IRRIGATED MAIZE PRODUCTION IN THE TOP END OF THE NORTHERN TERRITORY

PRODUCTION GUIDELINES AND RESEARCH RESULTS

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INTRODUCTION

Maize, which is a native of Mexico, is one of the oldest and most productive cereal food crops. It is the third most planted crop after wheat and rice. However, with approximately 600 million tonnes produced each year, it is the leading cereal in terms of production. It is grown throughout the world for human and animal consumption. The Food and Agriculture Organisation of the United Nations estimates the demand for maize for human and animal consumption will increase by nearly 300 million tonnes by 2030, which does not include the increased demand for bio-fuel production.

Maize is being increasingly used for industrial purposes, such as the production of starches, bio-degradable plastics and ethanol. In the US, the price of maize (corn) doubled between 2006 and 2007 due to an increasing demand from the ethanol industry. Maize is still a minor crop in Australia, but is gaining prominence due to its high yield potential and many uses. The use of maize in bio-fuels is increasing each year to feed a rising demand for alternative fuels.

Maize was grown by the first white settlers in the Northern Territory (NT) as far back as 1824. Research in rain-fed (dryland) maize began in 1954 in the NT when the Animal Industry and Agriculture Branch of the NT Administration conducted trials at Berrimah, Batchelor and Tortilla Flats. Trials continued until 1963. However, yields were variable due to weeds, waterlogging, seed-set failures and diseases such as “wallaby ear” virus (WEV).

Dryland maize trials were conducted at Douglas Daly Research Farm (DDRF) from the early 1980s to the early 1990s. DDRF is located at the junction of the Douglas and Daly Rivers, (13º50´ S, 131º45´ E, altitude < 200 m), 220 km south-west of Darwin. Commercial maize production was supported by the NT Government as part of its policy to promote agriculture in the north (Agricultural Development and Marketing Authority). Commercial dryland maize was grown in the Douglas Daly region for about 12 years but crops invariably suffered from high soil temperatures at emergence, nutritional deficiencies and moisture stress at flowering. Many of the nutritional deficiencies, establishment and soil temperature related problems were experienced on the lighter sandy-surfaced soils. Maize generally performed better on the heavier clay loams due to their higher nutrient and moisture-holding characteristics. Paddock yields of 4.0 to 5.0 t/ha were recorded but the average yield for the region was approximately 3.0 t/ha. Cattle, pasture and hay crop production largely replaced grain production in the region in the mid 1990s.

Maize is essentially a warm season rather than a hot season crop. It is not well-adapted to the harsh, hot conditions in the Top End during the wet season. Although it performed poorly under rain-fed conditions in the NT, maize yields of over 10.0 t/ha were achieved under irrigation in Katherine and Kununurra in the 1980s (Muchow 1989; Warren 1982). The first commercial irrigated maize was produced in Katherine in the early 1990s on what was then known as Hickey’s Farm. Grain yields of between 9.0 t/ha and 11.2 t/ha were reported. Maize silage has been produced for several years on what was formerly Rowland’s Dairy at Katherine.

The Department of Primary Industry, Fisheries and Mines (DPIFM) conducted a four-year (1999-2002) evaluation of irrigated maize on “Blain” soil (sandy textured red earth) at DDRF. The objective was to identify the best adapted varieties and determine the agronomic requirements for producing dry season irrigated maize in the NT. The trials confirmed the potential of irrigated maize with yields approaching 13.0 t/ha. The average yield for all varieties over four years was 9.3 t/ha.

Maize is one of the most researched crops and a lot of information is available on its production and management. This Technical Bulletin is not intended to replace available information. It is intended to provide information relating specifically to management issues of dry season irrigated maize production in the Top End to assist those who wish to grow the crop in this environment. Many of the guidelines in this Technical Bulletin are based on results obtained from a four-year trial (see details of the trial in Appendix 3).

SELECTING A SUITABLE VARIETY

Selected maize varieties should have a high yield potential, good disease and insect tolerance, good resistance to lodging and a maturity length to suit environmental conditions. A medium maturity variety is a good compromise between yield and water requirement. Tight husk covers offer resistance to heliothis caterpillars. Table 1 lists the varieties which performed well in evaluations under irrigation at DDRF. New improved varieties are being constantly developed and information on them can be obtained from commercial seed companies and DPIFM.

Table 1. Maize varieties trialled and recommended for commercial irrigated production in the Top End

Variety	**Uses**	**Maturity (days to relative maturity)**	**Resistance to disease, insects and lodging**	**Husk cover**	**Average trial yields* (t/ha)**
Pioneer 3237	Feed and silage	Medium (116-120 days)	Good	medium tight	10.9 three trials
Pioneer 3153	Feed and silage	Medium (116-120 days)	Good	tight	10.4 three trials
Hycorn 424	Feed and silage	Medium quick (113-115 days)	Good	medium closed	11.3 two trials
Hycorn 901	Feed and silage	Medium (116-120 days)	Good	tight	11.6 one trial
Pacific 675	Feed and silage	Medium (116-120 days)	Good	medium tight	12.7 one trial

*Yields taken from 0.5 ha, machine harvested irrigated trials at DDRF from 1999 to 2002.

