrid sorghum is well suited to annual rotations with other crops like tropical legumes. With the development of mosaic agriculture in northern WA hybrid sorghum was one of the first species grown under irrigation. However, irrigators' have subsequently favoured the use of perennial grasses such as Rhodes grass because they do not require re-seeding each year, produce similar or more biomass and are more suitable for direct grazing.

Forage sorghum types and uses

There are a wide range of hybrid forage sorghum cultivars (*Sorghum* spp.), which can be placed into six groups depending on the parents involved in the cross:

- Sudan x Sudan grass
- sorghum x Sudan grass
- sorghum x Sudan grass plus brown mid-rib (BMR)
- sorghum x sorghum
- sweet sorghum x Sudan grass
- sweet sorghum x sweet sorghum

The key characteristics and their suitability for a range of uses are summarised in Table 1. Select a cultivar with desired characteristics for the planned use; whether intending to make hay, round bale silage, pit silage or for direct grazing.

Types and uses (mention of cultivar names does not imply a recommendation)

Sudan x Sudan grass

(Examples include: Centaur, Finerdan, Sprint, Superdan 2, Super Sweet Sudan (SSS))

The Sudan grass hybrids have comparatively fine stems with good tillering and rapid regrowth after cutting or grazing with multiple cuts (or grazing) possible.

- A range of varieties with different maturity, some are photoperiod sensitive.
- Highest quality is 0.8-1m, cut for hay at 1.0–1.5m as a good compromise between quality and quantity and at 2m for bulk feed.
- Lower prussic acid content – so can graze earlier than some other types; initial grazing height 60-100cm, regrowth grazing height 70-110cm.

Sorghum x Sudan grass

(Examples include: Astro, Betta Graze, Sweet Jumbo)

These are generally late-flowering types, with rapid regrowth that are suited for grazing and round bale silage, but less suited for hay production which would require use of a mower conditioner

Sorghum x Sudan plus BMR

(Examples include: BMR Octane, BMR Rocket)

Similar to Sorghum x Sudan grass, but with the addition of the brown mid-rib gene (BMR).

The brown mid-rib (BMR) gene is reputed to reduce the content of indigestible fibre (i.e. lignin), so the leaves and stems should be more palatable, have better digestibility and a higher energy content.

Early flowering with rapid regrowth they are suited for silage, autumn-winter carryover feed, grazing, but less suited for hay production which would require use of a mower conditioner.

Sorghum x sorghum

(Examples include: Chopper, Graze-N-Sile)

These types were specifically developed just for silage and have both high forage potential and good grain yield, with the increased grain content improving the silage quality.

Sweet sorghum x Sudan grass

(Examples include: Nectar, Sugar sweet)

These types have a combination of characteristics from Sudan grass (fast growth, leafy, low prussic acid) and sweet sorghum (juicy, sweet stems). They are versatile hybrids, suitable for grazing and with high vegetative growth.

Compared with the ‘Sweet x Sweet’ sorghum these hybrids have finer stems, more tillering and faster regrowth after grazing.

Sweet sorghum x sweet sorghum

Refers to the sweet sorghum x sweet sorghum varieties and **not** other crosses which include ‘sweet’ in the cultivar name (Examples include: SugarGraze, Mega Sweet)

- These are tall, late flowering with high sugar levels in the stems, prussic acid levels also can be high. They are characterised by thick stems (20−35mm), less tillering and have slower growth and regrowth than the Sudan grass-based hybrids. To maximise regrowth retain a stubble height of at least 15cm when grazed or cut for silage.
- In contrast with most forage sorghums, feed quality increases with maturity as they accumulate sugar in their stems once flowering commences and during seed-fill.

  This is the time to cut for silage, resulting in the valuable combination of high biomass production together with good metabolisable energy (ME) levels (ME 9.5 to 10MJ/kg DM). Water soluble carbohydrate (WSC) concentrations of 12−21% are typically reported (Almodares and Hadi 2009).

  The protein content will decrease with maturity to 4–7% depending on the level of N fertiliser. As a result a protein supplement when feeding mature sweet sorghum can improve livestock performance.
- A more resilient crop than maize. In a replicated trial at north Broome in 2018 a period of moisture stress severely affected the maize treatments, while the sweet sorghum was largely unaffected.
- Best suited to pit silage, but can also be used for carryover feed and for direct grazing.

  Less suitable for wrapped silage as the thick stems can puncture the plastic, or for making hay as drying the thick, juicy stems is problematic even with a mower conditioner.
- Caution ─ sweet sorghum contains prussic acid

  Avoid grazing or cutting new regrowth until ~1.5m in height and also avoid grazing stressed plants. However, can be grazed at all later stages and remains palatable.

Table 1. Sorghum hybrids, their characteristic features and suitability for a range of uses* (scale: 1 low to 9 well suited). Green shaded cells highlight the most suitable options for each intended use.

Hybrid sorghum type	Characteristic features	Relative prussic acid risk	Recovery after cutting or grazing	Potential uses*				
				Direct grazing cattle	Hay making	Round bale silage	Pit silage	Carryover feed
Sudan grass, Sudan x Sudan hybrids	Fast growing with fine stems and good tillering	Low	Rapid	7-9**	9	8	3	5
sorghum x Sudan grass	Potential high DM production	Low	Rapid	8-9**	6-8**	7-9**	3-7**	3-5**
sorghum x Sudan grass plus BMR***	Similar to above plus BMR gene	Low	Rapid	9	8-9**	9	7	5
sorghum x sorghum	High forage combined with high grain content	Intermediate	Limited	3	5	4	9	5
sweet sorghum x Sudan grass	Compact, leafy with juicy and sweet stems	Intermediate	Medium	9	7	6	9	9
sweet sorghum x sweet sorghum	Thicker, coarse stems, high sugar levels which increase with maturity	Intermediate to high	Slow	9	3-4**	2-4**	9	9

* Ratings by Industry

** Ranges in ratings represent varietal differences

*** BMR – Addition of brown mid-rib (BMR) gene, which is associated with lower lignin content and an increase in digestibility (energy)

Prussic acid and sorghum

All hybrid sorghum varieties contain prussic acid (also called hydrogen cyanide or hydrocyanic acid – HCN) – however the concentration:

- varies between types (sorghum grain > sweet sorghum > Sudan x Sudan grass hybrids),
- varies with the stage of growth (inversely with height) with concentrations highest in fresh green growth
- increases in stressed plants (drought, waterlogging, nutrient deficiency, insects or disease) and in regrowth following a period of stress, especially less than 0.5m
- reduces during ensiling by 50% which also prevents selective grazing of high HCN material.

High levels of prussic acid can cause stock mortality. Signs of poisoning are rapid and laboured breathing and staggering which can occur within an hour of the stock grazing the forage (Robson 2007).

Measures to reduce the risk:

- Avoid introducing hungry stock – pre-feed
- Avoid grazing before the regrowth has reached the recommended minimum grazing heights (varies with the type and outlined below)
- Can offer stock an alternative feed, e.g. hay or stubble
- Supply sulphur and salt blocks to compensate for low S and Na in forage sorghum and reduce HCN risk (NSW DPI Forage sorghum)
- Avoid grazing stressed plants
- Making hay may reduce the risk, but does not completely eliminate it (O'Gara 2010).

Prussic acid is a rapidly acting poison which enters the bloodstream and inhibits oxygen utilisation in cells, so the animal dies from asphyxia (Robson 2007).

Further information: 'Prussic acid poisoning in livestock'. NSW DPI PrimeFact 417.

Field trial results — hybrid forage sorghum

Key results for production and feed quality

- High to very high growth rates of hybrid forage sorghum
- As expected the feed quality declined with increasing biomass (except for sweet sorghum)
- The 2N treatment did not increase biomass compared with the N treatment, but there was an increase in crude
- Protein diluted with increasing biomass to levels below that required for animal production

Site	North Broome
Agro-climatic zone	Medium rainfall – coastal zone
Trial design	3 reps x 5 treatments with split plots
Treatments	4 hybrid sorghum types plus pearl millet
Date of sowing	25/7/2018
Sowing rate	25kg/ha (20kg/ha pearl millet)
Fertiliser	Two levels of N: 1 unit of N per day or 2 units of N per day, applied monthly

Excellent, uniform establishment with 40-60 plants per m^2. The focus in this trial was the regrowth following the first cut (17/9) with weekly biomass and feed quality measurements starting when plants reached ~1m in height. The initial regrowth was good, but growth rates increased exponentially after the first two weeks (Figure 1). There was no consistent difference in biomass production between the two N treatments.

After the first 3 weeks very high growth rates (>300kg DM/ha per day) were measured for all of the treatments and the growth rates between the nitrogen treatments (1N, 2N per day) were very similar (Figure 1, Table 2). After 7.5 weeks of regrowth the biomass ranged from 12.4 to 14.8t DM/ha, which equates to average growth rates over the 52 days of 240 to 285kg DM/ha per day.

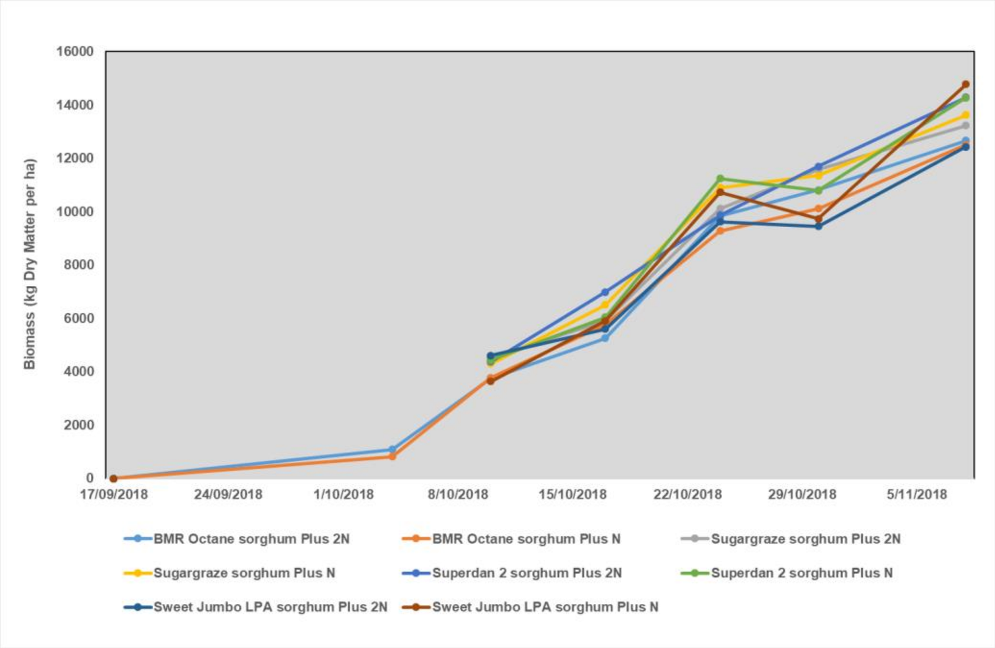


Figure 1. Regrowth of hybrid sorghum cultivars after first cut at North Broome with two levels of nitrogen fertiliser; 1 unit (plus N) or 2 units of nitrogen per day (Plus 2N) with the nitrogen applied monthly.

Table 2. Daily growth rates and total biomass of regrowth after first cut from 17/9/18 to 8/11/18 for four sorghum varieties with 2 units of nitrogen per day (2N).

Sorghum type (cultivar)	Average daily growth rate (kg DM/ha per day)			Average biomass (t DM/ha)
	First 23 days	Next 29 days (Day 23 to 52)	Average over 52 days	
Sudan x Sudan (Superdan 2)	190	340	275	14.3
sorghum x Sudan (Sweet Jumbo LPA)	200	270	240	12.4
sorghum x Sudan plus BMR (BMR Octane)	165	305	245	12.7
sweet x sweet (Sugargraze)	195	300	255	13.2

Feed quality: As expected the feed quality of the hybrid sorghum declined with increasing height (biomass). For example, with Superdan 2 the feed quality at 1-1.2m was good with ME ~9MJ and CP ~12.5%, but energy declined with increased biomass to between 8 to 8.5MJ and CP to less than 6% for the 2N treatment (Table 3). In contras the sweet x sweet sorghum cultivar Sugargraze had a marked increase in energy (ME to ~10MJ) and WSC with height and maturity (Table 3).

The exception was the sweet x sweet sorghum cultivar Sugargraze as the energy levels and sugars increased with height and maturity with ME increasing to about 10MJ and WSC to 24%; while fibre (NDF and ADF) declined. However, with the high biomass production the CP content was diluted to levels below that required for animal growth (Figure 2, Table 3).

Table 3. Height, biomass and nutritive value of irrigated forage sorghum Sudan x Sudan (Superdan 2) and sweet x sweet (Sugargraze) versus days of regrowth after first cut on 17/9/18 for the 2N treatment on a deep red sand at north Broome.

Sorghum type (cultivar)	Days of regrowth	Height (m)	Biomass (t DM/ha)	Nutritive value					
				NDF (%)	ADF (%)	CP (%)	DMD (%)	ME (MJ/kg .DM)	WSC (%)
Sudan x Sudan	23	1.3	4.4	63	34	12.5	59	8.9	4.9
(Superdan 2)	30	1.5	7.0	65	36	10.3	55	7.8	6.6
	37	1.3	9.9	64.5	34.5	11.2	57.5	8.3	7.3
	43	1.8	11.7	60	35	9.6	61	8.8	12.4
	52	2.05	14.3	58	37	5.7	58	8.4	16.4
sweet x sweet	23	1.2	4.5	61	35	11.6	60	8.7	7.9
(Sugargraze)	30	1.4	5.9	64	35	8.2	58	8.3	8.8
	37	1.2	10.1	60.	32	9.9	62	9.1	8.1
	43	1.6	11.6	51	31	8.3	68	10.1	19.9
	52	2.2	13.2	44.5	31	6.4	69.5	10.3	24.1

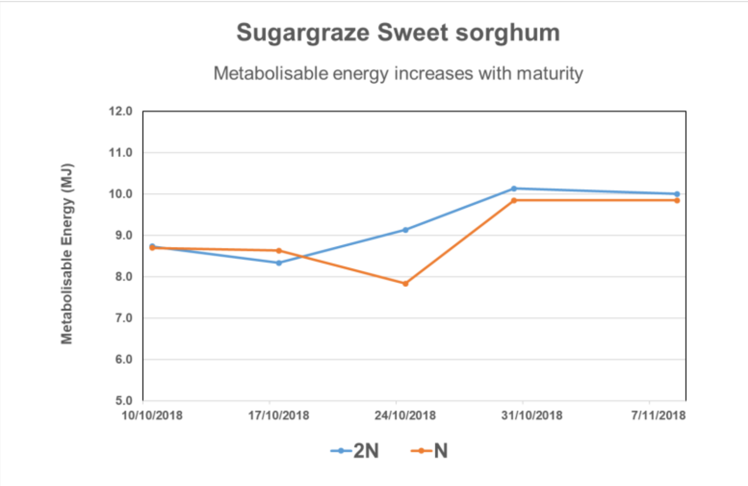


Figure 2. The metabolisable energy versus period of regrowth for the sweet x sweet sorghum cultivar Sugargraze at two levels of nitrogen fertiliser; 1 unit (N) or 2 units of nitrogen per day (2N).

The nutritional value of forage sorghums has proven to be reasonably consistent over sites and seasons in northern WA with ME values at the early flowering stage of 8.5 to 9.5MJ/kg DM, highest in the sweet sorghum x sweet sorghum hybrids (Table 4). The sorghum x Sudan hybrids were at mid-flowering and the Sudan x Sudan grass type (cv. Finerdan) had just begun to flower with all sorghums generally ranging 1.1–1.7m in height. Biomass was accumulating at about 150kg DM/ha per day.

Table 4. Height, biomass and nutritive value of irrigated forage sorghum on 5 September 2016, 73 days after sowing on a yellow loamy earth, 50km east of Broome.

Sorghum type (cultivar)	Height (m)	Biomass (t DM/ha)	Nutritive value					
			NDF (%)	ADF (%)	CP (%)	DMD (%)	ME (MJ/kg. DM)	WSC (%)
Sudan x Sudan (Finerdan)	170	6.2	62	31.5	14.7	62	9.1	8.1
sorghum x Sudan (Cowpow)	160	3.6	67	35	11.8	60	8.8	5.5
sorghum x Sudan (Sweet Jumbo)	140	3.7	64	33	15.1	64	9.4	<4.0
sorghum x Sudan plus BMR (BMR Octane)	120	3.4	60	29	13.9	64	9.4	8.0
sweet x sweet (Sugargraze)	110	3.6	62	30	13.5	64	9.5	7.0

Ready reckoner

Soil type	Wide range of well drained soils
Soil pH_w (1:5 water)	5–8.5
Waterlogging tolerance	Low
Temperature constraints for sowing	Soil temperature >15-16°C at 9am (Pastures Australia)
Seed size	Varies from 30,000–75,000 seeds/kg depending on cultivar
Sowing rate (kg/ha)	15–25kg/ha (varies with seed size)
Seeding depth	2–5cm
Row spacing	20-40cm
Plant density	10-15 plants per m of row (40–60 plants/m^2)
Seedling vigour	Very good
Herbicide options	Sensitive to carryover of sulfonylurea (SUs) herbicides, observe withholding periods
Plant nutrition	Requires NPK – fodder production removes large amounts of N and K
Livestock disorders	Contains prussic acid (HCN), the concentration varies with type and stage of growth – see Box
Special Notes	Feed quality declines markedly with height/maturity, except for sweet x sweet sorghum

(ii) Pearl millet

Features

- Easy to establish and well adapted to the soils and environment in northern WA
- Rapid growth over the wet season and also the dry season, except in the 'low rainfall – elevated inland' agro-climatic zone
- Faster growing than hybrid sorghum in field trials, but fewer cuts are possible and overall forage yield is lower, but responsive to N supply.
- Millet seed attracts birds, which can also attack and damage hay bales
- Key attributes like drought tolerance mean pearl millet is probably more suited to dryland cropping than irrigated production, however it could be a useful component of an annual rotation.
- Nutritive value (such as metabolisable energy) of millet is similar or slightly lower than forage sorghums but is safe for grazing at all growth stages as it does not contain prussic acid

There are a range of millets including Japanese (*Echinochloa esculenta*), white pennisetum or Siberian (*Echinochloa frumentacae*) and pearl millet, also called forage Pennisetum (*Cenchrus americanus*, synonyms: *Pennisetum glaucum*, *Pennisetum americanum*, also hybrid *Pennisetum*).

Pearl millet (forage Pennisetum) is a robust annual grass used for both animal feed and human consumption. It is an important staple food in hot, semi-arid regions of Africa and India due to its tolerance of high temperatures, moisture stress and infertile soils. Pearl millet is a tall, upright grass tillering from the base with comparatively fine, erect stems 150-300cm in height. It grows on a wide range of soils, but prefers well drained soils as it has a low tolerance of waterlogging (Muchow 1989, Tropical forages 2005).

Pearl millet can be used as a grain crop, but this is unlikely to be successful in northern WA due to damage from birds and other wildlife. Millet in this region should be grazed directly or cut for hay, silage or green chop. In Australia it is usually grown as a fast growing, high nutritive value summer forage crop.

There are a number of varieties of pearl millet and hybrid Pennisetum: 'Pearl', 'Maxa™', 'Siromill', 'Tamworth', 'Ingrid' and 'Pearler', which are all public varieties.

Uses

Grazing	Hay	Round bale silage	Pit silage	Carryover feed	Grain
√√	√√	√	√-√√	√	√-√√

Production and feed quality

There is limited data on pearl millet production under irrigation as it is usually grown under dryland conditions. It has faster growth than forage hybrid sorghum, but fewer cuts are possible and overall forage yield is lower. Pearl millets progress rapidly from establishment into a reproductive phase in as little as 60 days, even during the cooler winter (dry season) months. When cut, they recover quickly, flowering again as early as 16 days from cutting, but typically over 40 days, which limits their value in terms of feed quality.

In the DPIRD trial at north Broome described previously (Table 2), the regrowth of pearl millet following the first harvest was most rapid. After 17 days of regrowth the average biomass was 3.5t DM/ha with the 2N treatment which equates to a daily growth rate of 205kg DM/ha per day. However, two weeks later the pearl millet had >90% seed heads and the biomass was less than the hybrid forage sorghum.

Ideally fodder should be harvested before seed heads emerge. A mower conditioner is generally required when making hay. If regrowth is required then leave a high stubble of 15-20cm when cutting.

Feed quality: As with the hybrid forage sorghums there is a trade-off between feed quality and biomass. Feed quality declines with maturity as the grain yields are comparatively low (Table 5).

Vegetative (lower biomass) but higher quality (9.0-9.5 MJ, about 1-1.2m in height)

Early flowering (moderate biomass) (8.5-9MJ; 1.4-1.7m in height)

Late dough (high biomass) but lower quality (7.5-8MJ; >1.8m with seed heads)

Table 5. Biomass and nutritive value of irrigated Pearler and Siromil millet on 24 August (61 days from sowing when millets were flowering) and on 5 September 2016 (73 days from sowing when filling seed) on deep brown sand 50km east of Broome.

Pearl millet cultivar	Days from sowing	Biomass (t DM/ha)	NDF (%)	ADF (%)	CP (%)	DMD (%)	ME (MJ/kg.DM)	WSC (%)
Pearler millet	61	3.4	54	30.5	15.6	61.5	9.0	6.7
	73	7.7	60.5	35	11.9	54.5	7.8	4.2
Siromil millet	61	3.0	51	29	17.1	63.5	9.3	5.8
	73	5.4	59	34.5	13.2	54.5	7.7	<4.0

Ready reckoner

Soil type	Wide range of well drained soils
Soil pH_w (1:5 water)	5.5–7.5
Waterlogging tolerance	Low
Temperature constraints for sowing	Minimum soil temperatures >18°C, preferably >20°C (NSW DPI Sorghum booklet)
Seed size	Small (~190,000 seeds/kg)
Sowing rate	15–20kg/ha
Seeding depth	1.5–4cm
Row spacing	20–40cm
Plant density	15–20 plants per m of row (60–100 plants/m^2)
Seedling vigour	Good
Herbicide options	Sensitive to Group B herbicides (e.g. metalochlor, chlorsulfuron etc) which may lead to root pruning; tolerant of atrazine (Pastures Australia)
Plant nutrition	Requires good fertility - NPK
Livestock disorders	Nil (Does not contain prussic acid)

Maize crop in low rainfall inland agro-climatic zone

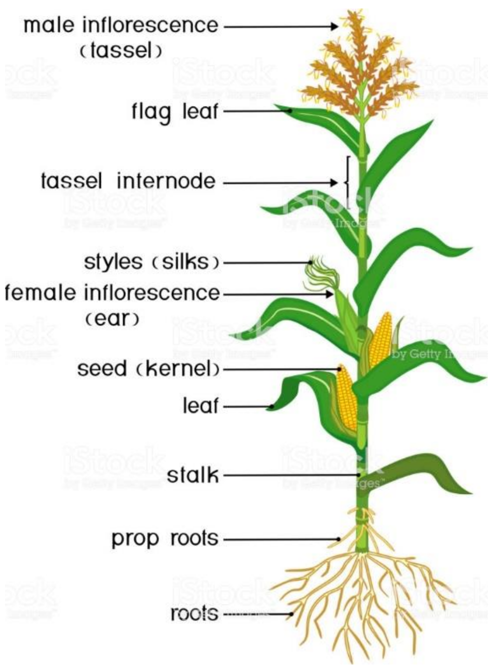
(iii) Maize

Features

- A high input, high value crop suited to pit silage, green chop, grain, or direct grazing.
- Potential high yields combined with high feed quality, especially energy (ME 10-11MJ/kg DM) makes maize an attractive option. However it is not a resilient crop and is much more susceptible to stress (moisture and nutrient deficiency) and insect damage than sweet sorghum.
- Requires good management to achieve high yields of a high-quality product.
- As a high fertility crop, providing adequate nutrition on the inherently infertile soils in northern WA requires special attention
- Maize is essentially a dry season (winter) option in northern WA as some growth stages are sensitive to high temperatures.
- Requires precision planting as optimum plant density is critical for a successful crop.