The major disease of concern at present in the NT is WEV, which causes stunting and a dramatic reduction in yield. It is transmitted by leaf-hoppers which inject a toxin while feeding on the plant. There are no varieties that are resistant to WEV. Disease prevention is through pre-treating the seed with a systemic insecticide to reduce the build up of the leaf-hopper vector.

Queensland and NSW have diseases such as Johnson grass mosaic virus, leaf blights and rusts. These diseases are not prevalent in the NT at present due to the limited areas of maize production.

SOIL TYPE AND LAND PREPARATION

Maize will grow in the NT on most soils in the dry season provided sufficient moisture and nutrients are available. However, it will perform best on fertile, friable and well drained soils with a pH range of 6.5 to 7.5. Maize is suited to the red-earths, including sandy Blain and Oolloo soils as well as the heavier Tippera and Tindal clay loams.

Maize can be sown conventionally into a fully cultivated seed bed or sown zero-till into mulch. The method will depend on soil type and condition, availability of machinery, grower preference and experience.

Seed should be planted at a uniform depth of 3.0 to 4.0 cm into moist soil. Sufficient soil cover and firm seed-soil contact is required for optimum establishment. Rolling the soil or using press-wheels will enhance emergence provided the soil surface is kept moist until seedlings have emerged.

Compacted furrows (in red earth soils) that dry out prior to emergence will crust and impede establishment. If the soil is rolled or the furrows are compacted with press-wheels, the soil surface should be kept moist until all seedlings have emerged. Crusting can be a problem on Tippera clay loam soils under conventional tillage.

Figure 1. Press-wheels such as “twin inclined” will assist germination on red soils provided the surface remains moist until emergence

Figure 2. Oolloo soil is a free draining sandy loam red earth

PLANT POPULATION, PLANTING RATE AND ROW SPACING

Achieving an optimum plant population is one of the most critical aspects of maize production. A survey of 549 maize producers in the US found that most believed that **plant population** and **nitrogen** were the two most important factors in determining crop performance (*Pioneer Seeds Maize Workshop Notes*).

Sowing rate is determined by the desired population, germination percentage, the expected establishment rate, row spacing and the number of seeds per kilogram. Seed size varies from 4400 (small) to 2500 (large) seeds/kg. Seed is separated into round and flat grades. Refer to the bag for an exact seed count and germination percentage (minimum germination specified is usually no less than 85%). Not all seeds planted will germinate and establish so planting rate needs to account for these losses.

Seed companies recommend plant populations for specific varieties and conditions. The better the growing conditions, the higher the plant population recommended. A population of between 70 000 and 85 000 plants per hectare is generally recommended for fully irrigated maize, depending on variety.

Row widths of 75 cm or 90 cm are the most common and must match harvest machinery. In the NT, 75 cm rows are preferable for quicker canopy closure, reduced soil surface evaporation and suppression of weeds. There is a trend to reduce row widths to 50 cm in many areas. Trials in the US and in Australia have shown yield improvements of 5% to 10% with narrow rows in some instances. The benefits of narrow rows are generally achieved under good growing conditions and in irrigated crops.

Table 2. Sowing rate and seed spacings for different sized seed at 90 cm row spacing

Desired plant population/ha	Number of seeds/kg				Average seed spacing (cm)
	2500	3000	3500	4000	
	Sowing rate (kg/ha) for respective seed sizes				
50 000	24	20	17	15	19
60 000	28	24	20	18	16
70 000	33	27	24	21	13
80 000	38	31	27	24	12

Note: Average seeding rates based on 85% germination rate and 100% emergence rate

The following calculation can be used to determine the sowing rate:

Sowing rate = desired population ÷ seeds/kg ÷ germination% ÷ emergence%

Sowing rate:

- Sowing rate = seed planted (kg/ha)
- Desired population = target number of plants per hectare (e.g. 75 000)
- Seeds/kg is indicated on the seed pack (e.g. 3000)
- Germination % is indicated on the seed pack (expressed as a decimal e.g. 85% is 0.85)
- Emergence % is the percentage of seeds that actually emerge to become viable plants e.g. 90%

Working example:

Sowing rate = 75 000 (desired plant population) ÷ 3000 (seeds/kg) ÷ 0.85 (minimum germination %) ÷ 0.90 (establishment %)

Sowing rate = 32.6 kg of seed/ha *(for a population of 75 000 plants per hectare)*

Uniform establishment and evenly spaced plants are critical for achieving high yields. Gaps or crowded plants will reduce crop yield. Using purpose built, precision row-crop machinery is necessary for establishing optimum plant stands.

Different planters will give different establishment results. Modern row-crop planters will give field establishment rates of up to 90% or greater. Older machinery may only give 50 to 60% establishment and therefore higher rates of seed will be needed.