Maize or corn (*Zea mays*) is widely used for feeding cattle either as grain or silage and globally is the third most widely grown crop behind wheat and rice. Maize can also be direct grazed – reported animal growth rates are up to 1−1.3kg LWG per day with good utilisation of both the cobs and stover using strip grazing.

Maize is a monoecious plant, as it has separate male and female flowers on the same plant. The tassel or male flower produces pollen while the ear with silks (female flower) produces ovules that become the seed or kernels.



Maize is a high input, high value crop which requires good nutrition, low moisture stress and the control of insect pests to achieve both high yields and quality. It is a much less forgiving crop than sweet sorghum. For example, moisture or fertility stress from tasselling through to pollination has a major negative effect on yield potential as yield losses of 8-13% per day have been recorded. Moisture stress accelerates the rate of development resulting in smaller grains and lower yields.

Uses

Grazing	Hay	Round bale silage	Pit silage	Carryover feed	Grain
√√	√	√	√√√	√√	√√

Variety selection

There are numerous hybrid forage maizes available with Comparative Relative Maturity (CRM) ranging from 88 to 125. The CRM is used by Australian seed companies to compare the maturity of one corn hybrid to another – it is a unit-less number and should not be related directly to 'days'. A variety with a CRM of 98 is earlier maturing than a variety with a CRM of 108, but it may not be 10 days earlier as the timing depends on the environment where they are grown. However, in the eastern states CRM relates quite closely to the number of days to chopping for silage.

Considerations when selecting a variety are matching the CRM to the length of the growing season, standability (susceptibility to lodging), and tolerance to diseases and herbicide.

For a high yield of good quality silage select a mid-maturity variety with a high grain content and high stover (i.e. leaf and stem) digestibility (Kaiser et al. 2004). With early maturing varieties the plant density can be increased to partially compensate for the lower yield potential.

Production and feed quality

The attraction with maize is that under favourable conditions it can produce both high biomass with high nutritive value, especially metabolisable energy (ME). In the Northern Territory (NT), well adapted maize varieties under irrigation produced 10.4 to 12.7t/ha of grain – these grain yields can be converted to potential silage yields of 60 to 75t (wet)/ha; or 21 to 24t DM/ha. These yields relied on good irrigation management and weed control, adequate nutrition and control of multiple insect pests (O'Gara 2007).

Grain yields of 14t/ha have recently been achieved on black cracking clay soils on the Ord Irrigation District (www.abc.net.au/news/).

At Newman in the low rainfall inland elevated agro-climatic zone on a well-drained, red loamy earth two varieties of maize with a CRM of 111-114 sown on the 27th May 2019, produced biomass yields of 24.3-25.4t DM/ha when harvested on the 14th October (appropriate for silage). In this agro-climatic zone maize needs to be established before June to avoid low night temperatures during the establishment phase.

Feed quality: Well-managed maize silage crops have high feed quality, especially energy with typical values of 10-11MJ/kg DM. The protein levels tend to be low (CP<8%) as the CP is diluted as the biomass increases in the latter growth stages.

Table 6. Feed quality (Mean and range) of irrigated maize cut for silage from irrigated trial at Newman and from silage samples sent to a laboratory

Location	NDF (%)	ADF (%)	CP (%)	DMD (%)	ME (MJ/kg)	WSC (%)	Biomass (t DM/ha)
Newman DPIRD trials 2019	51.4	25.5	4.6	70.9	10.6	12.8	24.3-25.7
Maize silage samples submitted to FEEDTEST laboratory*			7.8 (3.3 – 16.5)	69.1 (50.6 – 78.0)	10.5 (7.2 – 12.4)		

* Source: FeedTest Victoria

Planting time

The planting time for maize needs to be adjusted so that it can be harvested before the onset of high to extreme temperatures.

Maize can be considered a warm season crop and the optimum temperature for growth is a high 33-38°C. However, maize is sensitive to high to extreme temperatures at key growth stages. For example, temperatures above 35-37°C can be lethal to pollen viability and can result in kernel abortion (Luo 2011, Sanchez *et al*. 2014). Maize also grows well at mild temperatures, so is best suited to growing over the dry season.

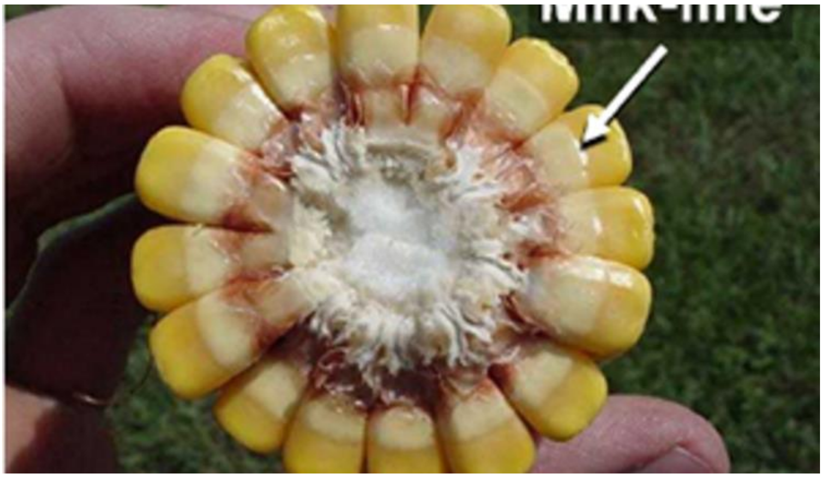
In the NT the suggested planting time is March to April when average maxima are less than 35°C so that the crop matures in July-August when it is coolest (O'Gara 2007).

When to harvest

After the kernels have dented, a milk line appears across the kernels. The 'milk line' – the colour difference between the soft and hard starch content of the maize kernels when a cob is snapped in two, can be used to determine starch content and when the crop should be harvested. This line moves down the kernel towards the cob. When the hard starch line approaches the cob, the black layer will form. It usually takes 20 days for the milk line to progress from the kernel tip (early dent) down to the base.

The milk line score (MLS) varies from 0 (no visible milk line at the top of the kernel) to 5 when the crop is physiologically mature and the milk line has reached the bottom of the kernel and a black-brown line has formed across it (Kaiser et al. 2004). As a guide MLS progresses one unit in 7 to 10 days.

Maize is ready for ensiling when the milk line has moved halfway down the kernel which corresponds with a milk line score (MLS) of 2.5 (see photo). Also termed ½ milk line, or 50% milk line. Aim to maximise the starch content and have a moisture content of 60-70% (dry matter 33-38%).



A corn cob snapped in two to show a milk line score of 2.5

For a guide on ensiling maize including: cutting height, chop length, moisture content and use of additives to produce a high quality silage which is well received by stock – see Further Reading.

Ready reckoner

Soil type	A range of soils, but high fertility requirement
Soil pH_w (1:5 water)	5.5–8
Waterlogging tolerance	Well drained soils
Temperature constraints for sowing	Soil temperature >12°C at 9am but growth is slow, so higher temperatures preferable (>15°C), optimum (20-30°C)
Seed size	Varies with variety (2500–4400 seeds/kg)
Sowing rate (kg/ha)	Depends on kernel size (usually in range of 15-40kg/ha)
Seeding depth	30–100mm with a precision seeder with good seed – soil contact (e.g. press wheels) to ensure optimal plant density
Row spacing	50 to 90cm row spacing, Use a wider row spacing to reduce trampling if planning to direct graze and a narrower row spacing to increase weed suppression
Plant density	Achieving optimal plant density is critical Usually 7* to 9 plants/m^2 evenly spaced along the rows with no twins (i.e. *70,000 to 90,000 plants per ha)
Seedling vigour	Very good
Herbicide options	A number of pre-emergent herbicide options Also Imidazolinone-tolerant (IT) varieties are available for use with residual herbicides
Plant nutrition	High fertility requirement (NPK plus trace elements) especially during critical growth stage (weeks 5 to 12)
Livestock disorders	Risk of acidosis if start feeding maize with a high grain content to stock (adjust ration slowly)
Special Notes	Requires a high level of management to achieve good yields

Further reading:

‘Corn growers guide’ – Enhancing the success of your corn crop. Pioneer Seeds https://www.pioneerseeds.com.au/content/file.php?file=MTA4

‘Maize growth and development’, O’Keefe, K. (2009) NSW Department of Primary Industries, Procrop. https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0007/516184/Procrop-maize-growth-and-development.pdf

‘Successful silage – Topfodder’ – editors Kaiser *et al.* (2004) NSW Department of Primary Industries and Dairy Australia.

3.4 Warm season perennial grasses

Geoff Moore, Sam Crouch and Clinton Revell

Key Messages

- Well adapted warm season (C4) perennial grasses have a very high biomass potential, assuming adequate irrigation and fertiliser. Peak growth is from October to April, when potential growth rates are >100kg DM/ha per day.
- Highly responsive to nitrogen (N) fertiliser providing other nutrients like phosphorus (P) are non-limiting.
- Feed quality is strongly related to the proportion of leaf compared with stem and there is often a trade-off between biomass production and feed quality.
- In field trials, Rhodes grass has the highest biomass production, but feed quality is moderate unless best management practices are applied. It is the best option for a system based on fodder production.
- Panic grass is a palatable, productive option for stand and graze systems.
- Other perennial grasses with potential for year-round production under irrigation are limited. Kikuyu, jarra grass, Bambatsi panic and perennial sorghum have some positive attributes, but also some limitations and in field testing had significantly lower biomass production than either Rhodes grass or panic grass (Figure 1).

The warm season (C4) grasses includes both sub-tropical and tropical species, the former come from sub-tropical environments which have cool to mild winters, while the 'tropical' species come from areas near the equator. In general, most grow well at the high temperatures experienced in northern WA from October to April, however the key difference is their adaptation to growth under irrigation from May to September when temperatures, especially minimum temperatures, are below the optimum range. The grasses from sub-tropical environments continue growing at mild temperatures when the tropical species have stopped growing.

A number of warm season perennial grasses have been evaluated in northern Western Australia (WA) under irrigation, however many have one or more of the following limitations:

- Species from tropical regions which have limited growth over the dry season (jarra grass)
- Specific soil requirements (Bambatsi panic)
- Poorly adapted to the high to extreme temperatures from October to April (kikuyu)
- Better suited to dryland (rainfed) production as key attributes include drought tolerance (sabi grass).

Perennial pasture research on the Ord River Irrigation Area in the 1970-80s used pangola grass, which is a palatable, productive species, but is vegetatively propagated which rules out its broad-scale use. Likewise, elephant grass is a highly productive perennial that is well utilised by stock, but is also vegetatively propagated.

The positive attributes and limitations for a range of species are summarised in Table 1. At this stage, Rhodes grass and panic grass are the only species widely recommended for irrigated production in northern WA.

The warm season grasses are well suited to grazing, although most require some form of rotational grazing to persist in the medium-term. Rhodes grass and panic grass are well suited to hay production and high yields can be achieved. Baleage has been successfully produced in northern WA and is of good quality. Ensiling C4 perennial grasses in pits has not been attempted, however is technically possible (Kaiser *et al* 2004).

Cutting perennial grass plots in the replicated trials at north Broome

Table 1. A summary of the warm season perennial grass options

Species	Optimum temperature for growth[1,2]	Waterlogging tolerance[2,3]	Wet season production	Dry season production (Coastal zone)	Soil adaptation[2,3]			Palatability	Suitability for stand and graze
					Sands	Loams	Clays		
Rhodes grass	20-37°C	Moderate	√√√	√√	√√√	√√√	√√	√√	√√
Panic grass	19-30°C	Low	√√-√√√	√√	√√	√√√	√√	√√√	√√-√√√
Other options – Generally not recommended for irrigation									
Bambatsi panic	17-26°C	Moderate	√√	√	–	√√	√√√	√√	√√
Strong soil preference for fertile clay soils (clay loams to cracking clays), tolerant of short-term flooding tolerance, poor cool season growth									
Buffel grass	22-37°C	Low	√√	√	√√	√√√	√√	√-√√	√√
Best suited to dryland production as limited cool season growth, moderate palatability and feed quality, but high drought tolerance. Assessed as a very high environmental weed risk for northern WA.									
Finger grass (Jarra grass)		Low-moderate	√√	√	√√	√√√	√√	√√-√√√	√√-√√√
Palatable, high nutritive value, spreading tropical grass with low cool season growth. Extremely small seed size makes uniform establishment challenging. Invaded by more rapidly growing species.									
Kikuyu	16-22°C	Moderate	√	√√-√√√	√√√	√√√	√√	√√	√√√
Spreading grass with excellent grazing tolerance and good cool season production, but the limited adaptation to the high to extreme temperatures experienced over the October to March period in northern Australia results in comparatively poor wet season production.									
Perennial sorghum	19-26°C	Moderate	√√√	√√	√√	√√	√√√	√-√√	√-√√
Tall, robust, tussock-forming perennial grass which is easy to establish, but short-lived — best suited as a pioneer species on new land (Young leaf may contain hydrogen cyanide (prussic acid))									
Setaria		Good	√√	√√	√√	√√	√√√	√-√√√	√√
Tall, bunch grass, tolerant of waterlogging and flooding, but contains high levels of oxalate ('big head' in horses) — yet to be evaluated in northern WA.									
Signal grass	25-35°C	Low to moderate	√√-√√√	√	√√√	√√	√√√	√√	√√-√√√
Tropical grass with low cool season growth which can contain high levels of saponins (secondary photosensitisation)									

[1] EcoCrop Database (FAO)

[2] 'Perennial pastures for WA' (Moore *et al*. 2006)

[3] Cook *et al*. (2005) Tropical forages database

Key:

√√√	Highly suitable
√√	Moderately suitable
√	Marginally suitable, consider other options
–	Not suitable

Confidence level for particular species

(light orange)	Low – limited testing or grower experience
(light green)	Moderate – some testing or grower experience
(green)	High – extensively grown or tested

Production

Well adapted warm season (C4) perennial grasses have a very high biomass potential, assuming adequate irrigation and fertiliser. Key factors that influence growth are nitrogen supply, temperature and frequency of cutting or grazing. Peak growth is from October to April, when potential growth rates are >100kg DM/ha per day (Figure 1).

Species vary in their requirements for growth and these are outlined in more detail in species descriptions below. Hay production can be in excess of 40t/ha dry matter per year, but this generally means growing the grass to maturity between each cut for 6-8 weeks and feed quality declines dramatically. In a stand and graze situation with regular grazing rotations of 5-7 days with 3 to 7 weeks recovery depending on the time of year, overall production may be reduced to 25-30t DM/ha per year, however the stand remains vegetative and nutritive value will be higher.

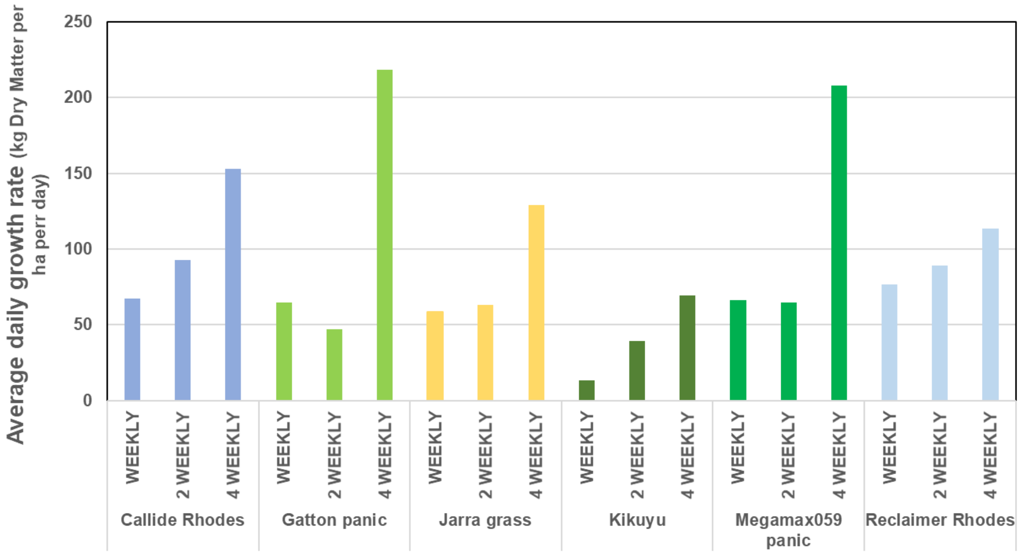


Figure 1. Average daily growth rates of a range of perennial grasses with weekly, 2 weekly and 4 week cutting cycles (red deep sand at north Broome, October 2018).

Feed quality and stage of growth

Feed quality and stage of growth or maturity are intrinsically linked. Stage of growth is the major factor influencing the composition and nutritive value of pasture. As plants grow there is an increasing requirement for structural tissues and therefore the structural carbohydrates like cellulose, hemicellulose and lignin increase.

In general, feed quality in warm season grasses is strongly linked to the stage of growth and the proportion of leaf. The best quality feed is new re-growth which consists predominantly of leaf with a small amount of young stem (Tables 2, 3). With longer periods of regrowth and as plants mature the stem comprises an increasing proportion of the total herbage and hence has a much greater influence on the digestibility of the whole plant than the leaf (Table 3). Feed quality declines rapidly from the commencement of flowering (maturity) as there is an increase in the proportion of structural carbohydrates and lignin, which reduce digestibility. Typically across a range of species, the dry matter digestibility of re-growth declines by 0.1-0.4% per day (Minson 1971).

Feed quality may decline with rapid growth rates and extreme temperatures over summer due to an increase in lignin production. The application of N fertiliser can lift nutritive value, but the effect is mostly seen with increased levels of crude protein rather than digestibility. Frequent cutting and at low cutting heights may produce the highest quality leaf, but grass stands will inevitably become unproductive as the plants have little time between defoliations to rebuild a strong root system and plant density may decline.

Table 2. Nutritive value of leaf and stem material for selected perennial grasses growing on a red deep sand near Broome (sampled November 2018).

Variety	Leaf or stem	NDF (%)	ADF (%)	CP (%)	DMD (%)	ME*
Reclaimer Rhodes grass	leaf	64.4	29.8	11.5	59.2	8.6
	stem	70.1	34.1	8.6	52.1	7.4
Callide Rhodes grass	leaf	63.5	31.9	11.8	58.6	8.5
	stem	73.6	37.0	7.8	49.4	6.9
Gatton panic	leaf	60.6	29.8	13.3	70.8	10.6
	stem	72.0	40.0	5.8	55.1	7.9
Jarra grass	leaf	53.7	25.9	13.3	70.8	10.6
	stem	66.5	35.6	7.0	55.1	7.9
Kikuyu	leaf	51.8	30.6	18.5	76.4	11.5
	stem	63.0	39.0	11.5	64.9	9.6

*ME is MJ ME/kg DM

Table 3. The nutritive value (average ±standard deviation, range) of leaf and stem of Callide Rhodes grass growing on a red deep sand near Broome with 2, 4 and 6 weeks regrowth (sampled on 28 August 2017).

	NDF (%)	ADF (%)	CP (%)	DMD (%)	ME (MJ/kg.DM)
Leaf	57.9±3.8 (52.0−65.0)	26.8±2.8 (22.3−30.7)	12.4±3.4 (9.2−15.8)	66.4±5.9 (60.3−72.7)	9.8±1.1 (8.8−10.8)
Stem	71.5±3.7 (67.3−76.3)	36.5±2.1 (34.3−38.7)	8.4±2.3 (5.8−10.0)	53.1±4.7 (49.7−56.3)	7.5±0.7 (6.9−8.0)

The feed quality of C4 grasses is inherently lower than for temperate (C3) grasses like perennial ryegrass at the same stage of growth because of a number of factors:

- Temperate grasses commonly contain higher levels of non-structural carbohydrates, protein and lower levels of fibre and silica than C4 grasses.
- In temperate grasses the fructans (sugar) are the main storage carbohydrates, while C4 grasses store starch rather than sugar and as a result have low water soluble carbohydrate (WSC).
- Temperate grasses can have high WSC and these soluble carbohydrates are highest in the stems, rather than the leaves and at their highest concentrations just prior to flowering. This contrasts with C4 grasses where the stems are markedly lower in digestibility (energy) and protein and higher in fibre than the leaves.
- C4 grasses are higher in fibre than temperate grasses which is related to the cells involved in the C4 photosynthetic pathway and to a higher content of structural carbohydrate and lignin.
- At high temperatures the feed quality of temperate pastures declines. However, while the feed quality of C4 warm season grasses improves at mild temperatures, it is still significantly lower than temperate grasses.

Temperate pasture swards have a fairly even nutrient content throughout the sward, however tropical grass pastures often vary in composition and nutritional value with higher quality leaf and lower quality stem. Cattle grazing tropical pastures can partially compensate for the lower overall feed quality by selectively grazing the higher quality parts of the sward. However, the upper limit of production is limited by the nutritional value of the highest quality diet which can be selected (Stobbs 1975). As a pasture is grazed down then the animals are forced to eat lower quality pasture with a higher stem content which is lower in energy and protein.

Warm season C4 grasses can produce a large bulk of forage, however this bulk quickly becomes fibrous with a low leaf to stem ratio and has low nutritive value. Rank growth has low palatability and poor feed quality and will be avoided by stock. However, providing a protein lick can increase the intake of rank (mature) grasses.

Metabolisable energy (ME) is consistently higher in the leaf than the stem by 1 to >1.5 units of ME (Table 2). Crude protein (CP) content is highly variable from less than 6% to more than 18% in highly fertilised pastures. The CP is very dependent on the level of N fertiliser and stage of growth, with CP decreasing with maturity and being consistently higher in the leaf than the stem (Tables 2 and 3).

Rhodes grass

Features

- Rhodes grass has a number of strengths, as it is easily established, tolerates heavy grazing, has relatively few pests or diseases of economic importance (except locusts and fall armyworm), drought tolerant and grows over a broad temperature range.
- Reliably high biomass production from irrigated agronomy trials in west Kimberley and Pilbara (Tables 5 and 7). On a monthly cutting cycle under favourable temperature conditions and adequate N, the potential production is 100-150kg DM/ha per day.
- Feed quality is variable. With well-managed Rhodes grass the feed quality is comparable with other warm season perennial grasses. Good feed quality is about maintaining a high proportion of leaf, however it can be difficult to maintain the pasture in the sweet spot for quality under a stand and graze system.
- There is a ‘biological ceiling’ for rotationally grazed Rhodes grass corresponding to the feed quality of 2-3 week old regrowth (9 to 9.5MJ of energy and 12-19% CP). This would equate to animal growth rates of 0.5-0.7kg LWG per day in the medium term.
- Two distinct types: (i) diploid varieties which are daylength insensitive and flower from late spring to autumn and (ii) tetraploid varieties which respond to shortening day length with a strong flush of flowering during autumn.
- Generally sensitive to frost and growth rates are considerably slowed down with low night temperatures over winter (Climate 1.3).

[INSERT Photos of seed head, whole plant from Photo Library]

Rhodes grass (*Chloris gayana*) is a warm season (C4) perennial grass which is both tufted and spreads through stolons (runners). The degree of stoloniferous growth not only varies between varieties, but can also vary between different environments and with management. Vegetative growth is generally 30 to 100cm in height, while seed heads are 60 to 180cm in height.

In Australia, Rhodes grass has been widely used as a perennial pasture grass for summer rainfall regions and more recently in south-western Australia in areas with mild winters (Moore *et al*. 2014).

Rhodes grass is the main perennial grass under centre pivot irrigation in northern WA where it is used for both fodder production and direct grazing. Producers' grow Rhodes grass because of the reliable establishment, good production under irrigation and its resilience. Rhodes grass can recover from stress or over-grazing and produces useful amounts of biomass even with sub-optimal management. With good management and high fertiliser N inputs very high biomass production is possible. Growth over winter depends on the prevailing temperatures, but there is little or no production for about 3 months in the inland agro-climatic zones. The strengths and weaknesses of Rhodes grass are summarised in Table 4.

There are two groups of Rhodes grass based on the ploidy level; diploids and tetraploids (the latter having double the number of chromosomes). The diploids come from sub-tropical regions and are generally more robust with higher frost, drought and salinity tolerance (Moore *et al*. 2006). The diploids are generally insensitive to day-length and flower from late spring through to autumn. On the other hand the tetraploids are from tropical regions and are late flowering − refer to varieties below.

Table 4. Rhodes grass – strengths and weaknesses

Strengths	Weaknesses
High biomass production and well adapted to the climate and most of the soils in northern WA	Generally moderate feed quality and palatability unless best management practices are applied
Wide temperature tolerance – from extremely high temperatures to comparatively good growth at mild temperatures	Difficult to maintain high leaf content (i.e. 'sweet spot' for feed quality), especially under direct grazing
Can develop a deep root system and tolerates dry or drought periods. Once established, competes strongly with broadleaf weeds	Stock can pull out small plants as the stolons act like a 'lever'. Also, it can be difficult to 'thicken' a stand under direct grazing as the cattle pull out stolons before they are strongly anchored.
Stoloniferous growth means stands can recover from loss of plant density without re-seeding.	Preferentially eaten by locusts (Australian Plague locust and Yellow winged locust) and fall armyworm
Salt tolerance with salt glands on leaves (Some varieties have been selected for irrigation with brackish water in the Middle East)	If unable to mow/graze over the wet season due to access/trafficability, this can result in a large biomass of rank growth which is likely to lodge and subsequently needs to be removed off-site.

Production and feed quality

Given conditions favourable for growth (temperature, irrigation) then Rhodes grass has high production potential given adequate soil nutrition, especially fertiliser N:

- With moderate rates of N (1–1.5kg N/ha/day) then growth rates of 100kg DM/ha/day are realistic targets on a monthly cutting cycle
- With high rates of N (3kg N/ha/day) then growth rates >150kg DM/ha/day are achievable on a monthly cutting cycle

Growth rates of Rhodes grass for different periods of regrowth during July to November 2017 for Reclaimer and Callide Rhodes grass are shown in Tables 5 and 7. Performance of varieties was generally similar with differences primarily a function of management and seasonal conditions. Yields of 7-8t/ha DM are possible on 6-8 week cutting cycles, however, there is a trade-off between biomass production and feed quality even with high levels of fertiliser N.

The proportion of stem increases as the biomass increases, but this has lower feed quality and palatability than the leaf. For example, fresh leafy growth (<1,000kg DM/ha) may have less than 10% stem, however when the biomass is 4,000kg DM/ha it will consist of approximately half leaf and half stem (Figure 2). Rhodes grass plants produce stem even when they are not flowering (Pembleton *et al*. 2009). Research from Queensland suggests the rate of leaf growth is steady, but stem growth increases exponentially from about the third week after cutting or grazing (Ehrlich *et al*. 2003).

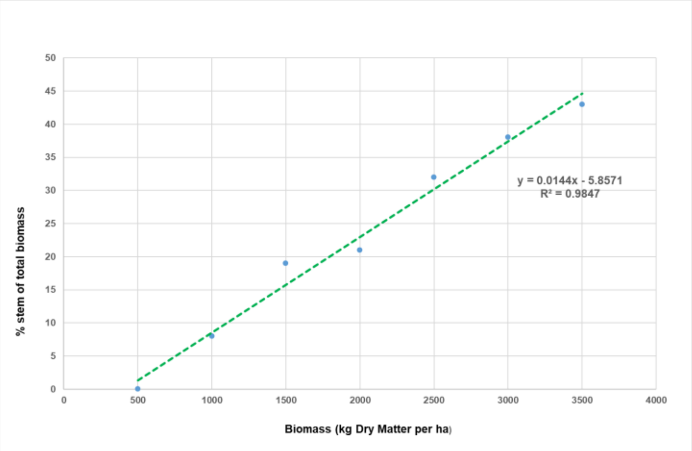


Figure 2. The % stem versus the total biomass in a pure Rhodes grass sward
(Data from K. Bell)

Rhodes grass hay crop

Table 5. Biomass (kg DM/ha), average daily growth rates (kg DM/ha per day) and nutritive value of selected irrigated perennial grasses grown on a deep red sand near Broome sampled on 16 August 2017 with 14 and 28 days of regrowth plus 90 days (uncut).

Variety	Days of regrowth	Biomass	Growth rate	NDF (%)	ADF (%)	CP (%)	DMD (%)	ME (MJ/kg.DM)
Reclaimer Rhodes grass (diploid)	14	850	61	53.9	25.7	16.4	70.4	10.5
	28	2730	101	61.5	29	15.1	63.7	9.3
	90 (uncut)	8720	105	77.2	41.4	9.6	46.0	6.3
Callide Rhodes grass	14	860	61	52.5	24.4	17.3	71.2	10.6
(tetraploid)	28	2740	102	56.6	26.6	16.3	65.6	9.6
	90	7950	96	74.4	40.0	11.1	48.8	6.8
Gatton panic	14	940	67	49.8	22.8	22.6	74.2	11.1
	28	2520	93	59.7	27.7	16.9	64.6	9.5
	90	6520	79	74.9	37.7	11.3	50.8	7.1
Megamax059™ panic	14	860	61	51.5	23.4	22.4	74.9	11.2
	28	2290	85	59.4	26.3	21	68.3	10.1
	90	6330	76	71.9	35.9	12.4	54.1	7.7

Table 6. Biomass (kg DM/ha), average daily growth rate (ADGR: kg DM/ha per day) and nutritive value of selected irrigated perennial grasses (mean of 3 reps) for 2, 4 and 8 weeks of regrowth after cutting (north Broome sampled during October and November 2017).

Species / variety	Days of regrowth	Biomass	ADGR	NDF (%)	ADF (%)	CP %)	DMD (%)	ME*
Reclaimer Rhodes grass	15 (19/10)	970	65	58	29.9	9.6	59	8.5
	30 (19/10)	1900	64	59	30.4	8.5	57.5	8.3
	13 (2/11)	1460	104	59	31.1	13.2	55.3	7.9
	58	8140	140	72	39.5	6.0	46.7	6.4
Callide Rhodes grass	15	1050	70	56.5	27.1	9.8	61.5	8.9
	30	2120	71	62	32.0	8.6	56.5	8.1
	13	1430	102	58	30.1	15.0	59	8.5
	58	7900	136	69	37.3	6.8	49.7	6.9
Gatton panic	15	860	58	56	28.7	10.3	64.5	9.4
	30	2130	71	60.5	30.8	9.2	59.5	8.5
Megamax059™ panic grass	15	830	55	55.5	27.8	11.2	65.5	9.6
	30	2460	82	60	30.6	11.8	63	9.2
	13	1430	102	59	30.0	15.8	61	8.9
	58	7880	136	69	37.6	7.6	52	7.4

*ME is MJ ME/kg DM

Indicative monthly growth rates for Rhodes grass in a rotational grazing system and growing in a warm coastal environment are shown in Figure 3. In this situation, the plants are managed to keep them in a leafy vegetative growth stage and overall production is lower compared with growing out for hay production.

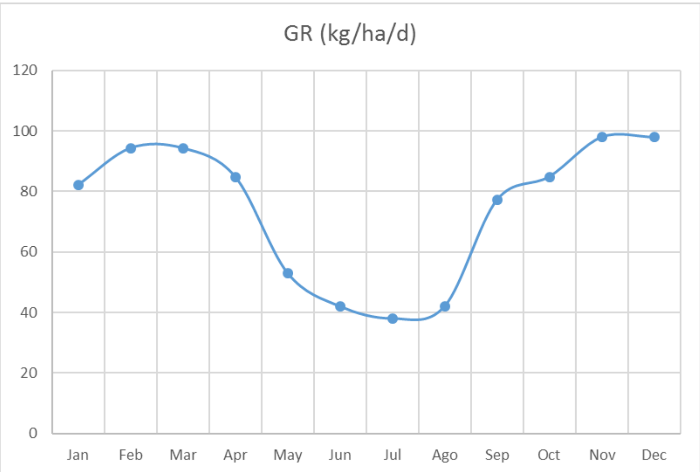


Figure 3. Indicative monthly growth rates of Rhodes grass over 12 months in a rotational grazing system for a warm coastal environment in the Pilbara.

Growth rates of Rhodes grass are substantially reduced in inland environments, especially when night temperatures are less than 10°C. This has a key impact in inland and elevated regions with winter growth rates typically falling to under 20kg DM/ha per day for 2-3 months. For example, at Woodie Woodie in the low rainfall inland agro-climatic zone the average daily growth rates for irrigated perennial grasses from late May to late August was 15kg DM/ha per day for panic grass and 20kg DM/ha per day for Rhodes grass.

Feed quality

The feed quality of Rhodes grass is variable. It has a reputation of being a lower quality feed, but the quality of well-managed Rhodes grass is comparable with other warm season perennial grasses. However, mature rank growth has low palatability and is at best a maintenance diet.

Good feed quality is about maintaining a high proportion of leaf which has higher digestibility (energy) and protein than the stem and is also much more palatable (Tables 5 and 6). Cattle grazing Rhodes grass will have a strong preference for selecting leaf over stem. In a grazing experiment on irrigated Rhodes grass, cattle selected a diet of 82-87% leaf, compared with the composition of the sward which had 32-48% leaf (Ehrlich et al. 2003).

In practice, Rhodes grass leaf equates to animal growth, while the stem fraction is essentially a maintenance diet (Table 3). As a result there is an upper limit to feed quality of 9 to 9.5MJ of energy and 12-19% CP which corresponds with fresh leafy growth. On the other hand, stem has lower energy (7-8.5MJ) and 8-15% CP which corresponds with maintenance to slow growth. Quality may decline with faster growth rates and higher temperatures over the ‘wet’ season (Table 6).

With well-fertilised Rhodes grass pastures digestibility (energy) is the limitation to higher animal growth rates not protein.

Varieties

Rhodes grass is a morphologically variable out-crossing species and there are a number of both diploid (e.g. Pioneer (superseded), Topcut, Katambora, Finecut, Gulfcut, Reclaimer, Endura, KP8) and tetraploid (e.g. Callide, Epica, Mariner, Sabre, Toro) varieties.

Diploid types

‘Topcut’ (public variety) is a selection from Pioneer developed primarily for hay production, which is reported to be leafier, finer-stemmed and produce more dry matter.

‘Katambora’ (public variety) is mid-flowering and is characterised by strong stolon development, heavy seeding and drought tolerance. In Queensland, it is more persistent on low fertility soils than other cultivars.

‘Finecut’ (public variety) is a selection from Katambora developed primarily for hay production and is reported to be leafier, finer-stemmed and to produce more dry matter in Queensland.

'Gulfcut' (PBR) is a selection from Finecut Rhodes grass for improved plant growth and survival under saline conditions and then improved agronomic characteristics (fine stems, erect and leafy growth habit).

'Reclaimer' (PBR) is a selection from Finecut Rhodes grass for improved plant growth and survival under saline conditions and then improved agronomic characteristics (fine stems, leafy and stoloniferous growth habit).

'Endura' (PBR) and 'KP8' (PBR) are both selections from Tolgar (KP4) for improved germination, growth and survival under saline conditions and then improved agronomic characteristics (late flowering, prostrate growth habit and stoloniferous growth).

Tetraploid (Giant) types – are tall (>1.8m when flowering) and have coarse leaves, stems and stolons.

'Callide' (public variety) an introduction from Tanzania is widely grown in Australia.

'Epica' (PBR) is a synthetic cultivar derived from the tetraploid 'Boma' developed primarily for increased salt tolerance.

'Mariner' (PBR) is a selection from 'Samford' Rhodes grass for improved germination, growth and survival under saline conditions and then improved agronomic characteristics (late flowering, leafy growth habit).

'Sabre' (PBR) is a selection from 'Callide' Rhodes grass for improved germination, growth and survival under saline conditions and then improved agronomic characteristics (early flowering, leafy growth habit).

'Toro' (PBR) is a selection from 'Callide' Rhodes grass for improved germination, growth and survival under saline conditions and then improved agronomic characteristics (late flowering, leafy growth habit).

Uses

Rhode grass is widely used for grazing (stand and graze) usually under some form of rotational grazing. Given the feed quality of well-managed Rhodes grass pastures LWG of 0.5-0.7kg per day can be expected. If allowed cattle will preferentially select a higher quality diet than the bulk pasture, however if forced to eat all the available pasture their diet will reflect the feed quality of the bulk pasture.

Some of the challenges with direct grazing of Rhodes grass are:

- In practice it is difficult to maintain a sward with high leaf content (i.e. 'sweet spot' for feed quality) in front of the cattle to maximise the potential animal growth rates.
- Rhodes grass pastures with very high growth rates (>1t DM per ha per week) and high rates of fertiliser N need to be managed tightly. A slight delay in grazing a paddock can result in a large increase in pasture biomass, but also a decline in feed quality, due to an increased proportion of stem.
- Matching stocking rate with pasture growth especially at the start and end of winter when pasture growth rates change rapidly. For example, from August to September pasture growth rates can increase three-fold in less than one month. Too many stock results in over-grazing, while if too few stock then the pasture will quickly mature with a commensurate decline in feed quality.
- Patch grazing due to stock avoiding or only lightly grazing urine and dung patches.

Management options include taking a sector out of the rotation and cutting for hay and regularly re-setting the pasture by mulching, or cutting and removing the ungrazed patches. However, topping the pasture at 40-50cm to remove seed heads could inadvertently restrict the pasture available for grazing, by forming a physical barrier of old stems.

Refer to Section 3.5 'Rhodes grass grazing management'

Fodder production

Rhodes grass is widely used for fodder production, predominantly hay, but also baleage when high humidity makes drying hay difficult. With Rhodes grass hay then 'fit for purpose' depends on the end use.

For bulk hay production for station-use the objective is to produce a maintenance hay at low cost. Cut the Rhodes grass after 5-7 weeks to get the benefit of the exponential increase in pasture growth rates after 3-4 weeks (potential hay yields 6-8t/ha). The fertiliser N input can be reduced as the protein requirement for good rumen function in a maintenance diet is 7-

8% CP. For bulk hay production then Rhodes grass is relatively forgiving and the time of cutting is less critical.

For high quality hay to grow animals either fed alone or as part of a ration then a higher quality product is required. The Rhodes grass will need to be cut at 3-4 week intervals with expected hay yields of 3.5-4t/ha at 12% moisture depending on the time of year and level of N nutrition.

Generally less suitable for silage due to the low WSC, but if making silage then important to cut when feed quality is high. As a guide cut less than 4 weeks regrowth, as quality declines with late cutting. The low WSC content in warm season grasses like Rhodes grass means that wilting is essential to concentrate the WSC, however avoid excessive wilting. The high fibre content can make silage compaction more difficult, so fine chopping is essential to improve compaction and increase acid production (Topfodder Silage Book).

Ready reckoner

Soil type	A wide range of soils, but reported to be difficult to establish on heavy clay soils
Soil pH_w (1:5 water)	4.5-9
Waterlogging tolerance	Moderate (Also tolerates short-term flooding)
Temperature constraints for sowing	Optimum germination 15-40°C
Seed size	Very small (4-10 million seeds/kg) seed is light and fluffy unless coated
Sowing rate	15kg/ha coated seed (assuming 60% germination)
Seeding depth	0.5cm (very sensitive to seeding depth)
Plant density	30-40 plants/m^2 (10-12 plants per metre of row) Stoloniferous growth can fill-in gaps in the sward
Seedling vigour	Good, easily established
Herbicide options	Susceptible to glyphosate and pre-emergence atrazine
Plant nutrition	Highly responsive to N fertiliser to very high rates providing other nutrients are adequate
Livestock disorders	Nil
Special Notes	Rhodes grass has a weak primary root system, so plants rely on developing a strong secondary root system and are easily pulled out by stock during the establishment phase. Ensure plants are well anchored before grazing.

Panic grass

Features

- Very leafy, highly palatable bunch grass with high potential production
- Nutritive value typically higher than Rhodes grass
- Well suited to stand and graze with good animal growth rates
- If sown as a monoculture, then important to have excellent establishment as the sward will not thicken under regular rotational grazing
- Two distinct types, the tall Guinea grasses and the shorter 'panic grasses' which are the focus of this section

[INSERT Photos of seed head, whole plant from Photo Library]

Panic grass (*Megathyrsus maximus* syn. *Panicum maximum*) is a tufted, warm season (C4) perennial bunch grass which is widely grown around the world, in sub-tropical Queensland and more recently in the northern agricultural region of south-western WA. Panic grasses are shade tolerant and often found around tree lines in their native environment (tropical and sub-tropical Africa) where the soil fertility is higher.

The species is highly variable and two distinct types are often identified:

(a) short types commonly called panic grass which are mainly from sub-tropical regions and are generally <1.5m when flowering; and

(b) tall types, commonly called Guinea grasses which are usually >1.8 to 4m when flowering and predominantly from tropical origins.

Panic grasses are moderately drought tolerant (varies with variety) and can respond rapidly to rainfall. Most varieties are intolerant of waterlogging or flooding. It is a productive forage grass for pasture, green-chop, hay and silage.

Panic grass has been evaluated in a range of field trials in northern WA and has been grown to a limited extent commercially. The tall Guinea grasses have not been evaluated and the focus in this section will be on the shorter panic grasses.

Attention to establishment is critical in order to get the required plant density. If the plant density is patchy there is little opportunity to thicken up the stand, unlike Rhodes grass which has stoloniferous growth. The crowns of individual plants will increase, but productivity will be reduced and bare ground can lead to weed invasion. Good quality seed (check germination) and shallow depth of seeding are essential.

Production and feed quality

High biomass potential: Panic grass has performed consistently well in field trials under various cutting regimes to simulate different rotational grazing (Tables 5 and 6). However, biomass yields can be up to 15% lower than Rhodes grass with similar nitrogen fertiliser application. Good levels of nutrition are required for maximum production.

Well managed panic grass has good feed quality with digestibility of 3-4 week old regrowth in the range of 60-68%, metabolisable energy 8.5-10MJ and 12-18% CP (Tables 5 and 6). Note these values are from bulk cuts and grazing cattle can select a higher quality diet.

In field experiments in the west Kimberley the feed quality of panic grasses has consistently been higher (digestibility 5-6%; metabolisable energy 0.8-1.0MJ) than Rhodes grass.

Varieties

There are a number of commercial varieties:

‘Gatton’ panic (public variety) is a robust, tufted grass from Zimbabwe which has indeterminate flowering and often contains anthocyanins (purple pigmentation) near the base of the stems.

‘Megamax™059’ is a medium to large panic grass selected for superior growth characteristics including increased production, high persistence and cool season tolerance.

‘Megamax™049’ is a short to medium panic, with soft, fine-leafed foliage selected for superior growth characteristics including increased production, high persistence and cool season tolerance (Note: Seed supply is uncertain).

‘Green panic’ (or ‘Petrie’) (public variety) is an erect, tall (seed heads up to 1.8m), tufted grass which is distinguished by its light-green foliage. It is less palatable than some other varieties.

Guinea grass varieties include: ‘G2 panic’, ‘Makueni’, ‘Natsukaze’, ‘Tanzania’ and ‘common’.

Uses

Panic grass hay crop

Grazing

Well-managed panic grass pastures are leafy, highly palatable and well utilised by livestock. Stands generally have a higher leaf to stem ratio than Rhodes grass and are slower to move into a flowering phase. In a mixed sward panic grass is often preferentially grazed.

Pasture growth rates of panic grass have been slightly lower than Rhodes grass in cutting experiments (Tables 5 and 7), but this is off-set by higher utilisation (i.e. less wastage). Panic grass is also easier to manage under grazing.

Panic grass will tolerate periods of heavy grazing, but some form of rotational grazing is normally required. However, industry experience has shown that panic grass can be set-stocked over the wet season with good animal growth rates.

A stubble of old stems can be used to prevent over-grazing of individual plants. The cattle will only graze down to the level of the old (dead) stems which act as a physical barrier and ideally would be at a height of 8-10cm. On the other hand, continual grazing of fresh growth down to the crown will result in the death of individual tillers, lead to the death of the centre of the crown and eventually the whole plant will die.

Fodder production

If sowing a pasture solely for hay production, then Rhodes grass would be the preferred option, but panic grass is suitable for fodder production. As with the other grasses the quality will depend on the stage of growth when cut. There is increased stem growth if grazed or cut infrequently.

Like other warm season (C4) perennial grasses it is less suited to silage production due to the low content of soluble carbohydrate. However, good quality silage can be made by cutting the stand after 3-4 weeks with a high leaf content and then wilting to 30-40% DM to concentrate the soluble carbohydrate.

Ready reckoner

Soil type	Range of soils, but prefers well drained, fertile loams.
Soil pH_w (1:5 water)	5-8.5
Waterlogging tolerance	Low
Temperature constraints for sowing	Minimum soil temperature at 9am >15°C, preferably >18°C, optimum 25-30°C
Seed size	Very small (0.8-1.3 million seeds/kg)
Sowing rate	10-15kg/ha coated seed (assuming 60% germination)
Seeding depth	0.5-1cm
Plant density	30-40 plants/m^2 (10-15 plants per metre of row)
Seedling vigour	Slow
Herbicide options	Tolerant of atrazine (Tropical forages)
Plant nutrition	Requires fertile conditions to grow well
Livestock disorders	Contains low to moderate levels of oxalates, so not suitable for horses and can contain steroidal saponins, but usually at low levels
Special Notes	Check Seed Certificate when purchasing seed – as recently harvested seed has a high proportion of 'fresh' seed which is dormant seed. Seed takes 6-9 months from harvest to break dormancy.