Calculating seed spacing along the row

This calculation is used to calibrate the planter to sow at the required rate:

Distance between seeds in a row (m) = (10 000 ÷ row width (m)) ÷ (sowing rate (kg/ha) x (seeds/kg)

Working example:

- Seed required = 32.6 kg
- Seeds/kg = 3000
- Row width (m) = 0.9
- Square metres /ha = 10 000

Distance between seeds (m) = (10 0000 (Sq m/ha) ÷ 0.9 (row width)) ÷ (32.6 (sowing rate) x 3000 (seeds/kg))

Distance between seeds = 0.11 m or 11 cm (each seed should be 11 cm apart)

When precision planters are calibrated correctly, seeds will be spaced evenly along the row at a specific distance to achieve the desired population. If seeds are closer or more widely spaced than the specified distance, the planter may need re-calibration. Seed companies supply charts which specify seed spacing for different row widths and populations.

Figure 3. Optimum and uniform plant stands are critical for achieving high yields of maize

Key points:

- **Optimum plant population is one of the most critical aspects in achieving top maize yields**
- **70 000 to 85 000 plants/ha is optimum for most irrigated maize varieties**
- **Narrow row spacings will assist in moisture conservation, weed suppression and enhanced yields.**

TIME OF PLANTING

Maize can be grown as a rain-fed (i.e. dryland) wet season crop, a supplemented irrigated crop or a fully irrigated crop.

Rain-fed crops are planted in mid to late December and harvested in late April. They rely solely on seasonal rainfall, which is intense, with intermittent periods of moisture stress. The duration and timing of the dry spells will largely dictate crop yield. If late February/March is dry (i.e. coinciding with tasselling and fertilisation) yield will be significantly reduced.

Managing nutrients and weeds is also a challenge due to the potential for intense rainfall to leach fertiliser and herbicide out of the root zone. As a result maize is recommended for the heavier clay loam soils due to their better moisture holding capacity and nutrient retention. Rain-fed maize is recommended for the Douglas Daly area and north due to better seasonal rain reliability. Rain-fed maize yields have been historically low in the Top End. However, maize has potential as a dryland crop if it is grown on the best soil types with careful attention to varietal selection and agronomy.

Supplementary irrigated crops can be planted from December through to late January. February is the wettest month in the Top End and in many seasons access to land during this period is restricted. This means to take advantage of February and March rainfall, crops need to be established by mid January before conditions get too wet. Irrigation will then be required in late March to April to finish-off the crop. One or two irrigations may be required depending on duration of the wet season.

Fully irrigated crops are planted at the end of the wet or early dry season, (late February to early April) depending on seasonal conditions. Apart from some residual soil moisture remaining from the wet season, the crop is entirely reliant on irrigation throughout the growing season. Planting while temperatures are high and there is residual moisture helps to ensure that the crop establishes quickly and may save on initial irrigation costs. Early dry season planted crops mature in the coolest part of the dry season (July/August), reducing heat stress, respiration losses and total crop water requirement.

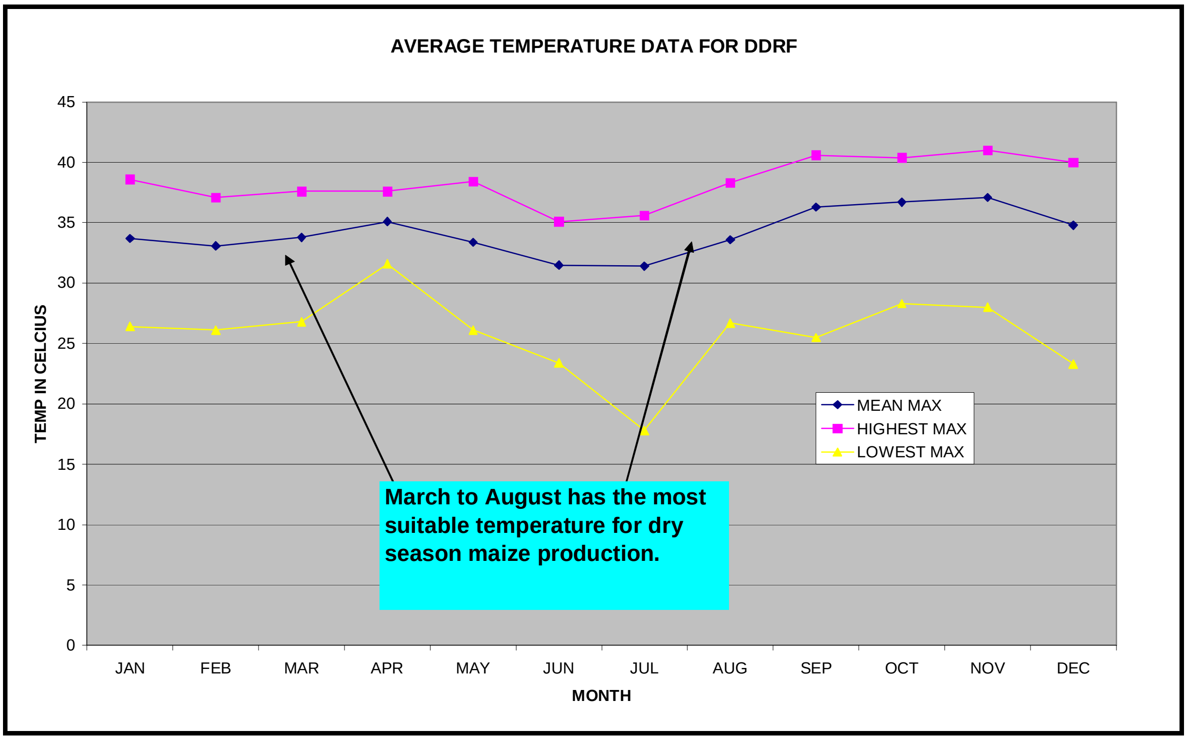


Figure 4. Mean, highest and lowest maximum temperatures at DDRF (1968-1999)