Further reading:

Tropical forages Factsheets link: http://www.tropicalforages.info/index.htm

3.5 Tropical legumes

Sam Crouch, Geoff Moore and Clinton Revell

Key Messages

- The key role of tropical legumes is to provide a source of high quality feed, being readily digestible and high in protein. While direct grazing is possible, they are typically grown in a rotation and conserved as hay or baleage.
- Biomass yields are typically lower than for C4 grasses, however modest production of a high protein feed source can have particular value for young growing animals.
- Can act as a disease break between grass crops and provide 'free' nitrogen (N) input to build soil fertility (sometimes as a specialist green manure crop).
- The main tropical legume options are centro, cowpea, lablab and butterfly pea. They have some limitations that restricts their usefulness under irrigation and butterfly pea may not be approved for use on pastoral lease due to its status as an environmental weed.
- The tropical legumes are generally less productive than the warm season grasses and with the exception of lablab, their growth pattern is typically constrained over the dry season.
- When sowing in high temperature conditions there can be issues with inoculation and effective nodulation, which may reduce N-fixation.

The main tropical legume options with application for irrigation are: lablab (*Lablab purpureus*), cowpea (*Vigna unguiculata*), centro (*Centrosema pascuorum)* and butterfly pea (*Clitoria ternatea*). Given suitable conditions, these legumes can all produce high protein, highly digestible fodder. They are widely grown in tropical and sub-tropical environments, but predominantly under dryland conditions, not irrigation.

Other species are excluded on the basis of their status as an environmental weed risk (leucaena) and/or are better suited to dryland production (stylos, desmanthus, siratro). The value of tropical legume crops such as soybeans, pigeon pea and peanuts in northern WA remains to be evaluated.

Lablab, cowpea, centro and butterfly pea are decumbent or twining plants, which result in a dense canopy. If using a mower-conditioner, it can be very slow and hard on machinery as the stems tend to wrap around the conditioning rollers, causing blockages. Using a mower that can get underneath the canopy with no conditioner is the best option.

These legumes have a 'tropical' growth pattern reflecting their origins near the equator. They require warm to high temperatures for good growth and are sensitive to low temperatures, which will result in a sharp reduction in growth rates. Over the dry season the legumes will stay green, but will produce little biomass even when irrigated. The exception is lablab, which can tolerate much lower minimum temperatures (Table 1). The upper range of optimum temperatures for growth is lower than for most of the warm season C4 grasses, so they are less suited to extremely high temperatures.

Productivity of tropical legumes is generally much less (up to 60% lower) than the annual and perennial warm season (C4) grasses, but the higher feed quality can partially compensate for lower yields. Modest production of a high protein feed source has particular value for young growing animals.

Table 1. The lower (T_b), optimum range (T_{opt}) and upper thresholds (T_{max}) temperature for growth of tropical legumes (Source: EcoCrop Database)

Legume	T_b (°C)	T_{opt} (°C)	T_{max} (°C)
Butterfly pea	15	19-28	32
Centro	10	22-32	40
Cowpea	15	25-35	40
Lablab	3	15-32	38

Tropical legumes can be grown with a companion C4 grass but can be difficult to manage due to competition for light, nutrients, water and different rates of regrowth after cutting or grazing (refer to section 3.1).

A key advantage of legumes is their ability to fix atmospheric nitrogen (N). Legumes are able to form a symbiotic relationship with nitrogen-fixing soil bacteria called rhizobia. The result of this symbiosis is to form nodules on the plant root, within which the bacteria can convert atmospheric nitrogen (N_2) into ammonia (NH_3) for use by the plant. Legumes do not require the addition of N fertiliser, although a small 'starter' application of N at seeding is sometimes beneficial.

Legumes that have formed an effective symbiosis can fix substantial amounts of N, as 1t/ha of legume dry matter with 20% CP equates to ~30kg N/ha, or 70kg/ha of urea. Legumes with effective nodulation typically 'fix' 65-95% of their N from the atmosphere, the balance coming from soil (Unkovich and Sanford 1997). Residual N after a legume can be in the range of 20-140kg/ha and slowly breaks down by an important process known as nitrification that can take many years. Approximately 90% of nitrogen in the soil is organic and must be converted to an inorganic form, such as ammonium or nitrate, to be used by the plant. This complex conversion takes place when soil microbes are activated by moisture and warm soil temperatures, to transform ammonia into nitrite and then into nitrate. However, the increased N-status will also promote weed growth, so good weed control is essential following a legume crop.

Rhizobium are found naturally in most soils; however most legumes have specific Rhizobium requirements. The seed must be inoculated with the correct strain of inoculant before sowing to ensure effective nodulation and nitrogen fixation (refer to box 'Seed inoculation').

Seed inoculation

Ron Yates (Rhizobiologist, DPIRD, Murdoch University)

Inoculation is the application of rhizobia (root nodule bacteria) to a legume seed or soil in which the legume is sown, to facilitate root nodulation. Improving the nodulation of a legume can increase symbiotic nitrogen fixation, biomass, seed yield and increase the amount of organic nitrogen contributed to the soil from residues.

To ensure delivery of adequate numbers of rhizobia to the surrounding area of the legume roots some safeguards need to be taken. With all inoculant used, rhizobia are living organisms and their growth and survival can be reduced by coming into contact with chemicals and fertilisers, high temperatures (above ~35°C), freezing temperatures (below 3°C), sunlight, desiccation, low soil pH (acidic) and high soil pH (alkaline).

Frequent inoculation is encouraged as the commercial inoculants are regularly updated with superior strains with increased effectiveness and survival. Some other important reasons to undertake inoculation include where the legume has not been grown in the paddock previously or the legume has not been grown there for at least 4 years.

Legumes must be inoculated with the correct rhizobial strain for effective nodulation and N-fixation (refer to species descriptions – Ready reckoner for the specific strain of inoculant).

A range of different inoculant formulations are available including: peat, granular, freeze-dried powder, liquid and pre-inoculated seed (Table 2). All inoculants are expected to work well when sown into moist soils when temperatures are mild, however only some granular inoculants are suitable for sowing into dry soils. The soil-applied inoculants (i.e. granular and

Table 2. A comparison of pros and cons of the inoculant formulations

<table>
<tr><th rowspan="2">Inoculant formulation</th><th colspan="2">Availability</th><th rowspan="2">Cost</th><th rowspan="2">Ease of use</th><th rowspan="2">Time from application to seeding</th></tr>
<tr><th>Tropical legumes</th><th>Temperate legumes, pulses</th></tr>
<tr><td>Peat slurry</td><td>Yes</td><td>Yes</td><td>$</td><td>√</td><td>Maximum 24 hours</td></tr>
<tr><td colspan="6">The highest quality and the least expensive option and still the most popular even though often considered inconvenient.</td></tr>
<tr><td>Freeze-dried powder</td><td>Yes</td><td>Yes</td><td>$$</td><td>√</td><td>Maximum 5 hours</td></tr>
<tr><td colspan="6">Needs to be used once the vial is cracked open. Used with a protecting agent like EasyRhiz then suitable for both coating seed prior to sowing and liquid injection during sowing.</td></tr>
<tr><td>Granular</td><td>No</td><td>Some species</td><td>$$$</td><td>√√√</td><td>Can be stored for 6 months after manufacture</td></tr>
<tr><td colspan="6">Granular inoculants contain fewer rhizobia per gram than peat and need to be applied at higher rates and cost more per hectare, but are attractive for large sowings of pasture legumes (>1t of seed).</td></tr>
<tr><td>Liquid</td><td>No (except soybean)</td><td>Yes</td><td>$$</td><td>√√√</td><td>Use immediately after dilution</td></tr>
<tr><td colspan="6">Suspensions of rhizobia in a nutrient solution, only used where the seed-bed is moist, injected into furrows. Not to be mixed with fertilisers or pesticides.</td></tr>
<tr><td>Pre-inoculated seed</td><td>No</td><td>Some species</td><td>$$</td><td>√√√</td><td>Weeks to months - depends on strain</td></tr>
<tr><td colspan="6">Convenient, but varies in quality, with the number of rhizobia on the seed at the point of purchase sometimes inadequate. The seed coatings can add significant cost.</td></tr>
</table>

liquids applied in-furrow) allow the separation of the inoculant from potentially harmful seed applications such as fungicides, insecticides and trace elements.

Pasture seed is often coated with fine lime immediately after the application of peat slurry to help dry the seed and to prevent clumping. Liming also protects rhizobia against acid soils and acidic fertilisers. **With the tropical pasture legumes; centro, cowpea, lablab and butterfly pea which all use bradyrhizobium the advice is NOT to lime pellet.**

Effective nodulation under conditions of high soil temperatures can be problematic resulting in poor or no N fixation and the legume relying on soil N for growth. Check whether the plants have effective nodules.

Checking for nodules and effective nodulation

Assessing your legume nodulation during active plant growth provides an understanding of N-fixation efficiency. Evaluate legume nodulation when the soil is moist. Nodules on the roots should be apparent 3-4 weeks after germination, but assessment is usually carried out when the plants have been growing for 8-10 weeks.

Get a representative sample by collecting whole plants (at least 5 in each location) from different areas within the paddock.

- Dig, don't pull the plants up, as the majority of nodules will dislodge if the root systems are pulled from the ground or shaken aggressively to shed the soil.
- Wash, don't shake. This is particularly important with fine-textured clay and loam soils. With light textured sandy soils the bulk of the soil will fall away and a light rinse will reveal the nodules. Fine-textured clay soils can be problematic and may require soaking in a bucket of water to soften and disperse the soil before you can assess the nodules.
- Once washed, spread the root system on a flat white surface and rate the nodulation using the rating system in Figure 1.
- Carefully slice the nodules open. Pink nodules are deemed to be healthy and fixing N, whereas brown, pale or white provide little or no N-fixation.

The target is a rating of 'adequate nodulation' with pink nodules.

A *root nodule cut open – the pink colour means effective nodulation.*

In a symbiotic relationship the nodules 'fix' atmospheric N using the bacterial enzyme nitrogenase.

N_2 + 6H + energy → $2NH_3$ (ammonia)

Remove O_2 by leghaemoglobin (pink)

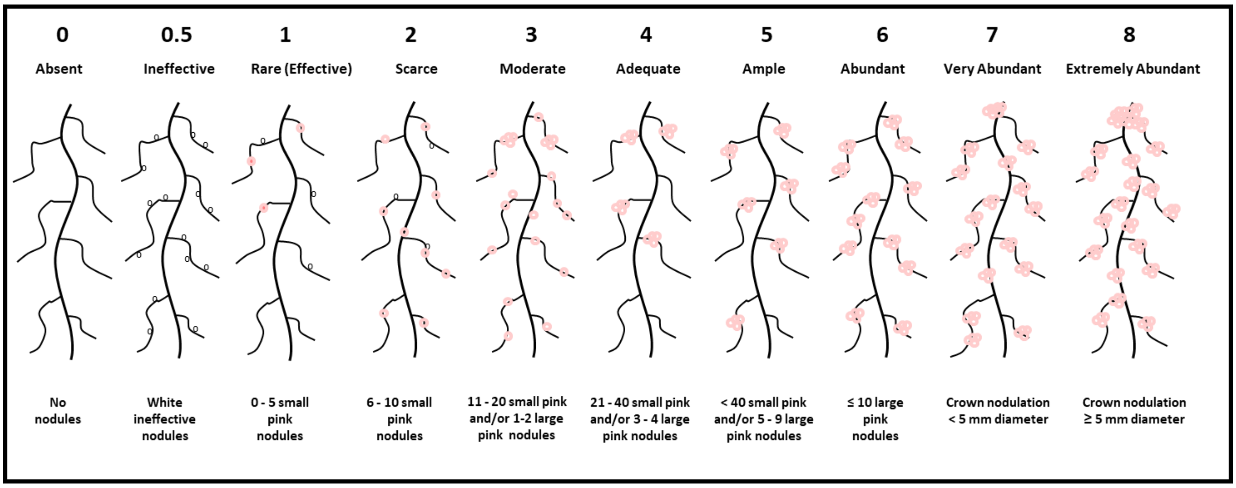


Figure 1. A nodule scoring chart (Source: 'Working with rhizobia' Chapter 8, Figure 8.13)

Further information:

GRDC-Booklet 'Inoculating legumes: A practical guide' https://grdc.com.au/GRDC-Booklet-InoculatingLegumes.

Centro

Features

- An easy to manage warm season, annual legume pasture.
- Suited for hay production, however the dense canopy and twining growth habit can make cutting difficult.
- May be suitable as a companion legume with warm season perennial grasses.

Centro (*Centrosema pascuorum*) is a warm season, annual herbaceous legume with a twining growth habit with relatively fine stems up to 2m long. Leaves are trifoliate and the leaflets are long (50-100mm) and narrow (5-10mm wide) which can give centro a 'grassy appearance' (Cameron 2013). Centro is commonly referred to by the variety name, 'Cavalcade'.

Centro is well adapted to northern Australia and is grown extensively through the Top End of the Northern Territory (NT), making up over 90% of the legume hay produced (Cameron 2005). Centro is also used to produce legume cubes for the live export trade. The centro grown in the NT is almost all dryland. Suitable as a green manure crop ─ centro can provide 80-100kg N/ha to a following crop (Thiagalingam *et al*. 1997).

There has been limited centro grown in northern WA, either dryland or under irrigation, but it is now being evaluated over summer under irrigation in the low rainfall coastal agro-climatic zone. As a warm season, annual legume it is well suited to all of the climatic zones with a growing period from September-October through to April-May. It has poor frost tolerance with limited growth over the cooler dry season.

Uses

Grazing	Green manure	Hay	Round bale silage	Pit silage	Grain
√-√√	√√	√√	√	(√)	X

Production and feed quality

Centro is palatable and well accepted by stock, but requires some form of rotational grazing to persist. In the NT broadleaf weeds such as sida (*Sida acuta*), senna (*Senna obtisifolia*) and portulaca (*Portulaca oleracea*) can be difficult to control in a centro pasture.

Centro is well suited for hay production with fine stems and long narrow leaves there is minimal leaf loss during raking and baling. However, due to its twining and scrambling growth habit and dense canopy cutting can be difficult as the stems can wrap around the mower blades. If left for too long before cutting, then centro begins to lose lower leaves and the lower part of the canopy can go mouldy, resulting in loss of yield and quality. Centro is not usually used for silage.

There is limited data on irrigated centro production, but under irrigation at Katherine (NT) Bundey produced 15.2t DM/ha and Cavalcade 18.7t DM/ha over four cutting cycles over 12 months with an average of 16.5% and 15.6% CP respectively. However, there was little production from May until the temperature increased in September-October. Even through the plants remained green over winter the stands were invaded by weeds and plant numbers declined (NT ref unpublished).

In the NT under dryland conditions a pure sward of Cavalcade centro can yield between 4 to 6t DM/ha over the wet season (Cameron 2013). Crude protein of tops during the wet season (January to March) often 18-20%, while good hay is 12-14% CP.

Cavalcade centro was sown in a demonstration on a deep red sand near Broome in the middle of September 2017. Four months later in mid-January 2018, 3.6t DM/ha had been produced with 62% digestibility and 15.9% CP (Table 3). Reports suggest the digestibility of tops can be up to 79%, but is more commonly 65-70% (Pastures Australia).

Table 3. The nutritive value of centro from trials at north Broome (deep red sand) and Fitzroy Crossing (cracking clay)

Site	Date	NDF (%)	ADF (%)	CP (%)	DMD (%)	ME (MJ/kg.DM)	WSC (%)
Fitzroy Crossing	May ‘16	43.0	32.0	12.9	66.5	9.8	17.7
North Broome	Jan ‘18	43.2	31.5	15.9	62	9	4.5
	Nov. ‘18	39	27	15.2	69	10.2	7.5

Varieties

There are two main commercial varieties available, 'cavalcade' and 'bundey'. Cavalcade is the main variety grown in the NT, as its shorter growing season suits dryland production.

Cavalcade (public) is a quantitative short-day plant that flowers with 12-hour photoperiod or less. In longer days (13-hour photoperiod) buds may be produced, but they abort at high temperatures (33/28°C day/night) and no seeds are produced (Plant Resources of South-East Asia).

'Bundey' (public) is morphologically similar to cavalcade, except has hairy stems, smaller seeds and is later flowering (~1 month in NT). Bundey has superior waterlogging tolerance and can survive up to three months of seasonal flooding, however it will not start growing until the floodwaters recede.

'Cardillo' (public) is a different species of centro (*Centrosema pubescens*) which is agronomically similar to *C. pascuorum*, but has superior cold tolerance. Cardillo is becoming popular in Queensland as it will grow in both coastal tropical regions as well as inland, cooler elevated environments.

A centro sward has a grass-like appearance due to the long narrow leaflets

Ready reckoner

Soil type	Adapted to a wide range of soils from coarse-sands to fine-textured clays, but prefers a near-neutral pH (Not suited to very acid, low-fertility soils)
Soil pH_w (1:5 water)	5-8.5
Waterlogging tolerance	Good tolerance of waterlogging and seasonal flooding
Temperature constraints for sowing	22-32°C (October to January)
Seed size	Medium (48,000-58,000 seeds/kg)
Inoculum	Specific Rhizobium - CB1923
Sowing rate	10-15kg/ha
Seeding depth	10-20mm
Row spacing	20-30cm
Plant density	20-30m^2
Seedling vigour	Good, providing temperatures are adequate
Herbicide options	Cavalcade is susceptible to the insecticide, Carbaryl (Pastures Australia) Tolerant of Spinnaker®, Sertin® and Verdict (Pastures Australia)
Plant nutrition	Responds well to P and S
Livestock disorders	Nil
Special notes	Prolific seed producer and can regenerate from seed.

Cowpea

Features

- A fast growing, short-season annual legume producing high quality forage.
- Suited as a green manure or break crop in an annual cropping rotation.
- Creeping growth habit can make harvesting for hay or silage difficult.

Cowpea (*Vigna unguiculata*) is an annual, herbaceous twining and trailing legume with a coarse main stem and large ovate-shaped leaves. Depending on the variety the growth habit can vary from prostrate to climbing, or sub-erect, with stands growing to a height of 50 to 100cm (Cameron 2003, Tropical Forages).

Cowpea has multiple uses including for human consumption and there are three types of cowpea according to their use: grain, forage or dual-purpose. In Queensland, cowpea has been grown as a green manure for crops such as sugarcane, as forage, for hay, silage and as a grain crop (Tropical Forages).

Uses

Grazing	Green manure	Hay	Round bale silage	Pit silage	Grain
√-√√	√√√	√√	(√)	√√	√-√√

Cowpea can make high quality hay and the ideal time for cutting is at peak flowering when CP is 17-20% (Cameron 2003). However, there can be difficulties when cutting, raking and baling. Cowpea can be difficult to harvest, as the prostrate growth habit means it is difficult to harvest all of the biomass. Typically, between 50 and 70% of the biomass can be collected with hay-making.

Making baleage is not recommended as the stalks have the potential to pierce the plastic wrap, ruining the ensiling process.

Pit silage is an option to overcome the issues with round bale silage. Legume crops have comparatively low WSC and high buffering capacity, so must be wilted before ensiling (Kaiser et al. 2004).

Cowpea is suitable for grazing, but susceptible to trampling damage and recovery from grazing is less than for lablab. With dual purpose types the grain yields are variable, but usually range between 0.4 and 1.0t/ha.

Cowpea is also suitable as a green manure option, with 50-100kg N fixed per ha (Tropical Forages). Best incorporated into the soil about peak flowering (Cameron 2003).

The use of cowpea in northern WA has been limited, but mostly as a forage option and occasionally as a companion species with forage sorghum. As a companion legume the agronomy, quality and yield potential are not well understood.

Production and feed quality

There is limited production data on irrigated cowpeas from similar environments. In the NT irrigated cowpea at Katherine produced 8.8t DM/ha over the wet season, but had low production over the dry season (NT ref unpublished DDRF, Katherine).

Half the biomass of cowpea consists of leaf which has a high CP% (20-25% CP), while the stem fraction has a much lower protein content (8-10% CP). In south-east Queensland, *Bos indicus* X steers grazing an irrigated cowpea-pangola pasture gained ~1.2kg LWG/day. The cattle preferentially grazed the cowpea leaf, but also consumed some stem (28-36%) with little negative effect on animal performance (Holznecht *et al*. 2000).

In a legume demonstration trial on deep red sand near Broome, the cumulative biomass of Ebony cowpea was 11.4t DM/ha from 3 cuts (Table 4). The daily growth rate varied from a low in winter of 21 to 76 kg DM/ha per day in summer. The nutritive value for the first two sampling times was high with metabolisable energy over 10MJ/kg DM and 11-14% CP, but this declined over time with an increasing proportion of lower quality stem (Table 5).

There was good production and feed quality of cowpea on cracking clay soils in the Fitzroy Valley with 4.6t DM/ha with a growth rate of 59kg DM/ha per day from seeding with 11.4% CP and ME of 9.9MJ (Table 6). Early growth was much slower at site 2 with a later sowing (20th June) as it took 4 months to grow the same biomass. Cowpea leaf sampled on 25/11 had 24.1% CP and ME 11.3MJ.

Table 4. Plant density (plants/m^2), dry matter (DM) production and average daily growth rate (kg DM/ha per day) in parenthesis of irrigated cowpea and lablab on a deep red sand near Broome (sown on 18 May 2017).

Variety	Plants /m^2	Biomass from sowing (t DM/ha)			Recovery after cutting (t DM/ha)		Total biomass
		20/7	24/8	29/9	29/9 to 14/11	14/11 to 15/1	
Ebony cowpea	28	1.3 (21)	2.5 (34)	4.0 (42)	2.7 (59)	4.7 (76)	11.4
Rongai lablab	13	0.9 (15)	3.0 (60)			3.9 (63)	
Dash lablab	13	1.6 (26)	3.5 (54)	4.3 (22)	3.0 (65)	3.3 (53)	10.6

Table 5. Nutritive value of cowpea and lablab on a deep red sand near Broome which was sown on 18 May 2017. Recovery after cutting: 14 Nov '17 and 15 Jan '18 (early flowering).

Variety	Date	NDF (%)	ADF (%)	CP (%)	DMD (%)	ME (MJ/kg.DM)	WSC (%)
Ebony cowpea	24/8	30	22	14.2	71	10.6	7.3
	29/9	31.9	19.4	10.8	69	10.2	5.1
	14/11	34.8	25.1	6.5*	64	9.4	9.2
	15/1	43.9	31.5	7*	57	8.2	0.6
Rongai lablab	24/8	40	28	15.7	67	9.9	1.9
	29/9	34.7	25.3	13	64	9.3	2.1
	15/1	42.9	32	9.8	55	7.8	0
Dash lablab	24/8	35	26	11.1	69	10.3	9.8
	29/9	24.6	15.4	14.3	73	10.9	6.8
	14/11	39.8	28.2	10.6	58	8.3	3.7
	15/1	40	28.3	12.2	60	8.7	0.9

*A question-mark on nodulation

Cowpea has multiple uses including dual-purpose forage and grain varieties

Table 6. Dry matter production and feed quality of irrigated lablab and cowpea on cracking clay soils in the Fitzroy Valley – site 1 was sown on 1st March 2016 and sampled on the 18th May 2016 (11 weeks); site 2 was sown on 20th June 2017 and sampled on the 24th October (12 weeks).

Variety	Dry matter (t/ha)	NDF (%)	ADF (%)	CP (%)	DMD (%)	ME (MJ/kg.DM)	WSC (%)
Site 1: sown on 1st March and sampled on 18th May							
Rongai lablab	4.8	48.5	32.5	16.2	60.5	8.8	6.5
Highworth lablab	5.5	47.5	34.0	12.7	64.0	9.4	11.7
Ebony cowpea	4.6	37.0	26.0	11.4	66.5	9.9	17.4
Site 2: sown 20th June and sampled 24th October							
Highworth lablab	5.8	24.4	18.9	15.8	72	10.7	6.0
Ebony cowpea	4.8	30.4	19.15	17.2	70	10.3	2.5

Varieties

The main forage (Ebony PR, Calypso, Meringa) and dual-purpose forage and grain varieties (Black stallion, Red Caloona) grown commercially in Australia are all quantitative short-day plants. Cowpea is susceptible to the fungal disease phytophthora stem rot (*Phytophthora vignae*) which can devastate susceptible varieties, especially under waterlogged conditions.

Ebony PR (Public) is a forage variety with black seeds which has effective tolerance to *P. vignae*. It is currently the only variety grown by producers in northern WA.

Meringa (Public) is a late-maturing forage variety used as a cover crop in the sugarcane growing areas of Queensland, however it is highly susceptible to *P. vignae*.

Calypso (PBR) is a late-maturing forage cowpea with *Phytophora* stem and root rot tolerance.

Red Caloona (Public) is a medium-maturity, dual-purpose variety for grazing and/or grain production. It is partially tolerant of *P. vignae*, but is susceptible to races 3 and 4 (Ebony PR is resistant to both of these races).

Black stallion (PBR) is a dual-purpose forage and grain variety which is later flowering than Red Caloona with good recovery post-grazing.

Ready reckoner

Soil type	Adapted to a wide range of soils, but prefers deep, well-drained sandy loam
Soil pH_w (1:5 water)	4–7.5 (including very acid, low-fertility soils)
Waterlogging tolerance	Low (waterlogging reduces growth and increases fungal diseases)
Temperature constraints for sowing	Soil temperature >18°C and <35°C (Covell, et al. 1986)
Seed size	Medium-large (8-15,000 seeds/kg)
Inoculum	Group I – CB1015, however can also nodulate with native strains of rhizobia in some soils
Sowing rate	20-40kg/ha (soft seeded)
Seeding depth	3 to 6cm
Row spacing	30-50cm
Plant density	20-25 plants/m^2
Seedling vigour	Good, but windblasting on sandy soils can be an issue
Herbicide options	Highly sensitive to the phenoxy herbicides such as 2,4-D, M.C.P.A., 2,4-D-B, Tordon-50-D® and dicamba.
Plant nutrition	P, K
Livestock disorders	Nil
Special notes	Low regeneration from seed

Lablab

Features

- Fast growing legume with large showy leaves, but the edible biomass is reduced as the coarse stems have low palatability.
- Potential as a legume break crop in an annual rotation.
- Better growth at mild temperatures than other tropical legumes.

Lablab (*Lablab purpureus*) is an herbaceous annual tropical legume with a vigorous trailing and twining growth habit. It has large trifoliate leaves and coarse stems, which can reach up to 3m in length (Murphy and Colucci 1999). Lablab has not been widely grown in northern WA.

Uses

Grazing	Green manure	Hay	Round bale silage	Pit silage	Grain
√-√√	√√	√	(√)	√√	√

Grain and forage production was evaluated in the Ord River Irrigation Area (high rainfall zone) where it grew well on the cracking clay soils (Wood 1983). Grain yields range from 1-2.5t/ha, however the twining habit, large amount of herbaceous material, indeterminate flowering and long growing season are disadvantages for a grain crop. Lablab can be grown as a green manure crop, with an estimated 70-210kg N/ha on a cracking clay soil at Kununurra (Wood 1983).

Lablab growth comprises about 30-50% leaf and about 50-70% stem, which differ widely in nutritive value and palatability. The large, showy leaves have a high protein content (23-26%), good digestibility and are well utilised by stock. In contrast, the stem fraction has a much lower protein content (8-10%), lower digestibility and low palatability (Murphy and Colucci, 1999). The result is that the effective palatable biomass of lablab is only about half the total biomass as there is limited utilization of the stem when grazed (Hendricksen and

Minson 1985). As the leaf fraction decreases the voluntary feed intake is reduced due to the small bite size (Hendricksen and Minson 1985). Lenient grazing is also required otherwise the post-grazing recovery is compromised. The plant density decreases with successive grazing, so normally limited to 3 grazing periods (NSW DPI webpage).

Conserving lablab as a hay is possible but can be problematic as there can be loss of leaf when the windrow is raked, turned and baled. With the thick stems, drying can also be challenging. Typically, 75% of the biomass can be collected with hay-making and is easier than for cowpea. Cattle are likely to preferentially select leaf from hay.

Round bale silage is not recommended as the stalks have the potential to pierce the plastic wrap, ruining the ensiling process. Pit silage is an alternative to overcome the issues with making hay. Either a single silage harvest or graze then close for silage (crops do not recover for further grazing).

Production and feed quality

In a legume demonstration trial sown on a deep red sand near Broome on 19/5/17, lablab had cumulative biomass of 10t DM/ha from 3 cuts (Table 4). Nutritive value for the first cut was high with metabolisable energy 9.5-10.5 MJ/kg DM, but declined over time with an increasing proportion of lower quality stem (Table 5). Lablab left uncut had 8.4t DM/ha, but the feed quality had declined (ME 8.3MJ, 9.1% CP).

On a cracking clay soil with a March sowing Highworth lablab produced 5.5t DM/ha by mid-May at an average daily growth rate of 71kg DM/ha per day, while Rongai lablab produced 4.8t DM/ha at 62kg DM/ha per day (Table 6). In the second trial with a mid-June sowing it took almost considerably longer to grow a similar biomass with slower growth over winter. Lablab leaf sampled on 25/11 had 26% CP and ME 12.2MJ. In the literature lablab is reported to have good feed quality, the CP varies from 12-20% (whole plant), leaf (23-26%) and stem (8-10%) (Murphy and Colucci, 1999)

Varieties

The currently available commercial varieties grown in Australia are Rongai, Highworth and Dash, which are quantitative short-day plants. In northern Australia they flower during the early dry season, May to July, although flowering is indeterminate (Wood 1983).

The varieties are similar in appearance, although Dash and Highworth have a more upright growth habit, making harvest more manageable.

- Rongai has white flowers, light brown seeds and is a late flowering variety.
- Highworth has purple flowers, black seeds and flowers 20-30 days earlier than Rongai
- Dash has purple flowers, black seeds and is 2-4 weeks earlier flowering than Highworth.

Ready reckoner

Soil type	Wide range (sands to cracking clays) although establishment on sands has been less than expected
Soil pH_w (1:5 water)	4.5 to 7.5
Waterlogging tolerance	Low (But tolerates short-term flooding)
Temperature constraints for sowing	12–36°C (McDonald 2002) preferably soil temperature >18°C (Hills and Penny 2005)
Sowing time	Flexible
Seed size	Large (3,600-4,300 seeds/kg)
Inoculum	Group J (CB CB1024), however can also nodulate with native strains of rhizobia in some soils
Sowing rate	20–30kg/ha
Seeding depth	4–10cm
Row spacing	20–90cm; use a wide row spacing when grazing to reduce the impact of trampling
Plant density	~10 plants/m^2
Seedling vigour	Good (But windblasting of seedlings on sandy soils can be an issue)
Herbicide options	Highly sensitive to the phenoxy herbicides such as 2,4-D, M.C.P.A., 2,4-D-B and dicamba (Tropical Forages)
Plant nutrition	P, K (check with soil test)
Livestock disorders	Nil (Seeds contain anti-nutritional factors - tannins, phytate and trypsin inhibitors)
Special notes	Low level of hard seed and poor regeneration from seed bank

The seedlings of large-seeded legumes like cowpea and lablab are susceptible to sand-blasting damage

Butterfly pea

Features

- The role of irrigated butterfly pea in northern WA is still being determined, but it appears less suited to the inland agro-climatic zones due to low production over the dry season.
- Butterfly pea is assessed as a very high environmental weed risk in the Kimberley and is currently not approved for use on pastoral lease. Its risk is high in the Pilbara and may not be approved for use on pastoral lease.
- Butterfly pea produces a high quality, highly digestible hay with minimal leaf loss in the haymaking process.
- Potential companion legume for bunch grasses like panic grass.

Butterfly pea (*Clitoria ternatea*) also called blue pea, is a short-lived perennial legume with a semi-erect woody base with fine twining stems and pinnate leaves with 5-7 leaflets. Individual plants may persist for 2-4 years, but where well-adapted has good regeneration from seed, so re-seeding is usually not required in permanent pastures.

Butterfly pea is generally grown as a dryland pasture in high to very high rainfall zones on fine-textured clay soils. There is limited information on its performance under irrigation and it has not been grown commercially in WA. It will not persist in areas that experience frosts, so will be unsuited to the low rainfall inland elevated zone. It has no major pests or diseases.

Uses

Grazing	Green manure	Hay	Round bale silage	Pit silage	Grain
√√	(√)	√√	√	(√)	X

Butterfly pea is very slow to establish compared with lablab, cowpea or centro and biomass production is likely to be compromised if grown an annual crop. This makes it less suitable as a green manure crop and is not usually used for silage.

In central Queensland butterfly pea has persisted as a companion legume with competitive perennial grasses like buffel grass (Collins and Grundy 2005). Therefore, the potential of butterfly pea as a companion legume for warm season bunch grasses like panic grass is worth investigating.

Production and feed quality

A palatable legume with high digestibility and protein content which does not cause bloat. Requires rotational grazing ─ well established plants are tolerant of periodic heavy grazing, but continuous grazing will adversely affect persistence.

Fodder production - butterfly pea produces a high quality (CP 12-15%), highly digestible hay. Best cut when the leaves and branches are still soft and succulent and before mature pods form. The cutting height should not be lower than 7–10cm as it re-shoots mostly from existing stems rather than the crown. In general, the leaves stay attached to the stems, and there is minimal leaf loss in the raking and baling process (Collins and Grundy 2005). When actively growing an 8-10 week cutting cycle under irrigation.

Butterfly pea is a shrub and tends to shed the lower leaves as it grows. If cutting is left for too long, the hay can contain a high proportion of stem (Cameron 2010) with lower feed quality.

At Douglas Daly (NT) irrigated butterfly pea yielded 15.3t DM/ha over the dry season with four cutting cycles with an average of 20.9% CP and ME of 10.1MJ, while at Katherine RS produced 23.6t DM/ha over 12 months with 17.0% CP (ref-NT-Small Plot Evaluation of Selected Pasture and Crop Species under Irrigation at DDRF, 1995 and 1996).

Cattle growth rates of 0.5 to 1.45kg LWG per day have been recorded over summer in central Queensland from butterfly pea swards or mixed grass-butterfly pea swards (Collins and Grundy 2005). However, these were under dryland conditions with stocking rates which may have allowed for selective grazing.

An irrigated legume demonstration trial sown on Pindan sand near Broome in May 2017 showed little growth of butterfly pea over winter, but produced nearly 6t/ha DM from 29/9/17 to 15/1/18 (Table 7). A demonstration plot sampled for nutritive value on 26/11/18 had 14.1% CP and a ME of 10.2MJ.

Table 7. Production and nutritive value of irrigated butterfly pea at Broome, sampled over the 2017 summer. Sown on 18/5/17, but had little production until after cutting on 29/9/17.

Period	DM (t/ha)	NDF (%)	ADF (%)	CP (%)	DMD (%)	ME (MJ/kg.DM)	WSC (%)
29/9 to 14/11	2.2	53.5	42	11.4	52	7.3*	4.2
26/11 to 15/1	3.7	50	38.4	13.2	58	8.3*	5.6
TOTAL	5.9						

*A question-mark on nodulation

Varieties

Millgarra is the only commercial variety available. It was bred using a composite of introduced and naturalised lines, so variation in growth habit (erect or semi-erect) and flower colour (i.e. blue, mauve or white) can be observed. Flowering is insensitive to daylength, indeterminate and can start within 60 days of sowing (Collins and Grundy 2005).

Millgarra grows best on fertile soils with a high waterholding capacity. Good soil fertility and irrigation management is required on coarse-textured soils. It tolerates short periods of waterlogging, but won’t survive being inundated for more than 12 hours.

Ready reckoner

Soil type	Wide range of soils, but prefers fertile clay soils. Has some tolerance of sodicity and salinity
Soil pH_w (1:5 water)	6 – 8
Waterlogging tolerance	Low (Not suitable for areas subject to seasonal flooding)
Temperature constraints for sowing	Ideal 24–32°C, with no germination >40°C (McDonald 2002)
Seed size	Medium-large (23,000 seeds/kg)
Inoculum	Group M CB756 (Siratro), however can also nodulate with native strains of rhizobia in some soils (Cameron 2010)
Sowing rate	15-20kg/ha (assuming >90% germination)
Seeding depth	2.5-5cm
Row spacing	20-30cm
Plant density	Desirable >20plants/m^2
Seedling vigour	Relatively slow and can have staggered germination if hard-seed present
Herbicide options	Weed control during establishment Spinnaker® glyphosate with either metsulfuron methyl (e.g. Ally®), fluroxypyr (e.g. Starane®) or 2,4-D (e.g. Amicide 625®) Butterfly pea is easily controlled with herbicide when cropping
Plant nutrition	High K requirement
Livestock disorders	Nil
Special Notes	Produces a large amount of seed that shatters when mature. Will self-seed following season (Gomez and Kalamani, 2003)
Preferred agro-climatic zones	To be confirmed, but best suited to the coastal zones, plus high to very high rainfall zones.

Further information:

The Butterfly Pea book, a guide to establishing and managing butterfly pea pastures in central Queensland'. (2005) Department of Primary Industries and Fisheries, Queensland Government.

Pastures Australia Factsheets https://keys.lucidcentral.org/keys/v3/pastures/Html/index.htm

Tropical forages Factsheets link: http://www.tropicalforages.info/index.htm

3.6 Temperate crops and pastures

Clinton Revell, Chris Schelfhout, Geoff Moore and Sam Crouch

Annual temperate grass evaluation site at north Broome Water Corporation 2017 (L) and grazing oats on 17 August 2017 (R)

Key Messages

- Temperate cereal crops in a single-cut system can play an important role for irrigated hay production, especially in the inland and inland-elevated agro-climatic zones (Pilbara) over winter.
- In general, temperate crops and pastures are poorly suited to the high to extreme temperatures which are common from October to April across northern WA. However, they can play an important role over the dry season particularly for inland areas where the cool nights from mid-May to the end of August constrain the growth of the warm season grasses and tropical legumes.
- Promising yields of forage oats and barley have been produced in field trials. Some early experimental work has demonstrated that high grain yields can be achieved with winter grown cereals, further research is required to confirm if this can be reliably achieved on scale.
- Annual ryegrass, temperate annual legumes and herbs produced good quality feed during the dry season, but were comparatively low yielding and are not economic options.
- The perennial legume lucerne can produce high quality forage, but is not well suited to growth over the hot ‘wet’ season from October to April and this limits annual production.

Introduction

Irrigated forage production in the northern rangelands of WA is based on either direct grazing or cut and carry production systems. In most situations, the target species are tropical or sub-tropical species that are well adapted to the environment and respond well to irrigation. However, temperate annual pasture and crop species (Table 1) may be an option in rotation with warm season species, particularly in inland areas where cool night temperatures over winter can greatly slow the growth of tropical and sub-tropical species.

The key with the temperate species is that in general they are poorly adapted to the high to extreme temperatures which are common from October to April right across northern WA. Therefore the annual species need to be harvested for fodder or grain before the on-set of high temperatures which can adversely impact on yield. The window when climatic conditions are favourable for the temperate species is relatively short, beginning from mid-May to early June through to late-August to mid-September depending on the location.

Ideally, the following warm season crop or pasture would be established before the onset of very high temperatures in October, so as a consequence the ‘winter’ crops need to be harvested by early September. This results in an effective growing season of 90 to 105 days, which automatically rules out species which are slow to establish and require a long growing season.

A benchmark of 100kg DM/ha per day for annual grass forages is required before they can effectively compete with the warm season annual and perennial grasses. With the legumes a lower benchmark of 60-70kg DM/ha per day is acceptable given their higher feed quality and lower costs as not applying fertiliser N.

The temperate crops and pasture options are summarised under:

(i) Temperate cereals

(ii) Temperate annual grasses and legumes

(iii) Temperate perennial legumes – lucerne ,

There are a number of other temperate crop options including pulses and canola, which from limited testing are unlikely to produce economic yields.

Field performance − production and feed quality

Experiments to evaluate the potential production and feed quality of some temperate crops and pastures in comparison with tropical species were conducted on a deep red sand site near Broome in 2017 and on a red-loamy earth at Newman in 2019.

Broome − 2017

Grazing oats and barley treatments grew well and were similar in production and nutritive value at 9 weeks, but grazing barley was superior by 14 weeks (Table 2), though it was earlier maturing with some grain fill and protein levels were lower. Cereals cut at 9 weeks (vegetative stage) recovered with valuable regrowth, but total production from a two-cut system was similar to the single cut system. While feed quality (CP and ME) was superior with an early cutting treatment, it would be unlikely to compensate for the additional cutting and baling costs involved with a two-cut system.

The temperate cereals maintained consistently superior feed quality (higher digestibility, energy) compared with Callide Rhodes grass (Table 3). This may compensate for overall lower productivity across winter (except for the coldest months), but the forage production system would need to be based on annual cropping with warm season species like forage sorghum, millet or tropical legumes being grown over summer.

The growth rates over winter were well under 100kg DM/ha per day, except for quinoa which had the highest winter production of all species evaluated. Further work is required to explore its feeding value – the literature reports instances of feeding quinoa to ruminants, but the impact of secondary compounds like saponins and oxalates needs to be considered. Forage brassicas also had useful early season growth with high quality forage, but suffered badly from insect attack late in the season and are unlikely to be viable options.

Table 1. A summary of the temperate forage options

Species	Wet season production	Dry season production			Palatability	Suitability for hay	Suitability for stand and graze
		Coastal	Inland	Inland – elevated			
Forage oats	X	√√	√√√	√√√	√√√	√√√	√√
Forage barley	X	√√	√√	√√√	√√√	√√√	√
Winter 'dry' season cropping options. Sensitivity to high soil temperatures at sowing varies with cultivar							
Annual ryegrass	X	√-√√	√√	√√	√√√	√	√√√
Low productivity in trials. May not flower if vernalisation (cold) requirements are not met.							
Lucerne	(√)	√√	√√	√√-√√√	√√√	√√	√-√√
Most productive during the cooler 'dry' season, growth is constrained by high to extreme temperatures from October to April, very susceptible to insect damage. Potential annual production of 12–18 t/ha hay per year from 5–7 cuts per year (1–4t DM/ha per cut). Can be hard to dry stem and leaf uniformly, low humidity may limit baling times and lead to substantial leaf loss. Expected stand life 1-2 years.							
Temperate pasture legumes	X	√	√	√	√√√	√	√√
Annual species, constrained by low productivity, which is linked to slow growth during the establishment phase.							
Vetch	X	√	√√	√√	√√	√√?	√√?
Annual species, Common vetch *(Vicia sativa)* preferred for grazing, hay and green manure.							
Forage brassicas Fodder beets	X	√√	√√	√	√√√	X	√√
Annual species, highly susceptible to insect damage.							

Key:

√√√	Highly suitable
√√	Moderately suitable
√	Marginally suitable, consider other options
X	Not suitable

Confidence level for particular species:

(light orange)	Low – limited testing or grower experience
(light green)	Moderate – some testing or grower experience
(green)	High – extensively grown or tested (or fundamentally unsuited to the conditions)

Table 2. Biomass (Dry Matter) of a range of temperate forage species compared with Rhodes grass, grown on a deep red sand near Broome (sown 18-19 May 2017).

Species	Cultivar	Plant type	Biomass 9 weeks (t/ha)	Dry matter 14 weeks (t/ha)
Grazing oats	Wizard (PBR)	forage cereal	3.9 (2.7)*	6.5
	Genie (PBR)	forage cereal	3.9 (3.4)	6.8
Grazing barley	Dictator 2 (PBR)	forage cereal	3.9 (3.2)	8.0
Ryegrass (tetraploid)	Abundant	annual grass	2.5	3.6
Ryegrass (diploid)	Jackpot	annual grass	2.4	2.7
Purple vetch	Barloo	annual legume	0.7	2.6
French serradella	Cadiz (PBR)	annual legume		2.9
Forage brassica	Leafmore rape	herb	3.7	
	Dynamo turnip	herb	3.8	
Quinoa	Breeding line	herb	5.9	
Rhodes grass (tetraploid)	Callide	perennial grass	3.6	8.0

*Values in parenthesis – regrowth on 27 Sept (10 weeks) after being cut on 20th July (9 weeks)

Table 3. Nutritive value results for temperate grasses and legumes (9 weeks and 14 weeks from sowing) on deep red sand at Broome 2017.

Species	NDF (%)	ADF (%)	CP (%)	DMD (%)	ME* (MJ)
Vegetative stage 20 July (9 weeks)					
Wizard oats	47	26	18.3	73.7	11.1
Dictator 2 barley	52	29	16.0	73.7	11.1
Abundant ryegrass	41	23	20.3	77.7	11.7
Jackpot ryegrass	45	24	20.7	76.3	11.5
Barloo vetch	33	23	21.3	71	10.6
Leafmore rape	26	18	19.5	79	11.9
Quinoa	47	29	20.7	62	9.1
Callide Rhodes grass	58	31	16.7	60.5	8.8
Maturity / Reproductive stage mid-August (13-14 weeks)					
Wizard oats**	55	31	12.4	65.7	9.7
Dictator 2 barley***	42	23	8.6	72.0	10.8
Abundant ryegrass	46	27	15.8	71.7	10.7
Jackpot ryegrass	49	28	17.3	69.0	10.2
Barloo vetch	48	34	19.4	60	8.7
Cadiz serradella	45	31	18.5	63	9.2

Note: *ME –MJ ME/kg DM; **Wizard oats – no heads; ***Dictator 2 Barley – grain fill

Newman – 2019

Forage oats produced 12-14t DM/ha in a replicated hay trial on a red loamy earth at Newman. The average daily growth rate from seeding to harvest was 100 and 120kg DM/ha per day for Wizard and Mammoth oats respectively. However, the feed quality was less than expected, especially for Wizard oats (Table 4). Typically oaten hay has an average 9.7MJ ME/kg DM from samples submitted to a laboratory for testing (Table 6).

Table 4. Biomass and nutritive value of forage oats at Newman in 2019 (sown 27 May) Feed analysis by wet chemistry

Cultivar	Date	Biomass (t DM/ha)	CP (%)	DMD (%)	ME*	WSC (%)
Mammoth oats	11/9	**8.4**	7.2	63.3	9.3	14.0
	25/9	**14.8**	6.3	59.7	8.7	12.4
Wizard oats	11/9	**9.7**	7.4	55.3	7.9	5.5
	25/9	**12.4**	6.6	52.2	7.4	6.2

*MJ ME/kg DM

In a replicated grain trial oats (cvv. Williams, Carrolup), barley (cvv. RGT Planet, Rosalind) and wheat (cvv. Reliant, Scepter) yielded between 5 and 6.5t/ha of grain. Berkshire triticale yielded an impressive 8t/ha grain. These are encouraging grain yields, but need to be confirmed at scale. The potential for a high energy grain product creates opportunities to contribute to feedlot rations with hay or silage as the source of roughage.

A range of pulses (faba bean, field peas, chickpeas, albus lupins, narrow-leaf lupins) in a replicated trial at the same site had low yields (<2.5t/ha).