Planting maize in May or June means the crop will mature in the hottest time of the year (late September to October) when evaporative demand and respiration losses are highest. The ideal day time temperature for maize is between 25°C and 32°C which coincides with mid-dry season temperatures. August has the highest number of sunshine hours (> 300 per month), which promotes high crop productivity. After August, temperatures increase beyond the optimum range and heat stress can affect the crop.

Research in the US has shown that moisture or fertility stress at tasselling through to pollination can reduce yield by 8% to 13% each day stress occurs. Water stress accelerates the maturation process resulting in smaller grains and lower yields. Temperatures above 32°C at pollination can result in kernel abortion. September and October temperatures may be as high as 38°C to 40°C in the Daly and Katherine regions. High night time temperatures also reduce maize yields by increasing respiration losses.

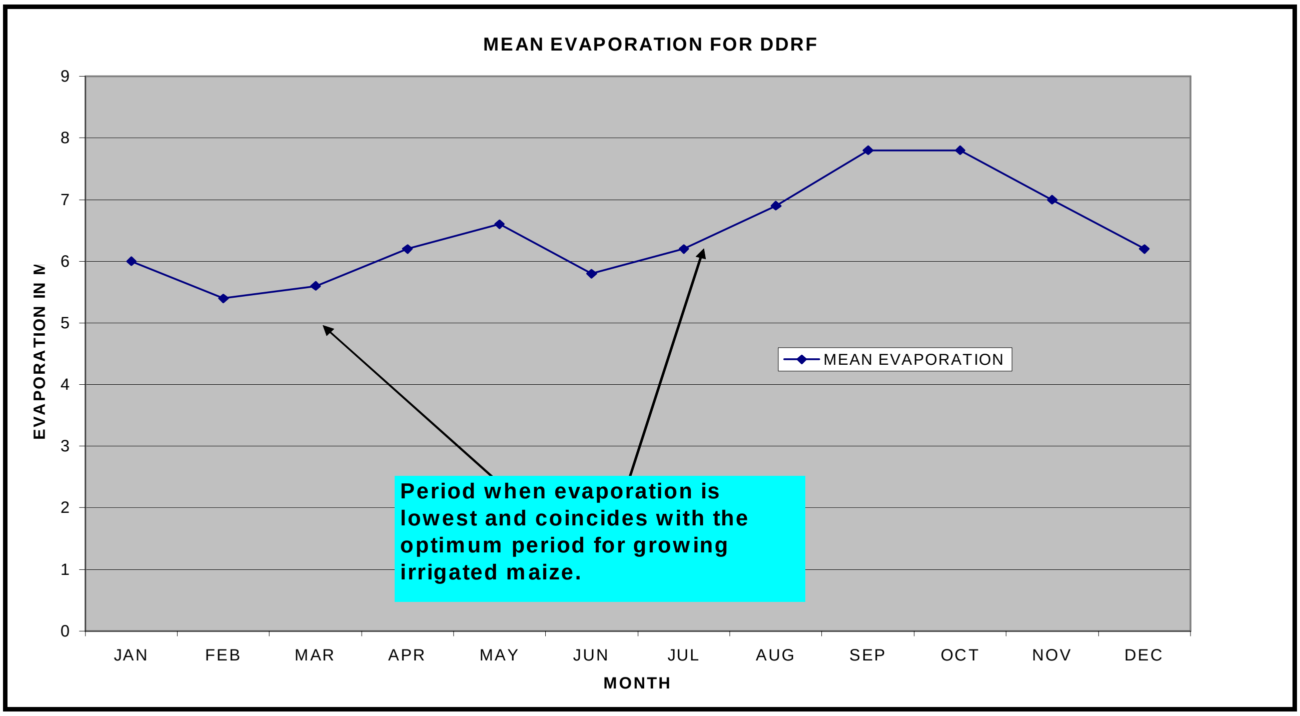


Figure 5. Average daily evaporation at DDRF (1968-1999)

ARE TWO MAIZE CROPS PER YEAR POSSIBLE?

In theory, growing two maize crops in 12 months is possible using irrigation. However, there will be logistical and agronomic problems to overcome. Provided agronomic issues are well managed, it may be possible to plant a supplementary irrigated or rain-fed crop in November to December and a dry season (fully irrigated) crop in late April or May.

Double-cropping may be an economic imperative due to the capital cost of establishing, running and maintaining irrigation infrastructure. It also makes more efficient use of natural resources (soils, wet season rainfall, solar radiation and land), machinery and labour units.