Table 5. Biomass and grain yields of temperate cereals

Cultivar	Biomass yield (t DM/ha)	Grain yield (t/ha)
Berkshire triticale	17.4	**8.0**
Williams oats	15.8	**6.6**
Scepter wheat	12.9	**6.5**
RGT Planet barley	12.4	**6.5**
Carrolup oats	15.3	**6.0**
Reliant wheat	12.4	**5.7**
Rosalind barley	10.6	**5.1**

(i) Temperate cereals

Features

- Well adapted to the growing conditions over winter especially in the inland agro-climatic zones, where forage oats produced 12-14t DM/ha over 120 days (Table 4).
- In warm coastal environments forage oats and forage barley produced 6.8 to 8t DM/ha (9t/ha hay yields at 12% moisture) over 13-14 weeks with metabolisable energy around 10MJ/kg DM.
- Promising grain yields (5-8t/ha) from trials in the low rainfall inland-elevated zone (Table 5), but need to confirm whether these yields can be repeated at a commercial scale. A grain option would be valuable from a feed-lot perspective.

The temperate cereals are some of the most widely grown crops worldwide; wheat (*Triticum aestivum*), barley (*Hordeum vulgare*), oats (*Avena sativa*), triticale (X *Triticosecale*) and cereal rye (*Secale cereale*).

For hay production: forage oats > forage barley > wheat, triticale

For growing grain for feeding cattle: barley > triticale, wheat > oats

Oats — oaten hay is widely grown in south-western Australia and good yields were produced in field trials in northern WA (Tables 2, 4). The expected feed quality from a large number of hay samples is 9.7MJ ME/kg DM (Table 6) which is the same as the feed quality at the Broome site after 14 weeks (Table 3), although the results from the Newman site were lower (Table 4).

Oats is not considered an ideal grain on its own for fattening cattle, but can be used in combination with any of the other grains.

Table 6. The average feed quality of hay samples from temperate crops and pastures (Source: Feedtest, Victoria 2019/20 Summary*)

Product	No. of samples	Crude protein (%)	Dry matter digestibility (%)	Metabolisable energy (ME)	WSC (%)
Barley hay	344	8.8	68.3	10.1	24.0
Oaten hay	1460	7.6	66	9.7	24.3
Wheat hay	1058	9.0	64.8	9.5	23.4
Lucerne hay	219	19.6	66.0	9.7	29.2
Vetch hay	888	19.8	70.2	10.5	28.4

*Source: Feedtest, Victoria 2019/20 summary https://www.feedtest.com.au/index.php/about/feedtest-information

Barley — forage varieties can be grown for hay production with good yields (8.0t DM/ha) at Broome. However, there was some lodging of forage barley at Newman.

Barley is the best grain for feeding cattle, but the other cereal grains can also be used, particularly if they are processed in some way (rolled, cracked, coarsely milled) as this will increase digestibility.

Wheat is the major grain crop both in Australia and worldwide. High grain yields of 5.7-6.5t/ha at Newman (Table 5). The most suitable wheat variety for the climate in the inland zones is still to be determined as conditions (latitude, temperature) are unlike any of the main cereal growing regions across Australia. Wheat also makes good quality hay (Table 6).

Triticale — had the highest gain yield at Newman (Table 5). It is an established, but minor cereal crop, which was developed by crossing wheat and rye. It is mainly grown as a grain, but also longer-season, dual-purpose types are grown for fodder use as hay, silage or grazing followed by grain production.

In livestock diets, triticale has a similar role to other cereals, being higher in energy than barley and is primarily an energy source, having moderate protein content with high starch and other carbohydrates (Table 7).

The benefit of triticale is that it can tolerate a range of difficult soil conditions including: high pH (alkaline) soils, waterlogging, low pH (acid) soils and sodic soils (GRDC Grownotes - Triticale).

Cereal rye is more sensitive to high temperatures than oats or barley and its main attributes of winter hardiness and growth on poor sandy soils limit its potential role.

Table 7. Dry matter, energy, protein and fibre content (dry matter basis) of cereal grains commonly used as feedstocks. The average plus the range for values tested in WA is shown in brackets (source GRDC Grownotes).

Cereals and pulses	Dry matter (%)	Metabolisable energy (MJ/kg)	Crude protein (%)	Acid detergent fibre (%)
Wheat	91	12.9 (12.4-13.3)	11.5 (7.5-15.0)	3.0 (2.55-4.5)
Barley	91	11.0 (7.0-13.0)	11.0 (7.0-13.0)	8.0 (7.0-9.5)
Triticale	90	12.5 (12.0-13.0)	11.0 (7.5-14.0)	4.0 (3.5-5.0)
Oats	92	10.7 (10.4-11.3)	9.0 (5.5-13.5)	18.5 (16.0-21.5)

Ready reckoner (Temperate forage cereals)

Soil type	Adapted to a wide range of soils from sands to clays, but prefer a near-neutral pH (Not suited to very acid, low-fertility soils)
Soil pH_w (1:5 water)	5−8.5
Waterlogging tolerance	Good tolerance of transient waterlogging
Temperature constraints for sowing	Ideal soil temperature for germination and establishment is 15-23°C
Seed size	Medium (25,000 seeds/kg barley to 50,000 seeds/kg oats)
Sowing rate	100−150kg/ha (higher rates for barley)
Seeding depth	30−50mm
Row spacing	15-25cm
Plant density	250−300/m^2 (higher plant density will lead to thinner stems for hay production)
Seedling vigour	Good
Herbicide options	A range of in-crop broadleaf herbicides
Plant nutrition	High requirement for N (50-100kg N/ha) Responds well to P, K and S
Livestock disorders	Nil
Special notes	Do not graze below 10-15cm

(ii) Temperate annual grasses and legumes

Features

- The annual legumes are fairly well adapted to the growing conditions over winter especially in the inland agro-climatic zones, but their potential is limited by slow early growth and as a result, comparatively low biomass
- Vetch with its larger seed and faster early growth is an annual legume of interest, but early results have been modest.
- The annual ryegrasses are highly palatable and maintained high nutritive quality, but biomass production was modest.
- No annual grasses or temperate legumes are recommended at this time.

Annual ryegrass and Italian ryegrass are highly palatable and produced high quality feed with metabolisable energy of 11.5-11.7MJ ME/kg DM and 20% CP after 9 weeks (Table 3). The ryegrass cultivars maintained high nutritive value throughout, but were not sufficiently productive under sub-tropical conditions (average daily growth rate of 25-35kg DM/ha per day) and as such do not appear to be a viable option for forage during the winter months.

The annual legumes and herbs had good feed quality, but with generally low forage yields are unlikely to be economically viable. Chicory has also been evaluated at north Broome under irrigation, but the biomass production was low.

Vetch has a larger seed and much faster early growth than the small-seeded annual clovers and serradella. It had low biomass at the Broome site (Table 2) and interestingly the feed quality was also low. The expected feed quality for vetch hay is good with >19% CP and >10MJ ME/kg DM (Table 6). Vetch may have potential as a green or brown manure crop in an annual rotation to improve the soil and to boost organic matter content.

(iii) Temperate perennial legumes − lucerne

Features

- Well suited to the conditions over the dry season, but poorly adapted to the consistently high to extreme temperatures from October to April.
- Predominantly used to produce high quality hay, but also suitable for rotational grazing and making silage.
- Lucerne has been grown commercially with moderate success in the low rainfall inland – elevated agro-climatic zone due to the milder conditions over winter.
- High nutritive value with crude protein (15-24%) and energy (9.5-10.5 MJ ME/kg DM)
- Susceptible to a wide range of insect pests and diseases.

Lucerne (*Medicago sativa*) is often called the 'queen of forages' and is one of the most important fodder crops in the world. Its nutritional properties, palatability and productivity make it the standard by which other fodders are compared. Known as alfalfa in the USA it is the most widely grown temperate perennial legume in the world.

Other temperate perennial legumes like red clover and white clover are not suited to high temperatures, let alone the extreme temperatures that occur in northern WA. Tedera was evaluated under irrigation at north Broome but was unsuited to the conditions.

Well managed stands of lucerne produce some of the highest crude protein and digestible forage possible. Lucerne hay samples had an average of 19.6% CP and 9.7MJ ME/kg/DM (Table 6). At north Broome across three sampling times from mid-July to summer, lucerne had an average CP of 21%, while ME declined from 11.2-11.7 to 9.4MJ ME/kg DM in summer when there was some leaf drop. However, nutritive value is dependent on leaf retention. Moisture stress will cause leaf drop and retaining leaf when baleing in hot weather can be problematic. Silage is an alternative to reduce leaf loss (Kaiser *et al*. 2004).

Lucerne has been used with variable success across the Pilbara region. Its productivity is typically reduced with high temperatures in the summer 'wet' season and consequently has proven difficult to manage consistently over a 12 month period. The issues for growing lucerne in northern WA mainly relate to the impact of high to extreme temperatures before the onset of the wet season and over summer and the high humidity over the wet season in coastal and high rainfall zones on disease incidence and therefore persistence. Stand life is generally only 1-2 years. Lucerne is susceptible to crown rot and root rot which have impacted on persistence in south-eastern Qld (Lowe *et al*. 2010).

The optimum air temperature for shoot growth is 27°C and for root growth is 21-25°C, while the optimum soil temperature for root growth is 12°C (Frame FAO; Hanson 1988). Lucerne is grown in diverse environments and can withstand extreme temperatures, however there is a difference between surviving and growing high quality fodder.

The reduced production and feed quality (lower digestibility) of lucerne at extreme temperatures (>35°C) is due to a combination of factors: high rates of respiration, reduced N_2 fixation, reduced carbohydrate reserves in roots and crowns and/or an increased resistance to CO_2 diffusion due to smaller cells and leaves (McKenzie et al. 1988 in Hanson *et al.* 1988). High temperatures also reduce forage digestibility as there is a decrease in total non-structural carbohydrates (Wilson *et al*. 1991).

Some observations suggest there is variation between cultivars to exploit, but regardless of cultivar, overall stand life is likely to be only 1-2 years in northern WA.

Lucerne needs to be sown in late May to early June to ensure it develops a deep, strong root system. Granular inoculant (Group AL) is available and would be the preferred method of inoculating the seed, especially if sowing into warm soils.

In addition to reduced production, signs of stress in lucerne include small, thickened leaflets with a blue-green colour

Insect pests have caused substantial damage in some Pilbara crops.

Production under irrigation

Irrigated lucerne is grown in diverse environments and can withstand extreme temperatures. For example, the Imperial Valley (El Centro) is a major lucerne hay and seed production region using irrigation water from the Colorado River which has extreme summer temperatures. On the other hand, it has cool to mild winter temperatures and good growing conditions for lucerne in spring and autumn. Commercial lucerne hay production is ~17t ha/annum (Summers and Putnam 2007).

In the Northern Territory a number of attempts have been made to grow lucerne commercially at Katherine, but in each case the stands have lasted only 12-18 months (Anon 2006).

Lucerne trials were conducted at the Douglas Daly Research Farm (DDRF) in the NT between 1997 and 2005 to assess the potential for irrigated lucerne hay production over the dry season. In the first year typically 4-5 harvests were possible with a cumulative hay yield of ~8t/ha, while in the second year there were 8 harvests (approximately every 4-5 weeks) starting in April with a cumulative yield of 19.8t/ha plus 2.5t/ha from a harvest over the wet season in February (Anon 2006).

However, in the trials at DDRF two major constraints reduced the persistence and productivity of the lucerne, first weed competition from summer grasses and second the build-up of 'little leaf', a disease associated with mycoplasmas (or phytoplasmas) which cause stunting of the plant, a very small leaf size and eventually plant death (NT DDRF unpublished 1995-96). Another issue with making high quality lucerne hay at DDRF was getting the leaf and stem moisture content right at baling. The leaves were drying down within 12-18 hours, but the stems were too moist to bale.

Further information:

Oat establishment https://www.agric.wa.gov.au/oats/oats-seeding-and-establishment

Lucerne production https://www.agrifutures.com.au/wp-content/uploads/publications/08-101.pdf

GRDC GrowNotes for Triticale, oats, barley and wheat https://grdc.com.au/resources-and-publications/grownotes

4.1 A guide to animal nutrition and expected growth rates from irrigated tropical pastures

Dennis Poppi[1]

[1]School of Agriculture and Food Sciences
University of Queensland

Key Messages

- Feed the rumen microbes is the first principle of good nutrition, but if the crude protein is >7% then a urea supplement is not beneficial.
- The *ad lib* intake of cattle (200kg) grazing a well-managed pasture (62% digestibility) is about 2.6% of bodyweight on a dry matter basis. With low quality hay (50% digestibility) the intake is reduced to 2.0%.
- With cattle grazing a well-managed tropical grass pasture the expected liveweight gain (LWG) in the medium-term is unlikely to exceed 0.7kg LWG per day.
- Feeding supplements can be used strategically to increase daily growth rates, but there will always be a substitution effect (i.e. reduced intake of the basal feed)
- Low growth rates maybe a consequence of over-grazing, mineral deficiency, internal parasites or poor water quality.

Introduction to animal nutrition

Animal growth rate is a function of energy intake (voluntary feed intake x metabolisable energy content of the feed), dietary protein, size of animal, physiological state and activity of the animal. The MLA publication 'Beef cattle nutrition-An introduction to the essentials' is the best local guide for cattle production in Australian conditions. Copies can be obtained from MLA or downloaded from the internet. https://futurebeef.com.au/document-library/beef-cattle-production-introduction-essentials/

An understanding of the digestive system of ruminants is important to best meet the nutrient requirements of cattle – refer to 'Ruminant digestion'.

The major nutrients required by cattle are energy and crude protein (from N content), but they also require water, minerals and vitamins.

Water quality is usually considered in terms of total dissolved salts (fresh water <1,000ppm) and nitrate content, although some irrigation water can contain relatively high levels of sulphur. High levels of S can induce a Cu deficiency if animals graze solely on this pasture for long periods.

Minerals are not usually required for irrigated pasture as they are well fertilised. However some trace minerals are needed or should be checked (e.g. Cu, Zn, Se and Co) and these can be provided in fertiliser, supplement blocks, loose licks, intra-ruminal devices or through the drinking water.

Energy

Energy is a general term to describe the energy in pasture and feed from carbohydrate, fats and protein. The gross energy of a feed varies little, but the amount of energy available for metabolism varies widely.

> Digestible energy (DE) = Gross energy minus energy in faeces
>
> Metabolisable energy (ME) = DE minus energy in urine and rumen gases
>
> Net energy for maintenance and production (growth, lactation) = ME minus heat produced in metabolism.

The available energy and protein need to be in balance. If the energy is deficient relative to protein, then the excess N is lost through urine, while if protein is deficient then the surplus energy will be used inefficiently and/or the animal eats less.

Cattle use energy for maintenance, growth, pregnancy and lactation. Maintenance is the energy used by the animal for their basal metabolic rate, activity and body temperature regulation. The maintenance requirements of *Bos indicus* breeds are 10% lower than *Bos taurus*. The remaining energy is used for production.

Maintenance is 40-70% of the total energy requirement in beef cattle and includes:

- Basal metabolic rate ─ varies with the size of the animal. For example, a 150kg steer will require about 22MJ ME/day for maintenance, while a 350kg steer will require 40MJ ME/day.
- Activity – the energy expended varies with the distance walked and the topography. This is a low requirement with stand and graze under a centre pivot with cattle walking about 2km/day, while in a feedlot it is negligible. Rangeland cattle walk about 7km/day.
- Body temperature regulation ─ refers to both extremes of heat and cold, although only the former is relevant in the Pilbara and Kimberley.

  Heat stress – can increase maintenance requirement by up to 25% and the animals will also stop eating during the heat of the day. *Bos taurus* breeds are less tolerant of high temperatures than *Bos indicus* and this is exacerbated in cattle with dark coats. In general, the higher *Bos indicus* content the greater the heat tolerance.

  As a guide shallow panting in beef cattle increases the maintenance requirement by 7%, while open mouth panting can increase their maintenance requirement by 18%.

Pregnancy ─ the energy requirement increases markedly in late pregnancy and maintains this high requirement through early lactation. The key factor is that the growing foetus and/or milk production takes priority for nutrient use and this can result in there being insufficient energy for body weight maintenance, so cows lose weight.

Lactation ─ the metabolisable energy requirement of lactating beef cows in late lactation is 20% higher than dry cows. The implications are:

- early weaning of beef cows reduces their metabolisable energy requirement

- reduces feed use and
- stimulates reproduction.

Growth – energy above that for maintenance can be used for growth. The intake of metabolisable energy (ME) determines the growth rate of the animal. ME is measured as megajoules per kilogram dry matter (MJ ME/kg DM). Cattle eat pasture or feed, but in nutritional calculations this is always described in terms of dry matter* as the moisture content varies widely.

ME intake = DM intake x ME content

The pasture or feed intake measured in DM is directly related to the digestibility of the pasture or feed (Figure 1). When intake is assessed as a % of liveweight then it decreases with the increasing weight of the animal. For example, the intake of a tropical irrigated pasture of 62% DM digestibility by 600kg steers will be about 1.75% W/day (i.e. 10.5kg DM per day), while 200kg steers will have an intake of about 2.4% of their liveweight (4.4kg DM per day). The ME requirements of cattle for maintenance and growth are summarised in Appendix 1.

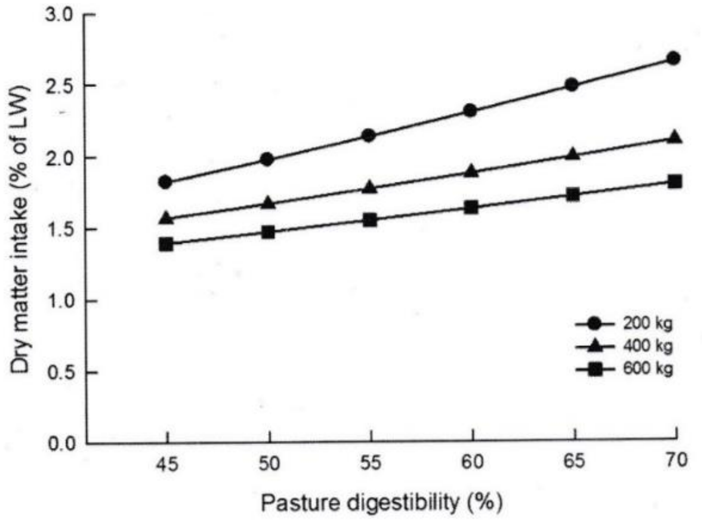


Figure 1. Predicted dry matter intake of forage by 200, 400 and 600kg steers as a % of their liveweight across a range of pasture digestibility. Note: these values assume the animals are housed as in a feedlot and their intake can increase with more activity up to 2km/day.
Source: Adapted from Minson and McDonald (1987) by McLennan (2015)

Crude protein

The other major nutrient assessed for nutritional value is protein which is required for many functions in the animal including building muscle. The term crude protein (CP) or total protein is used which includes both true protein plus non-protein nitrogen (NPN) and is measured from the N content. The conversion factor to measure CP from N analysis is:
Nitrogen x 6.25 = CP

Crude protein %

Less than 7%CP: CP is deficient for the rumen microbes and the animal. A urea (NPN) supplement is beneficial, but there is an upper limit to the rate of microbial protein synthesis, so urea will only ever give a maximum increase in liveweight gain (LWG) of about 0.3kg per day.

* Dry matter (DM) – pasture or fodder contains water and dry matter. All of the nutrients are contained in the dry matter, but the moisture content varies widely. That is why units of energy, protein etc are defined as a % of DM or per kg DM. It is not useful to have units described on as fed (or wet matter) basis other than describing how much to feed.

Ruminant digestion

Ruminants like cattle, sheep and goats have a specialist digestive system with a four-chambered stomach called the rumen, the reticulum, the omasum and the abomasum. The basic anatomy of the digestive tract in cattle can be seen in Figure 2. The rumen is by far the largest digestive organ and is essentially a large fermentation tank. It is anaerobic (no oxygen) and houses bacteria and protozoa (microbes or 'bugs') which under the anaerobic conditions can digest fibre and other carbohydrates and protein. Simple stomached animals (called monogastrics) such as humans and poultry cannot digest fibre. Ruminants have a unique ability to utilise the fibre in feed sources such as pasture and therefore do not compete with humans for food. However, monogastrics and ruminants are similar in the digestion of high energy starch diets like grains.

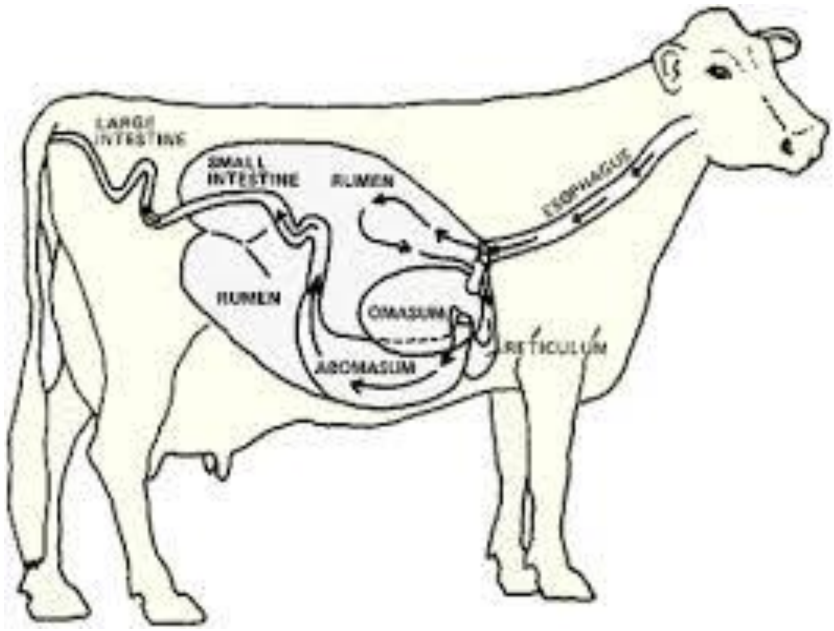


Figure 2. Basic outline of digestive tract of a cow.

Key processes in feed digestion

- Microbes in the rumen digest food, including fibre, to produce volatile fatty acids (acetic, propionic and butyric acid) which are absorbed across the rumen wall and provide energy to the animal.
- In the rumen, the protein in the diet is broken down into ammonia, from which the microbes then make their own microbial protein. The microbes can also make protein from Non-Protein Nitrogen (NPN) sources such as urea.
- The microbes are continually flushed from the rumen and are digested and absorbed in the small intestine providing most of the protein that the animal needs. Cattle over 250kg can get all the protein that they need for a moderate growth rate (up to 1kg/day) from this microbial protein.
- Balancing the nutrient requirements of both the rumen microbes and the animal is important. In fact, 'feed the rumen microbes is the first good nutritional principle' to ensure the rumen microflora are functioning well and providing the animal with the nutrients it requires.

More than 7%CP: There is enough N for good rumen function. Most importantly, a urea supplement is of **no benefit** unless the animals are supplemented with additional energy in the form of grain, molasses etc.

The CP required for growth depends mainly on the liveweight of the animal and its growth rate. For example, a 300kg steer growing at 0.75kg/day would require about 800g of protein which translates to about 11% CP in the diet. For most cattle in excess of 250kg liveweight and over the liveweight gain range of 0.5-1kg/day, a value of 10-15%CP will be adequate.

For growing animals (>250kg) of moderate growth rate and dry and lactating beef cows the rumen microbes can provide all the protein needed by the animal**.**

Feed the rumen microbes is the first good nutritional principle.