Peanut producers trying to double-crop found that wet season crops had relatively low yields and often compromised the planting of the dry season crop. Due to the variable conditions in the wet season, maize crops are likely to have lower yields than dry season crops. Intermittent dry spells, water-logging, lower radiation levels, above optimum temperatures and the difficulty in managing nitrogen nutrition and pests are factors which may contribute to lower wet season maize yields.

Research by CSIRO in Katherine showed that maize yields were not significantly different when planted on October 10, February 6 and August 20. However, maize crops planted before early November will mature in the wet-season making dry-down and harvest almost impossible.

Research in the US has shown that growing maize after maize reduces yields by between 10% and 20% compared to maize which follows soybeans, even when high rates of nitrogen are applied to the second maize crop. Similar results were reported by CSIRO's early research at Katherine when sorghum was grown after sorghum. Clearly there are several unexplained factors at work and these issues have not been researched recently in the NT. The performance of double-crop maize in the NT is still an unknown.

The objective of double-cropping should be to maximise economic returns without compromising the performance of either crop or the degradation of natural resources. Planting at the optimum time and maintaining viable yields while avoiding soil degradation will be some of the challenges for double-cropping in the NT.

Double cropping will only be successful when the following agronomic and resource issues are effectively managed for both crops:

- Stubble management
- Planting on the optimum dates
- Managing nutrient and water requirements for each crop
- Insect, disease and weed pressure and their changing dynamics
- Water allocation and irrigation requirements
- Conserving soil, its health and fertility
- Managing labour units and equipment
- Developing a farming system which reduces farm inputs and enhances yields
- Finding suitable rotation crops.

Key points:

- **Maize is a warm season crop and is not suited to extended periods of hot weather and moisture stress**
- **Planting in early dry-season allows the crop to mature under mild conditions, reducing water demand and irrigation costs**
- **Mild day and night temperatures at pollination and grain fill will enhance grain size and yield**
- **Two crops per year may be a possibility provided many of the timing and logistical issues are managed.**

NUTRITION

Maize is a high input crop and requires good nutrition and adequate moisture to achieve high yields. The amount and type of nutrient required for a maize crop will be determined by:

- Previous cropping/fertiliser history
- Expected yield and management
- Soil type, pH, condition and soil test result.

If fertiliser history is good or legumes have been grown, the amount of applied nutrients may be reduced in some instances. Regular soil testing will help determine the level of nutrient required and reduce possible deficiencies or over application. Foliar analysis will also assist nutrient management.

Nitrogen (N) is the most limiting element in maize production and is taken up in the greatest quantity.

Phosphorus (P) and potassium (K) are the next major elements required and also taken up in large quantities. N, P and K account for about 83% of the total nutrients taken up. Sulphur (S), calcium (Ca) and magnesium (Mg) make up another 16%. Trace elements such as zinc (Zn), copper (Cu), molybdenum (Mo) and boron (B) make up about 1% of the nutrients taken up. The trace element content of Territory soils is low especially on the sandy red earths. Maize is particularly sensitive to Zn deficiency and addressing low levels is essential for viable production.