To achieve high rates of weight gain (>1.0kg/day) in smaller animals (less than 250kg), microbial protein alone may be insufficient, and a source of undegraded dietary protein, often called bypass protein, will be required. This protein passes through the rumen without being broken down and is absorbed in the small intestine adding to that which comes from the rumen microbes.

Protein meal from oilseeds such as cottonseed meal, copra meal and canola meal contain a significant proportion of bypass protein. However, bypass protein is unlikely to be required in Kimberley and Pilbara irrigation production systems.

High CP: If the CP is high, there is an opportunity for a response to a rumen supplement of energy (e.g. molasses or grain). What happens is that there is more CP degraded to ammonia N than the microbes can use, given the ME content of the pasture or feed. This ammonia N passes across the rumen wall and is converted in the liver to urea and is otherwise excreted in the urine. However, some of it can also be recycled back to the rumen.

The CP% which is excess to the animals requirements varies with the feed quality (Table 1). For example, the threshold CP% is 11.3% when the pasture has a digestibility of 60%, but increases to 14.2% when grazing a high quality temperate pasture with 75% digestibility.

Table 1. The threshold dietary crude protein% (CP%) above which there is loss of N from the rumen for pastures varying in feed quality (DM digestibility%, metabolisable energy)

Dry matter digestibility%	50	55	60	65	70	75	80
Metabolisable energy (MJ ME/kg DM)	7.0	7.8	8.7	9.6	10.4	11.3	12.1
Threshold pasture CP%	9.4	10.4	11.3	12.2	13.2	14.2	15.1

Irrigated high N fertilised tropical pastures under a centre pivot often have a high CP content (13-18%) and moderate digestibility (60-65%) when rotationally grazed up to a herbage mass of 3,000kg DM/ha. Thus from Table 1 cattle grazing irrigated tropical pastures would tend to have an excess of CP in the diet relative to metabolisable energy supply and may benefit from the provision of a supplementary energy source. Note that both CP and DM digestibility decline quickly as plants mature.

There can be loss of CP from the rumen with these high N fertilised pastures. This is not a problem, but provides an opportunity for a response to a rumen supplement of energy.

Expected liveweight gain

Animal growth rate is a function of energy intake (voluntary feed intake x metabolisable energy of the feed), dietary protein intake, size of animal, physiological state and activity of the animal.

The expected cattle growth can be estimated from the liveweight and the feed quality of the pasture or fodder. For example, a 400kg steer grazing a Rhodes grass pasture of moderate feed quality (62% DMD, 9MJ ME) has an expected growth rate of 0.60kg per day (Table 2). The DM intake (kg/day) of a 600kg steer is effectively double (202-208%) that of a 200kg animal to achieve the same growth rate.

Table 2. Indicative cattle growth rates based on MLA feed intake, liveweight and feed quality relationships and assuming minimum protein requirements are met and that the cattle are walking 2km per day*.

Liveweight (kg)	Feed quality		Animal intake		Growth rate (kg/day)
	Metabolisable energy (MJ/kg DM)	DMD %	Dry matter intake (kg/day)	Metabolisable energy (MJ/day)	
200	8	56	4.8	38.2	0.30
	9	62	5.3	47.1	0.60
	10	68	5.6	56.2	0.95
400	8	56	8.1	64.1	0.30
	9	62	8.6	77.2	0.60
	10	68	9.0	90.0	0.95
600	8	56	10.5	83.2	0.30
	9	62	11.0	98.2	0.60
	10	68	11.3	112.6	0.95

*Growth rates will be lower where animals are walking long distances for water (e.g. 7km in total – Table 4).

Stand and graze

With cattle grazing a well-managed tropical grass pasture the expected liveweight gain in the medium-term is unlikely to exceed 0.7kg LWG per day. Note that:

- bulls may do slightly better due to the testosterone hormone effect
- heifers are likely to grow slightly slower
- with very high temperatures then growth reduced to 0.5kg LWG per day. Growth rates of *B. taurus* breeds will be more affected by high to extreme temperatures than *B. indicus*.
- in the short-term it is possible to have higher LWG due to compensatory growth.

The ceiling for cattle growth rates is determined by the metabolisable energy intake of the feed. In the case of grazed irrigated tropical grasses the cattle will preferentially select for leaf over stem as it is more palatable and of higher feed quality. When rotationally grazed the leaf has an ME of 9-9.5MJ ME/kg DM and cattle in the range 200-400kg have reached a growth rate of 0.6-0.7kg LWG per day under the pivots.

Many studies across northern Australia with cattle grazing wet season or irrigated tropical pastures and also from weighing animals on and off irrigated pastures in the Pilbara and

Kimberley confirm these growth rates. The range is from 0.3 to 0.9kg LWG per day without supplementation. The pastures include tropical grasses like Rhodes grass, pangola grass (high quality tropical grass) and leucaena-grass pastures (Appendix Table A2).

In direct grazing systems, maximising feed intake is dependent on the animal grazing easily accessible leaf which has the highest digestibility.

As a guide, following the grazing rule 'e*ntry 3000kg DM/ha and exit 1500kg DM/ha*' will maximise intake of intensively managed tropical grasses. Grazing below 1500kg DM/ha results in reduced intake (reduced bite size) and lower LWG, as the animals are forced to eat the portion of the plants that they had not previously selected. They also have to contend with pasture that has been damaged by trampling.

Well-managed Rhodes grass pastures should produce levels of LWG between 0.5 to 0.9kg per head per day (budget on 0.6-0.7kg/head per day). Daily LWG should be similar all year round provided intake is not restricted, however exceptions are very hot and humid conditions (e.g. around cyclones) where intake may be limited and LWG reduced. Grass growth in winter is much slower, at times only one third of the growth rate in summer, so the stocking rate needs to be adjusted accordingly.

The distance cattle walk has an effect on the growth rate if LWG is limited by the digestibility of the pasture (Table 3). On intensive pastures such as irrigated centre pivots cattle will walk about 2km/day while on extensive rangeland pastures they can walk about 7km/day.

Table 3. The effect of distance walked on liveweight gain (LWG) of 300kg steers grazing an irrigated tropical pasture of 9MJ ME/kg DM (62% dry matter digestibility). This assumes that intake is set at 2.3% W/day (7.0kg/day, from Table 2).

Distance walked (km/day)	2	4	7
Liveweight gain (kg/day)	0.60	0.55	0.48

Compensatory growth, or catch-up growth, is the faster than expected growth of cattle when they have access to good nutrition (e.g. during the early wet season) following a period of low nutrition (e.g. during the dry season). Often much of the weight lost during the low nutrition period is recovered through compensatory growth.

Cut and Carry

A cut and carry system is where the pasture or crop is cut for fodder (hay, baleage, silage), green chop or grain and then fed to the animals. An advantage is that the pasture utilisation with a cut and carry can be up to 80%, compared with about 50% for a well-managed stand and graze system. On the other hand, there are additional labour and machinery costs and there needs to be an area in which to feed the animals.

There is limited data on LWG results from cut and carry, but in general the expected LWG will depend on the liveweight of the cattle and the feed quality (Table 2).

Mature hay will only result in maintenance. For example, mature Rhodes grass hay with 6.6% CP and 52% DMD fed to light Brahman X for 63 days resulted in an average LWG of only 0.07kg per day (McLennan 1997). This might be acceptable for cows and holding sale animals, but if you want higher LWG, then the hay needs to be of high quality. The LWG from feeding this 'high quality' hay is still likely to be lower than the LWG from a well-managed stand and graze system because cattle will not have the opportunity to select a higher quality diet. Specialist crops such as sweet sorghum and maize will generally produce higher quality feeds (hay or silage) than Rhodes grass.

Feedlot rations

A bulk feed like Rhodes grass hay needs to be mixed with other ingredients of higher ME content as part of a ration. These high energy crops like maize silage or cereal grain can be grown under irrigation or sourced externally. A well formulated ration of the required ME and CP% for the target growth rate can then be designed.

A feedlot ration is best formulated by a feedlot consultant who can use a least cost linear program to design rations. In a commercial feedlot the ration is regularly adjusted to reflect the costs of potential ingredients at that point in time. Grain (e.g. wheat, barley, maize, sorghum), leguminous seeds or by-products (e.g. lupins, soybean meal, whole cottonseed, cottonseed meal, copra meal, canola meal) can be costed. The best combination of external and locally grown feeds can then be determined.

What if the LWG of your cattle is lower than expected?

If the LWG that you are getting does not match the values described above, possible reasons to consider are:

- Pasture is under-grazed (>3000kg DM/ha), or over-grazed (<1500kg DM/ha). Need to redo feed budget and adjust the stocking rate.
- The cattle have a mineral deficiency. Make sure P, Co, Se and Cu are adequate and supplement if necessary via fertiliser, intra-ruminal devices or in water supply (depending on the mineral).
- The cattle have internal parasites. Before animals go on the pivots, a parasite control program should be used (targeted drenching). Check by doing a faecal egg count.
- Dung and urine patches are appearing. The pasture between the dung and urine patches is being over-grazed. Mow the pasture and remove the cut material.

- Poor water quality - this should always be tested. Irrigation water from some bores in northern WA contain high levels of S, which can induce a Cu deficiency if animals graze solely on this pasture for long periods.

Effect of supplements on intake of pasture

Supplementing the cattle to increase the growth rate is an option, but it is important to understand the effect on pasture intake. A number of experiments across northern Australia have shown consistent gains from supplementing cattle on irrigated pastures with high energy feeds (cereal grain, maize, molasses). The increases in daily growth rates are typically 0.2–0.4kg LWG/day when the energy supplement was 0.5-1% by weight, but it does depend on the level of supplement.

When a supplement of urea or protein meal is given to cattle grazing dry season rangeland pastures, with very low levels of protein, this revives the rumen bacteria and enables the animal to increase its intake of pasture. However, when a supplement of protein or energy is given to cattle that already have adequate rumen function, as is the case with cattle grazing an irrigated pasture, intake of the pasture is reduced in response to the supplement. This is called substitution and the concept is illustrated in Figure 3. The overall intake (pasture plus supplement) would be higher and also LWG would be higher than pasture alone. With these high CP% pastures there is no response in intake or LWG to a urea supplement.

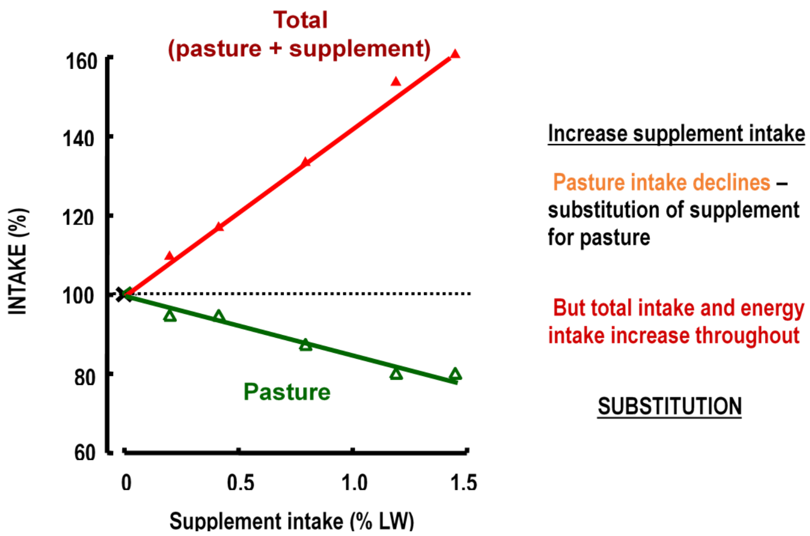


Figure 3. The effect of a supplement on pasture intake showing the principle of substitution where the pasture intake declines as the amount of supplement increases.

Table 4 provides an example of the effect of substitution when stock grazing pasture of moderate feed quality (8.6MJ ME/kg DM, 12% CP) are fed a supplement. When a high energy supplement like grain is fed at 1% of liveweight then pasture intake is 65% of the pasture intake of cattle grazing the same pasture with no supplement. As the level of supplementation is increased to 1.5%of liveweight then pasture intake is reduced to about half of what it would be without any supplement. Overall the intake of energy will increase, but there is always a substitution effect.

Substitution can be an advantage if feed is short. However, it can also result in grass growth exceeding animal intake and the grass becomes rank and over-mature when feed is adequate. Patch grazing will start to appear and LWG will decline. The solution is to increase the stocking rate either with more animals or by reducing the grazed area.

The decline in pasture consumed through substitution can be predicted using a number of methods – discuss with an animal nutritionist.

Table 4. An example of the impact on pasture intake (%) of a high energy supplement (grain or high energy pellets) at three levels of supplementation as % weight per day (% W/day) compared with pasture only (control). Note: the pasture is assumed to have an ME of 8.6MJ ME/kg DM and 12% CP. The values are pasture intake as a % of the pasture intake by cattle with no supplement.

Supplement	Level of supplement			
	Pasture (no supplement)	0.5% W/day	1.0% W/day	1.5% W/day
Grains, high energy pellets (13MJ ME/kg DM)	100%	82%	65%	47%

Calculating level of supplementation as a % of liveweight:

Daily supplement per head (kg) = % of supplementation x liveweight (kg)

For example, a 240kg animal provided with a supplement at 0.5% = 0.5/100 x 240 = 1.2kg per day

An alternative calculation for supplementation is based on grams of supplement per kg of liveweight

Level of supplementation as % of liveweight	Grams of supplement per kg of liveweight	Example 240kg steer supplement intake g/day
0.5	5g	240 x 5 = 1,200g (1.2kg)
1.0	10g	240 x 10 = 2,400g (2.4kg)
1.5	15g	240 x 15 = 3,600g (3.6kg)

Further reading:

The MLA book 'Beef cattle nutrition-An introduction to the essentials' - copies can be obtained from MLA or downloaded from the internet. https://futurebeef.com.au/document-library/beef-cattle-production-introduction-essentials/

4.2 Grazing Rhodes grass pastures

Kevin Bell
Technical Innovations Manager,
Pardoo Beef Corporation

Key Messages

- Correct grazing management of tropical pastures is required to get the best possible performance from cattle, and to maintain the pasture in a productive state.
- Irrigated pastures are a relatively expensive source of cattle feed and optimum utilisation is important.
- Cattle will preferentially select leaf over stem as the leaf is more palatable and of higher feed quality. Young, fresh leaf has the highest quality, while stem essentially equates to a maintenance diet.
- The feed quality 'sweet spot' for species like Rhodes grass is quite narrow, so continual review and balancing of stocking rate and the number of grazing days is necessary to balance the trade-off between quantity and feed quality.
- The rapid changes in pasture growth rates between seasons mean that provision must be made to either acquire or remove cattle from pastures at short notice. The key periods are typically May-June and September-October.
- Hay or silage making can be employed in conjunction with grazing as a component of managing growth rate changes.

Characteristics of grazed Rhodes grass and other tropical grass pastures

Each pasture species is different in growth habit and must be managed accordingly, however there are a number of grazing principles which apply.

Following grazing or mechanical defoliation, initially there is leafy growth from the level to which the pasture has been reduced. Leaf emergence is at a rate dependant on temperature and day length, in northern Australia this is typically over a range from 3 to 10 days. The initial re-growth after grazing or cutting will depend on whether the existing tillers re-grow or whether the plant needs to grow new tillers. As a guide, few if any tillers which have flowered will re-grow after cutting or grazing, while most leafy tillers will regrow. For example, after a large hay crop is removed there will be a lag period as most of the tillers won't re-grow. Observations have identified that high rates of fertiliser N may reduce this lag period.

The proportion of stem in the sward increases as the period of regrowth increases. With a Rhodes grass pasture growing under favourable conditions there is an exponential increase in stem growth after about 3 weeks re-growth (Pembleton *et al* 2009). The high growth rates in weeks 4 to 5 (e.g. in summer 150 to more than 200kg DM/ha per day) are associated with a higher proportion of stem, hence there is a trade-off between quantity and feed quality. However, as the pasture height and mass increase, the bulk density, or weight of dry matter per volume of the sward commonly decreases.

A common feature of most grazed pastures after one or more grazing periods is the variable height and density of the pasture sward. The major cause of variation is contamination by cattle excreta, mostly dung.

It is important to recognise the variable features of the pasture. Standing out are pasture clumps – taller, more mature areas ('EA, excreta areas or dung-affected areas). These typically occupy 15 to 25% of a pasture, the proportion increasing with time since pasture 'resetting' (See Tools below).

The pasture between these laxly grazed clumps, or interstitial areas (IA), is shorter and is the area favoured by cattle.

Rhodes grass pasture showing typical patchy growth after a few cycles of grazing. There will be lax grazing of the clumps, while the cattle will preferentially graze the areas in-between (interstitial areas)

Terminology

Dry Matter (DM) – expressed as kg DM/ha – the weight of a pasture sample after all of the water has been removed (Samples are oven dried @ 65-70°C for 24 to 48 hours).

All feeds and pastures are compared on a dry weight basis rather than a 'wet' or 'fresh' weight. The dry matter content of green feed can vary from 10% in young leaves to >30% in mature old growth, while hay is 86-88 % DM (i.e. 12-14% moisture) and silage 35-50% DM.

Excreta area (EA) – the clumps of tall grass in a pasture which have not been grazed or grazed laxly, predominantly associated with dung and urine patches.

Feed budget – An assessment of the FOO and number of grazing days available for a certain class of stock. A paddock or feed budget can improve decisions about allocating stock to pastures and determining when they need to be moved.

Feed-on-Offer (FOO) – describes the amount of pasture dry matter available for grazing animals at any one time and is assessed by estimating the pasture dry weight/ha. It is expressed as kilograms of pasture dry matter per hectare (kg DM/ha).

Cattle grazing characteristics on tropical grass pastures

The intake of animals at a particular time is largely determined by the leaf offered per unit area irrespective of the number of animals grazing. Therefore, leaf yield and to a lesser extent pasture density and leaf to stem ratio, provide a better expression of pasture supply than grazing pressure (cattle per hectare at any given time).

Cattle strongly prefer and select for leaf, and especially leaf that is younger and therefore more digestible and palatable. It is recognised that a major factor associated with cattle growth rate is leaf bite size (Stobbs 1973), and recognition of this will greatly guide decisions in grazing management and good allocation of grass to cattle. The highest leaf density is typically in pastures around the 3- to 4-leaf stages of growth. The upper canopy of such a pasture will have more leaf than stem.

Short pastures can have high feed quality (digestibility), but the bite size is often inadequate for a high daily intake. At the other end of the scale, as pastures become older and taller leaves may be large and long, but the pasture density is lower and as a result cattle intake per bite reduces. There is also more stem to deter and impede the grazing of leaf, and leaf quality reduces with age (Figure 1). Three to four week old Rhodes grass leaf is in the range of 8 to 9.5MJ, while stem is in the range of 7–8MJ. The stem is essentially a maintenance diet whereas the leaf is associated with weight gains of up to 0.8kg/day, depending on cattle age and breed.

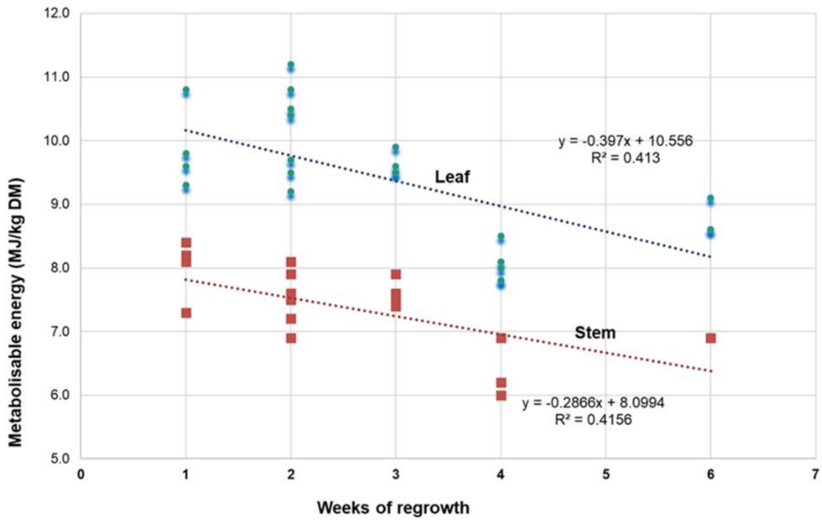


Figure 1. The metabolisable energy of Rhodes grass leaf and stem versus weeks of regrowth (Results from a DPIRD trial at North Broome in 2018).

Cattle select the more digestible shorter pasture between the EA clumps. If left to graze pasture IA below the critical level (see Grazing guidelines) they will degrade this area, often uprooting plants and stolons. They laxly graze the top of the clumps, which become more pronounced over time.

Grazing guidelines

For any grazed pastures, best utilisation is achieved by some form of rotational grazing, the principles are:

- Introduce cattle before the grass 4-leaf stage. *Remember all guidelines refer to the pasture in the interstitial areas (IA), NOT the clumps.* Leaf canopy height and FOO will be variable with seasonal growth, but may typically be 20–30cm with FOO of 2000–3000kg/ha.

- The shorter the period of grazing the less wastage and better utilisation. A grazing period of one day is ideal; it should not exceed 3 days.
- The period of regrowth from controlled grazing (or resetting) to the desired FOO will vary greatly with season. For example, in the low rainfall coastal zone of the Pilbara it can vary from 12 days over summer to 45 days in winter.
- With the large variations in pasture growth rate, it is essential to recognise and plan for often rapid changes in carrying capacity – especially the period from mid-August to mid-October when growth rates can increase three-fold.
- Know the cattle requirements in dry matter (DM) intake per day.
- Allocate the pasture to provide this, by estimating available leaf DM in the top pasture horizon of the pasture interstitial areas, as cut (see Tools). The pasture in IA is leafier, more digestible and favoured by cattle. Remember IA is usually less and sometime considerably less than the pasture as a whole, depending on the time and number of grazing periods since it was reset.
- Maintain a leafy component at the end of grazing to allow rapid recovery. Minimum FOO is 500kg/ha and, or 5cm above the stem level. This refers to IA, from which the decision to move cattle must be made, however the EA areas may still have high FOO, possibly 2,000 to 3,000kg DM/ha.
- Maintain pasture observations well ahead of the current and next planned area. Be prepared to re-assess grazing plans as grazing outside of the entry and exit boundaries suggested has immediate and longer-term effects on cattle and pasture.

Tools

Cattle requirements

For a table of metabolisable energy (ME) requirements for steers see McLennan 2015 (Appendix 1).

Cattle can eat about 2.5% of their bodyweight/day of typical irrigated Rhodes grass pasture leaf, based on the attributes of fibre, as measured by Neutral Detergent Fibre (NDF %) and digestibility. Their associated weight gain will vary with breed and weight, but as an approximation for northern cattle with some *Bos indicus* content, 0.25% of bodyweight/day weight gain can be expected. For example, a 220kg steer on well managed irrigated grass pasture would consume about 5.5kg DM pasture per day and might gain about 0.55kg LWG per day. Regular weighing is recommended.

Pasture quality

Ideally pasture leaf should be tested regularly at a feed analysis laboratory to monitor important feed attributes, the most relevant being energy as indicated by DDM and ME. Crude protein (CP, %) level is normally more than adequate for intake as it is governed by DDM and NDF.

Pasture quantity

The quantity of pasture in a paddock is estimated in kilograms of dry matter per hectare (kg DM/ha).

To estimate FOO with sufficient accuracy to manage cattle intake, a visual estimate by an experienced manager can be made following calibration with actual pasture cuts, aided by photo standards of a variety of pasture types. Combined with this is an awareness of seasonal influences on pasture production.

The cuts are made at the stubble level (i.e. height of old stems) junction between dead leaf and stem and/or the clear live and dead stem height which represents a barrier to grazing. This may be very close to ground level as can occur in winter, or as high as 15cm where pastures have become more mature. The level to which pastures have been reset is evident from a horizontal stubble (old stems) layer and is the level to make a calibration cut. From this level fresh pasture emerges and is available to the cattle.

A convenient paddock pasture DM estimation

1. Consider the variations across the paddock
2. Situate a quadrat (50cm x 80cm) in an area that is typical of the pasture type you are estimating (Avoid the pasture clumps)
3. Cut to litter/dead stem (stubble) height removing green material only
4. Weigh green pasture
5. (a) From October – April, the assumed pasture DM is 20%:

   Kg dry matter/ha = (green (fresh weight) weight in grams) multiple by 5

   e.g. 300g green = {(300x2.5) x 0.2 x 10} = 1500kg DM/ha

   (b) From May – September, the assumed pasture DM is 25%: so multiply by 6.25
   e.g. 300g fresh weight = (300 x 6.25) = 1,875kg DM/ha

Note: A quadrat can be made from 25mm PVC pipe and joiners. Battery operated garden shears are convenient for cutting. Kitchen scales can be used to weigh pasture if they have an accuracy to ±1 gram.

Typical Rhodes grass pasture under grazing – to measure FOO determine the pasture dry matter between the clumps.

Calculating grazing days?

Working out how long stock can be left in a paddock or a cell before it reaches the desired minimum FOO is a common feed budgeting question. To complete the calculation, you will need to know the current FOO, desired FOO when the animals are removed, the pasture growth rate, daily consumption of the animals, the number of grazing animals and an estimate of wastage.

Tools are available to assist calculating a feed budget (MLA Tools).

Pasture resetting

Resetting refers to mechanical removal of the clumps, which becomes essential after two or three grazing cycles, by mowing or mulching to approximately 10cm.

When resetting pastures, varying amounts of ungrazed material are removed. This comprises pasture which may be trampled and excreta-contaminated, laxly-grazed clumps, rejected uprooted pasture plants including stolons, and rejected stem.

If the material cut is of small amount it may not be necessary to remove it. If judged as excessive, however, to the degree that too much pasture is blanketed, the dead material should be removed, for example by raking and baling, and discarded if of poor quality, as is often the case.

In the case of mulching the grazed pasture, where the material is cut into small lengths and deposited back, it is important that the amount is not excessive as the resultant litter will act as a physical and nutrient barrier, as well as under warm conditions it provides an environment favourable for pathogenic fungal growth.

A thick mulch left on the surface can kill the underlying grass which reduces overall pasture production

Identifying problems with the pasture

Regular weighing of animals can often identify an issue which needs to be addressed more quickly than visual observations. For example, if the expected weight gain is 0.6-0.7 kg LWG per day and the cattle are only growing at 0.3 kg LWG/day then the underlying issue can be investigated whether it is due to low pasture growth rates, trace element deficiencies or parasites.

Many seed heads and low leaf growth

Stressed plants, whether that be from limited soil moisture, plant nutrition or insect attack (e.g. locusts) will often respond by sending up seed heads rather than leaf.

The first step is to identify the issue, then address the constraint. However, following a period of stress, there can be a delay or lag in the growth response even after the stress is removed.

Pasture clumps visibly darker green than rest of sward

If the clumps of tall grass associated with dung or urine patches are a markedly darker green than the surrounding grass this indicates there is a likely N deficiency across the remainder of the paddock. This can be confirmed with soil and tissue testing.

Small plants and stolons being pulled out

Notice young plants and stolons being pulled out by cattle grazing – this is due to over-grazing or repeated grazing of the interstitial areas or grazing below the minimum FOO (500kg DM/ha), If this occurs consider removing the stock earlier.

Nutritional deficiencies

Moderate to low pasture growth even though high rates of fertiliser N have been applied.

Assuming this is not related to moisture stress, insect attack or low night temperatures, then it is likely there is a deficiency of another nutrient, like phosphorous.

Specific deficiencies can be detected by tissue testing of young leaf and comparing with standards or from the plant symptoms.

Photo standards for assessing Rhodes grass Feed-on-offer (FOO)

500kg

1000kg

1500kg

2000kg

2500kg

3000kg

3500kg

4.3 Understanding feed quality

Clinton Revell

Key Messages

- Formulating grazing management strategies, feed budgets and feed lot rations requires an understanding of the feeding objectives in terms of weight gain and the forage needs to be fit for purpose and cost effective.
- Animal growth rate is a function of energy intake (voluntary feed intake x metabolisable energy of the feed), dietary protein, size of animal, physiological state and activity of the animal.
- Laboratory tests can provide an estimate of the nutritive value of feeds including digestibility, fibre content and crude protein.
- As a general guide, a diet with metabolisable energy >9.5MJ ME/kg DM and crude protein >10% is desirable for growing animals at 0.7kg LWG per day.

Nutritive value is a function of digestibility, protein, minerals, vitamins and secondary compounds, and the efficiency with which they are utilised by the animal for maintenance and growth. The best way to determine forage quality is to measure the growth response of the animal, as the animal integrates dietary preference, feed quality, intake (feed-on-offer, bite size etc.) plus any environmental stresses such as heat load. The research equivalent is to conduct animal feeding trials, but these are time consuming and costly. Laboratory techniques have been developed as an alternative but it is important to understand how the information is generated and how to interpret the output.

Feed quality testing and interpretation

Wet chemistry techniques are the most accurate for measuring nutrient content as a surrogate for animal trials. They use chemicals and heat to break down the forage and isolate the nutrients. *In vitro* dry matter digestibility is based on the *in vitro* digestion by two gut enzymes, pepsin and cellulose (which break down protein and carbohydrates, such as cellulose, respectively). Near Infrared Reflectance (NIR) techniques are a lower cost alternative to wet chemistry analysis. With NIR, a spectrophotometer is used to analyse the light spectrum reflected off a sample when it is exposed to infrared light. Each nutrient has unique reflection characteristics based on its molecular structure (carbon, nitrogen and hydrogen bonds). The reflectance of test samples are compared with that of a set of similar samples (calibration set) that have been analysed by wet chemistry. The quality of the calibration is important and will vary for different species. For example the calibration for tropical grasses will be different to the calibration for temperate grasses or legumes.

Feed quality is analysed by a number of laboratories in Australia and it is recommended to use those accredited by the National Association of Testing Authorities (NATA) and who are participants in the Australian Fodder Industry Association (AFIA) fodder testing proficiency program. *It is important to remember that laboratory analyses are only estimates of the digestible fractions and have error attached.* Feeds are naturally highly variable and it is vital the sample is representative of the feed being tested. Mixing multiple samples from the same forage 'lot' (e.g. hay load, variety, paddock) is desirable. Sampling guidelines are provided by most feed test laboratories. Taking the average of duplicate or triplicate samples will improve the accuracy of the feed test, but will obviously add to the cost of the analysis.

A feed analysis report will generally include results for the following tests:

Dry Matter (DM) % – the plant material remaining after all the water has been removed and is the basis for a true comparison between feeds. Dry matter is comprised of organic matter and ash. DM should always be used in nutritional calculations.

Organic Matter (OM) % - the component of feeds that provide energy to animals and includes proteins, carbohydrates and lipids (fats).

Ash % – is the total inorganic matter (minerals, soil) in a feed following high temperature combustion of the organic matter. Minerals do not yield energy directly but are required for cell metabolism in metabolic pathways that generate energy.

Dry Matter Digestibility (DMD) % - the proportion of dry matter in a feed that can be digested

Dry Organic Matter Digestibility (DOMD) % - the proportion of organic matter in the dry matter that can be digested. It is a calculated figure derived from DMD. (For roughages, DOMD% = 6.83 + 0.847 DMD%).

Metabolisable Energy (ME) MJ/kg DM – the amount of energy in a feed that can be used for maintenance, production and reproduction. It is a calculated figure derived from DOMD (ME = 0.203 X DOMD% – 3.001).

Carbohydrates are the primary source of energy for the rumen bacteria and the animal. Total Non-Structural Carbohydrates (NSC) content is a measure of all the available sugars and starches. Water Soluble Carbohydrates (WSC) are the labile sugars available to the animal and rumen bacteria.

Crude Protein (CP) % - includes protein and non-protein nitrogen and is calculated from nitrogen content x 6.25. Proteins are organic compounds composed of amino acids and they are a major component of vital organs, tissue, muscle, hair, skin, milk and enzymes.

Dietary Fibre – is the structural part of plants and feeds and is expressed as a percentage of DM, either as acid detergent fibre (ADF) or neutral detergent fibre (NDF).

NDF is a measure of the structural or slowly digested fibrous components of the cell wall of plants such as hemicellulose, cellulose and lignin (Figure 1). As a plant matures the NDF level will gradually increase. The lower the NDF reading, the easier and faster the animal will digest and absorb the nutrients. A higher level of NDF will often lead to a lower feed intake. ADF makes up a proportion of NDF levels and is a measure of the least digestible parts of a plant such as cellulose and lignin. Typically, when ADF increases, the digestibility of a feed will decrease and be reflected in lower ME. The digestibility of NDF (NDFd) can also be measured to improve the predicted energy value of forages.

In general, fibre (NDF and ADF) typically increases and water soluble carbohydrates, digestibility and metabolisable energy decrease as plants mature. The highest ME in Rhodes grass is found during the first 14 days of regrowth when the sward is dominated by new leaf (Section 3.4). As the stand matures, the proportion of stem, which is more lignified and less digestible, increases (reflected in an increase in ADF and NDF). There are also reports that high temperatures reduce nutritive value due to more rapid lignin synthesis (Wilson 1982,

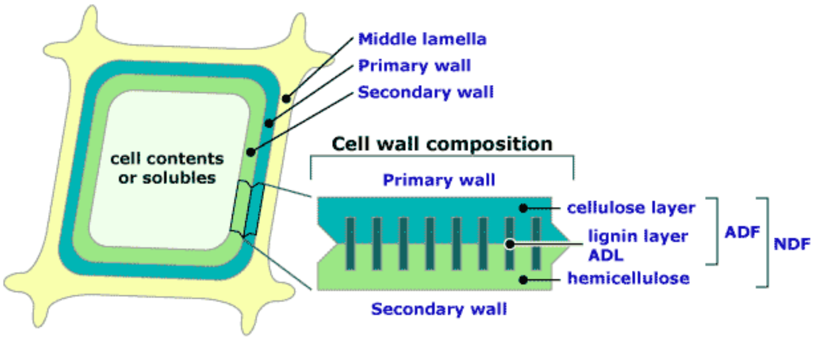


Figure 1. Cell wall composition showing components of Neutral Detergent Fibre (NDF) and Acid Detergent Fibre (ADF).
Source: https://courses.ecampus.oregonstate.edu/ans312/four/intro_rough_trans.htm

van Soest 1988), and this may be an issue for grasses over the hot, wet season. Temperate species such as oats and lucerne generally have lower fibre (particularly NDF) than the tropical grasses and are more digestible with higher ME contents (Section 3.6). Legumes are generally higher in protein content, but in grasses CP is strongly influenced by nitrogen supply.

Table 1 demonstrates the range in nutritive values from samples submitted to a laboratory for testing and the desirable targets for each component. There are not only large differences in feed quality between species, but also for the same product. For example, for maize silage the average ME of 62 samples submitted testing was 10.2MJ ME/kg DM, but the range was from 8.4 to 11.6 (Feedtest® Victoria samples 2019). The nutritive value of some selected forages is shown in Table 2 and ranks their relative feeding value according to a baseline of mature lucerne (the higher the feeding value index the better the feed quality for liveweight gain).

Table 1. Typical range in nutritive value components of forages

Component	Range	Desirable
Neutral detergent fibre (NDF) %	30 – 75	<50
Acid detergent fibre (ADF) %	15 – 55	<30
Crude protein (CP) %	5 – 25	7 for maintenance, 10–15 for growth
Ash %	5 – 15	varies with species, lower is better
Organic matter (OM) %	85 – 95	varies with species, higher is better
Dry matter digestibility (DMD) %	45 – 85	55 for maintenance, >60 for growth
Metabolisable energy (ME) (MJ ME/kg DM)	5 – 13	7.5MJ for maintenance, >10.5MJ for growth rates of 1kg LWG/day
Water soluble Carbohydrates (WSC) %	0 – 25	varies with species, higher is better

Feed quality is important as it drives feed intake and growth (weight gain). Voluntary feed intake is a function of digestibility (or metabolisable energy), the type of feed, the size of animal, breed and its physiological state. Animal growth rate is a function of energy intake

Table 2. Indicative Crude protein (CP%), Acid detergent fibre (ADF%), Neutral detergent fibre (NDF%), Dry matter digestibility (DMD%), Metabolisable energy (ME MJ ME/kg DM) and Relative Feed Value (RFV) of selected forages (derived from Future Beef). RFV index is relative to a baseline of mature lucerne = 100.

Forage	CP %	ADF %	NDF %	DMD%	ME	RFV
Lucerne, pre-bud	23	28	38	73	11	164
Maize silage	9	30	45	70	10.4	150
Sorghum-sudan grass vegetative (~1m), young Rhodes grass leaf	15	29	55	66	9.7	112
Lucerne, mature (full bloom)	15	41	53	65	9.5	100
Sorghum-sudan grass headed, mature Rhodes grass	8	40	65	59	8.5	83
Mature headed (rank) Rhodes grass[a]	7	40	75	50	7	75
Wheat straw	4	54	85	44	6	51

[a] Generated from field trials in northern WA

(voluntary feed intake x metabolisable energy of the feed), dietary protein, size of animal, physiological state and activity of the animal (Section 2.4). Dietary protein is particularly important for young growing animals.

Formulating grazing management strategies, feed budgets and feed lot rations requires an understanding of the feeding objectives in terms of weight gain and the forage needs to be fit for purpose to be cost effective (Section 2.4). A feed with an ME of 8MJ/kg DM and 7% CP may be suitable for yard feed or sale animals, but will be unsuitable for growing animals unless there is supplementary feeding of high quality concentrates or grains, but this will add to feeding costs. For growing animals at 0.7kg LWG per day a diet with ME of 9.5MJ and 10% CP is required, while for growth rates of 1kg LWG per day requires a diet with ME at least 10.5MJ/kg/DM and CP >12%.

Energy and protein requirements for specific classes of animals and specific weight gain objectives can be found in the MLA EDGEnetwork guidelines (Appendix 1) (https://www.mla.com.au/research-and-development/search-rd-reports/final-report-details/Extension-On-Farm/Review-and-update-of-the-FutureBeef-extension-training-packages/3281). Consultant animal nutritionists can design feed budgets and rations to cost effectively optimise animal performance.

Further information:

Australian Fodder Industry Association (AFIA) standards for hay quality https://www.afia.org.au/index.php/17-quality/24-national-grades

Future Beef – hay and silage analyses: what do they mean? https://futurebeef.com.au/knowledge-centre/hay-and-silage-analyses-what-do-they-mean/

APPENDICES

Table A1 – A summary of the main soil groups in the Pilbara and Kimberley

Table A2 – A summary of cattle growth rates on tropical pastures in northern Australia

From Section 1.4 'Understanding the soils' by Henry Smolinski

Table A1. A summary of the main soil groups in the Pilbara and Kimberley

WA soil group[a] overview	% Area		Australian Soil Classification[b]	General description	Landform	Major management consideration
	Pilbara	Kimberley				
Red Sandy Duplexes and Red Loamy Duplexes with moderate to strongly structured red clay subsoils	1%	1%	Red Chromosols	Moderately deep to deep well-drained red soils with a strong texture contrast between the A and B horizons. The A horizon is generally not bleached and B horizons not sodic and neutral to alkaline.	Undulating plains to hilly areas on a wide variety of parent materials	Widely used for agriculture in other regions but in northern WA, water erosion is often a major limitation.
Sandy or loamy duplex with moderate to strongly structured brown, yellow or grey clay subsoils	<1%	1%	Brown, Yellow or Grey Chromosols and Sodosols	As above, but moderately well-drained to imperfectly drained brown, yellow and grey soils. Yellow and grey soils can be sodic	As above	As above and may also be restricted by drainage related issues
Non-Cracking Clays and clay loam soils	1%	1%	Dermosols and Kandosols	Weak to strongly structured, neutral to alkaline with little or only gradual increase in clay content with depth. Grey to red, moderately deep to very deep soils	Plains, plateaus and undulating plains to hilly areas on a wide variety of parent materials	Generally high agricultural potential because of their good structure, and their moderate to high chemical fertility and water-holding capacity. Ferrosols on basalt and other basic landscapes may be shallow, rocky and water erosion can be a major limitation.
Wet or Waterlogged Soils. Seasonally or permanently wet soils	<1%	<1%	Hydrosols	A wide variety of soils grouped together because of their seasonal or permanent inundation. No discrimination between saline and freshwater	Coastal areas to inland wetlands, swamps and drainage depressions. Mostly unconsolidated sediments, usually alluvium	Not recommended for development – require drainage works before development can proceed. Acid sulfate soils and salinity are associated problems in some areas

Table A1 Continued.

WA soil group[a] overview	% Area		Australian Soil Classification[b]	General description	Landform	Major management consideration
Red loamy earths	20%	15%	Red Kandosols	Well-drained, neutral to alkaline red soils with little or only gradual increase in clay content at depth. Moderately deep to very deep red soils	Level to gently undulating plains and plateaus, and some unconsolidated sediments, usually alluvium	Moderate to high agricultural potential due to their good drainage. Low to moderate water-holding capacity, often hard-setting surfaces.
Brown, yellow and grey loamy earths	<1%	5%	Brown, Yellow or Grey Kandosols	As above, but moderately well-drained to imperfectly drained brown, yellow and grey soils	As above, but more common in lower parts of the landscape	As above, but may also be restricted by drainage related issues
Red deep sand and Red sandy earth	20%	17%	Red Tenosols	Moderately deep to very deep red sands, may be gravelly	Sandplains and dunes; Aeolian, fluvial and siliceous parent material	Low dryland agricultural potential due to excessive drainage and poor water-holding capacity. Potential for irrigated agriculture
Brown, yellow and grey deep sands and sandy earths	<1%	<1%	Brown Yellow and Grey Tenosols and Kandosols	Moderately deep to very deep brown, yellow and grey sands, may be gravelly	As above, but more common in lower parts of the landscape	Low agricultural potential due to poor water-holding capacity combined with seasonal drainage restrictions. May have potential for irrigated agriculture
Shallow and/or rocky soils	30%	50%	(Various)	Very shallow to shallow <0.5m. Usually sandy or loamy, but may be clayey. Generally weakly developed soils that may contain gravel	Crests and slopes of hilly and dissected plateaus in a wide variety of landscapes	Negligible agricultural potential due to limited soil depth, poor water-holding capacity and presence of rock
Sand or loam over sodic clay subsoils	<1%	<1%	Sodosols	Strong texture contrast between the A and B horizons; A horizons are usually bleached. Usually alkaline but occasionally neutral to acid subsoils. Moderately deep to deep	Lower slopes and plains in a wide variety of landscapes	Generally low to moderate agricultural potential due to restricted drainage, poor root penetration and susceptibility to gully and tunnel erosion.

Table A1 Continued.

WA soil group[a] overview	% Area		Australian Soil Classification[b]	General description	Landform	Major management consideration
Cracking clay soils	15%	9%	Vertosols	Clay soils with shrink-swell properties that cause cracking when dry. Usually alkaline and moderately deep to very deep	Floodplains and other alluvial plains. Level to gently undulating plains and rises (formed on labile sedimentary rock). Minor occurrences in basalt landscapes	Generally moderate to high agricultural potential. The flooding risk will need to be assessed locally. Many soils are high in salt (particularly those associated with the treeless plains). Gilgai and coarse structured surfaces may occur
Highly calcareous soils	9%	<1%	Calcarosols	Moderately deep to deep soils that are calcareous throughout the profile	Plains to hilly areas	Generally moderate to low agricultural potential depending on soil depth and presence of rock

a – WA soil group (Schoknecht and Pathan 2012)

b – Australian Soil Classification – Isbell *et al*. (2016)

From Section 4.1 'A guide to animal nutrition and expected growth rates from irrigated tropical pastures' by Dennis Poppi

Table A2. A summary of cattle growth rates on tropical pastures in northern Australia

Agro-climatic zone (location)	Pasture type	Irrigated (I) or Dryland (D)	Cattle type	Average entry weight	Number of head	Days on pasture (time of year)	LWG (kg per head per day)	Source
Low rainfall coastal (La Grange)	Rhodes grass	I	*B. indicus*	268kg	684	68 (Feb-April)	0.71 (0.55-0.88)	Station records
			B. indicus	394kg	776	60 (Sept-Nov)	0.61	
Low rainfall coastal (La Grange)	Rhodes grass	I	*B. indicus*	242kg	263	54	0.74	Station records
			B. taurus X	294kg	549	76	0.51	
High rainfall (Ord)	Pangola grass + leucaeana	I	*B. indicus* X	213kg	15	70 (dry season)	0.73	Petty et al. (1998)
			B. indicus X	213kg	15	98 (wet season)	0.60	
High rainfall (Ord)	Pangola grass + leucaeana	I	*B. indicus* X	252kg	10	92 (Aug-Nov '94)	0.71	Petty and Poppi (2012)
High rainfall (Ord)	Pangola grass	I	*B. taurus*	130kg	5	224 (Nov-Sept)	0.46	Blunt and Jones (1977)
High rainfall (Ord)	Pangola grass	I	*B. taurus*	127-146kg		12 months (Dec-Nov)	0.5-0.55	Blunt (1978)
High rainfall (Ord)	Forage sorghum	I	*B. taurus*	297kg		26 weeks (May-Nov)	0.41	Blunt and Fisher (1973)
High rainfall (Ord)	Oats	I	*B. indicus* X	282kg		14-19 weeks (June-Oct)	0.52-0.68	Blunt and Fisher (1976)
(South-east Queensland)	Setaria, Rhodes grass + setaria, pangola grass	I	*B. indicus*	203-272kg	4-6	90-180	0.58-0.96	D. Poppi unpublished various experiments
(Central Queensland)	Buffel grass	D	*B. indicus* X	160-169kg	6	120	0.96-1.03	McLennan (1997)

Glossary of abbreviations

ADF – acid detergent fibre

BoM – Bureau of Meteorology

CP – crude protein

DBCA – Department of Biodiversity, Conservation and Attractions

DPIRD – Department of Primary Industries and Regional Development

DM – dry matter

DMD – dry matter digestibility

DOMD – digestible organic matter in the dry matter

DWER – Department of Water and Environmental Regulation

kg/ha – kilogram per hectare

kg DM/ha – kilogram of dry matter per hectare)

LWG – liveweight gain

ME – metabolisable energy

MJ – megajoules (energy)

NDF – neutral detergent fibre

NDVI – normalized difference vegetation index

NIR – near infra-red reflectance

NT – Northern Territory

NPN – non-protein nitrogen

PBR – Plant Breeder's Rights -

PLB – Pastoral Lands Board

ppm – parts per million

VPD – vapour pressure deficit

WA – Western Australia

WSC – water soluble carbohydrates

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