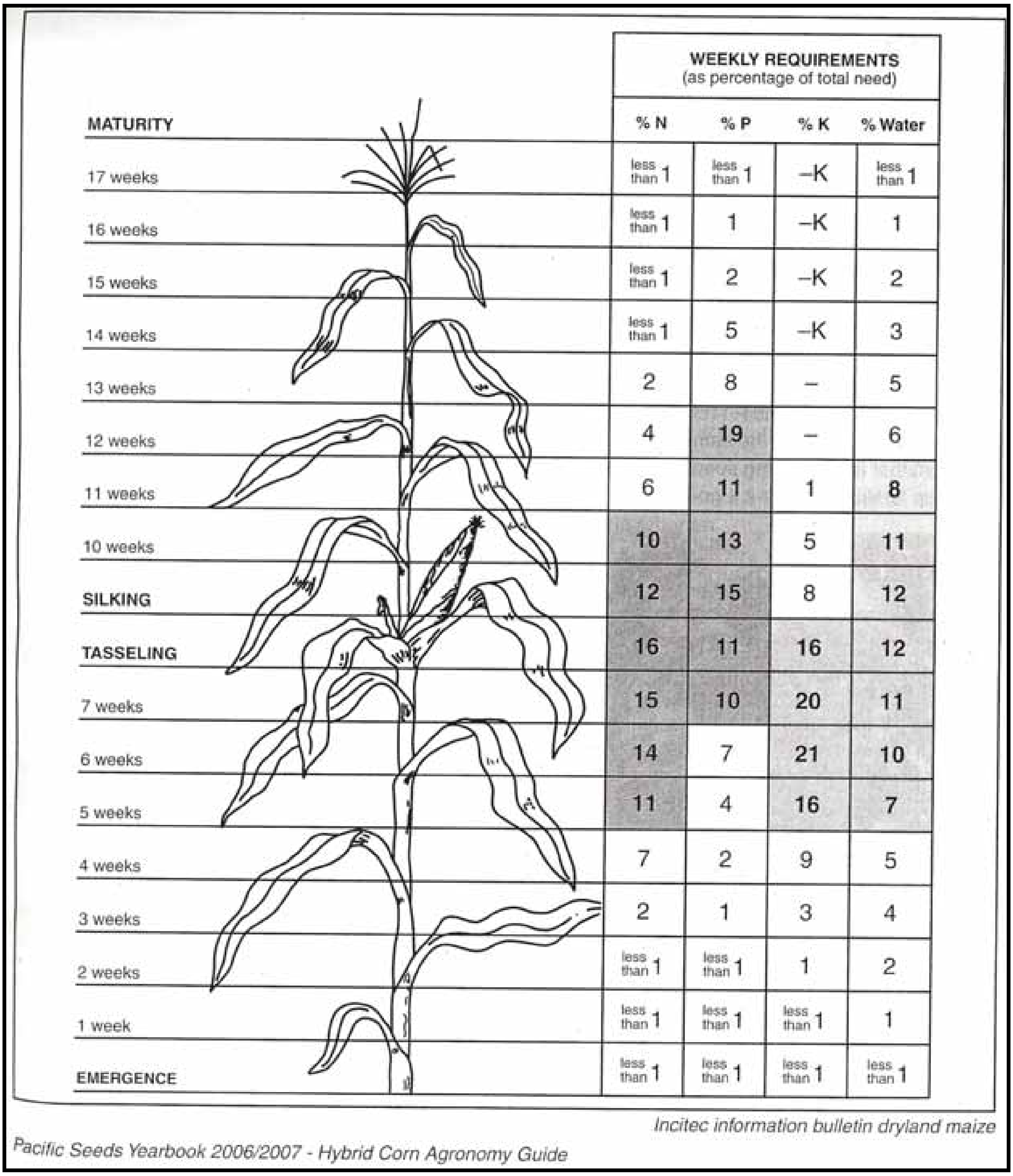
Nutrients need to be balanced to ensure they are available in the required quantities at the right time. Once a deficiency is identified in maize, yield will have already been affected. If one essential nutrient is lacking yield will be reduced regardless of how much other nutrients are applied.

This is referred to as the “law of the limiting” where a crop will only grow as well as the most limiting factor allows it. Research in the US has shown an interaction between P and Zn. When both the P and Zn were low, the addition of either P or Zn alone had no effect. However, applying both elements resulted in an increase in maize yield.

NITROGEN (N)

Adequate N is critical in achieving high yields. N deficiency will result in pale stunted plants with a typical V-shaped yellowing running from the tip of the leaves. N is the building block of plant material and protein. A 10 t/ha grain crop will contain about 160 to 180 kg/ha of N in the grain depending on grain protein. Another 100 kg/ha of N will be taken up in the stover.

The total quantity of N required to grow a maize crop is approximately 1.6 times the amount taken off in the grain. The yield and the protein level of the grain will determine N removal. A 10.0 t/ha crop with a grain protein level of 10% will remove 160 kg of N per hectare. The requirement for the entire crop (grain and stover) will be 160 X 1.6 = 256 kg N. This guide will work for any yield assuming a grain protein of around 10%.



	WEEKLY REQUIREMENTS (as percentage of total need)			
	% N	% P	% K	% Water
MATURITY				
17 weeks	less than 1	less than 1	–K	less than 1
16 weeks	less than 1	1	–K	1
15 weeks	less than 1	2	–K	2
14 weeks	less than 1	5	–K	3
13 weeks	2	8	–	5
12 weeks	4	19	–	6
11 weeks	6	11	1	8
10 weeks	10	13	5	11
SILKING	12	15	8	12
TASSELING	16	11	16	12
7 weeks	15	10	20	11
6 weeks	14	7	21	10
5 weeks	11	4	16	7
4 weeks	7	2	9	5
3 weeks	2	1	3	4
2 weeks	less than 1	less than 1	1	2
1 week	less than 1	less than 1	less than 1	1
EMERGENCE	less than 1	less than 1	less than 1	less than 1

Figure 6. Maize growth periods and nutrient uptake

N needs to be available immediately after germination for vigorous establishment. From week 4, maize takes up large quantities of N and grows rapidly. During weeks 5 to 10, maize takes up approximately 80% of its N requirement. If N runs low during this period, yield will be significantly reduced. At peak growth rates, maize takes up 4.0 kg/ha/day of N.

N application will be determined by the target yield, cultivation practice, mulch levels and the previous crop. Zero till crops generally require more starter N than conventionally planted crops due to N tie-up in the mulch.

Research in the NT has shown that a legume pasture phase can contribute between 42.0 and 136.0 kg/ha of N, depending on length of pasture phase, soil type, pasture use and seasonal conditions. Growing legumes in rotation will help reduce N fertiliser requirement. A soil analysis should be conducted to ascertain N content and determine how much fertiliser is required to meet target yield. Leaching of N in sandy soils can be very high (over 80.0 kg/ha) over the wet season, so this needs to be considered when calculating fertiliser rates for irrigated dry season crops on light soils.

Figure 7. N deficiency (light stunted plants) due to uneven application of fertiliser

PHOSPHORUS (P)

P is often the second most limiting nutrient in Top End soils. P is active in plant cells and assists in chemical and energy transfer within the plant. It is critical for early crop development and growth, because young plants have a higher requirement for P than older plants. A 10.0 t/ha grain crop will take up between 40.0 and 50.0 kg/ha of P and will have taken up 30% of this prior to tasselling. While P is taken up continuously, a deficiency will show up before the crop is about 65 cm tall.

Maize grown on light soils often shows an early P deficiency unless the crop has been banded with a P based fertiliser. Banding fertiliser close to the seed is more efficient as it reduces soil P fixation and allows the plants to pick up nutrients immediately after germination. As P does not leach, all of the phosphorus can be applied prior to planting. Phosphorus deficient plants are darkish green with purple colouration on the leaf edge and on the stems. Crops suffering from phosphorus deficiency are slow to develop and will have delayed silking.

POTASSIUM (K)

K is taken up in quantities second only to that of N. A 10.0 t/ha maize crop (grain and stover) will take up over 200.0 kg/ha of K. Light sandy soils such as Blain and Ooloo have low levels of exchangeable K and will require some K fertiliser. K is important for circulation of sugars, cell division and aids in diseases resistance. It also regulates water control in the plant which is critical for healthy crop growth.

Maize will have taken up 50% of its K requirement by week 8 and 75% by silking (week 9 to 10). The rate of uptake increases rapidly in the three weeks prior to silking so adequate K must be available during this period. K deficiency symptoms are usually seen on the lower leaves which have yellow-necrotic (dead) edges.

SULPHUR (S) AND MAGNESIUM (MG)

S and Mg are secondary nutrients and are taken up in relatively large quantities, although less than N, P and K. S is an essential part of plant proteins and is a constituent of many amino acids, vitamins and enzymes. S requirement is usually addressed when applying super-phosphate or other blended fertilisers. Much of the S is derived from organic matter in the soil and mineralised S forms. An S deficiency will also appear as pale green to yellow foliage similar to that of an N deficiency.

Mg deficiencies are generally infrequent in dryland crops but high yielding irrigated maize crops will take up 5.0 kg to 6.0 kg of Mg per tonne of grain. Mg can be applied as dolomite or in magnesium sulphate fertilisers.

TRACE ELEMENTS

Trace element deficiencies are common on light textured alkaline soils in the NT. Maize is susceptible to Zn deficiency and most NT soils will require Zn prior to intensive cropping. Zn Cu, B, iron (Fe), manganese (Mn) and Mo are essential for optimum growth but are required in minute quantities. For example, maize requires about 16.0 kg to 19.0 kg of N per tonne of grain but only 10.0 g to 20.0 g of Zn per tonne.

High-yielding irrigated crops will require trace element application to compensate for low soil levels. Most trace elements can be blended with basal NPK fertilisers and banded below the seed. Trace elements can also be applied through the irrigation water either prior to planting or during the growing phase.

Applications of 5.0 to 10.0 kg/ha of Zn as zinc-sulphate, every two years will build soil zinc levels. Applying Zn (1.0 to 2.0 kg/ha as zinc-sulphate heptahydrate) and N through the irrigation water during the vegetative and prior to silking will assist in preventing deficiencies. This can be avoided by banding 'start-up' fertiliser containing N, P and Zn beneath the seed.

Figures 8 and 9. Early nutrient deficiency in young maize on sandy surfaced soils

NUTRIENT AVAILABILITY AND SOIL PH

Soil pH affects the availability of many plant nutrients. The natural soil pH of red earths varies from slightly acid to neutral (pH 6.0 to 7.0). However pH can vary with depth and may change due to management, fertiliser history and water application. Most of the essential nutrients are readily available over pH 6.0 to 7.0, but many trace elements are "tied up" when soil pH increases.

Many bores in the Top End are high in Ca and Mg carbonates and high in pH. Continuous irrigation with high pH water increases soil alkalinity and can induce Zn, Fe, Cu, Mn and to a lesser degree B deficiencies. This effect is referred to as lime induced chlorosis when Zn and Fe deficiency causes yellow striping between the leaf veins. Light soils have low buffering capacities and are particularly susceptible to increasing soil pH under irrigation. On a light soil in Katherine, pH increased from 6.5 to 8.5, which induced Fe and Zn deficiencies resulting in a substantial yield reduction in both sorghum and soybeans.

Applying acidifying fertilisers such as ammonium sulphate, mono-ammonium or di-ammonium phosphates will assist to counter the rise in pH. Monitoring soil pH will assist in nutrient management.

TIMING AND APPLICATION OF CROP NUTRIENTS

The correct timing of nutrient application is critical in achieving optimum growth and yields. Maize takes up nutrients even before the seedlings emerge. A large proportion of the crop's requirements should be applied before planting to ensure nutrients are available when needed. By week 10 (70 days after sowing) maize will have taken up over 80%, 53% and 88% of its N, P and K requirement, respectively. It will continue to take up N and P after silking.

All of the P, K, S and trace elements can be applied prior to planting. N is best applied as split applications. Applying two thirds of the crops N requirement at planting and the remainder two weeks before silking is recommended. Early research at Katherine Research Station found that 120.0 kg/ha of N, pre-plant and 60.0 kg/ha of N at both 35 and 70 days after sowing gave the highest maize yields on a Tippera clay loam. N fertiliser is easily applied in the irrigation water when required.

Fertiliser should **not** be placed in contact with the seed as maize is sensitive to fertiliser burn, especially on light soils. Only about 5.0 kg/ha of N and 10.0 kg/ha of P should be placed with the seed. Banding fertiliser **beneath and to the side** (Figure 10) is the safest and most efficient option. Banding allows higher rates to be applied and ensures an immediate supply of nutrients, promoting vigorous establishment and growth. All the P, S, trace elements and some N can be banded at planting. K can be broadcast and incorporated prior to planting. Urea, if used as a pre-plant fertiliser, must be incorporated into the soil either by cultivation or irrigation to prevent loss to the atmosphere. The balance of the N fertiliser can be applied as one or more applications in the irrigation water prior to silking.

From about 21 days after sowing (DAS), maize grows rapidly and takes up nutrients in increasing amounts. At about 42 DAS when there are 12 fully formed leaves, the number of seeds (ovules) and the eventual size of the ear are determined.

The most critical period in terms of yield potential for maize occurs from **about two weeks before silking** (46 to 49 DAS) to about **two weeks after silking** (77 DAS). A larger reduction in yield will result from moisture and nutrient stress at this time than at any other period. Ensuring all nutrients are in adequate supply during this critical period will help achieve maximum yield potential.

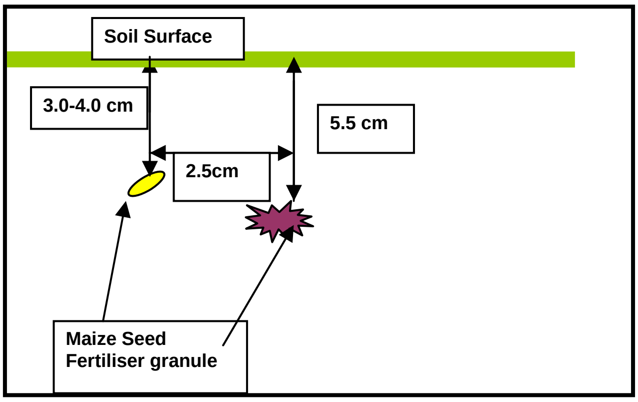


Figure 10. Schematic plan of fertiliser placement in relation to seed

FERTIGATION

Fertigation is the practice of applying soluble fertilisers through the irrigation water. It is an efficient way of applying many nutrients, particularly N. Maize in particular is suited to fertigation due to its tall stature and high demand for nutrients. The advantage of fertigation is that nutrients are applied at the appropriate time and level to maximise plant growth, reduce nutrient loss and avoid traffic over the crop.

Fertigation is an ideal way to split N applications and apply trace elements. Urea and ammonium sulphate are highly soluble fertilisers and can be dissolved with other nutrient such as Zn and B and applied at any time through the crop growth cycle.

Chemical and/or fertiliser injection systems shall not be installed into bore discharge lines without prior approval from the Controller of Water Resources.

Figure 11. Fertigation tank for applying nutrients in the irrigation water

Table 3. Nutrient uptake by maize crop (kg/ha)

	Yield (t/ha)	N	P	K	S	Mg
Grain	5.0	80	17	22	8	10
Stover	5 to 6	56	9	90	10	19
Total DM*	11.0	136	26	112	18	29
Silage	32 (wet)					
Grain	10.0	160	32	41	15	17
Stover	10 to 11	112	14	166	17	35
Total DM*	20.8	272	46	207	32	52
Silage	60 (wet)					
Grain	12.5	200	39	51	18	20
Stover	12 to 13	140	16	194	20	38
Total DM*	24	340	55	245	38	58
Silage	75 (wet)					

Table adapted from Pacific Seeds: Hybrid Corn Production Agronomy Guide 2006/7 (10% grain protein)
* Total DM (dry matter) refers to the combined dry matter yield of the grain and stover. Silage removes an equivalent amount of nutrients. Silage is usually harvested at 60 to 65% moisture resulting in high yields of forage/ha.

Key points:

- **Maize has a high nutritional requirement**
- **The period from week six to week ten is the most critical time in terms of nutrient requirement and yield determination**
- **Fertiliser inputs need to be balanced with soil fertility and yield expectation**
- **Optimum N and plant population are the keys to high yields.**

DISEASE AND INSECT CONTROL

Disease in maize in the NT is of relatively low importance compared to insect problems. This is in part due to the small areas in which maize is grown, but is mainly due to disease resistance of modern varieties. Nevertheless, there are several serious plant diseases which attack maize in the tropics because the environment encourages the growth and spread of plant pathogens. There are root, stalk and ear rots which can potentially cause economic damage to maize. However, foliar diseases such as leaf blights, spots and rusts are the most damaging in tropical environments.

Seed rots and seedling blights are usually caused by waterlogging or cool damp soil conditions. The main fungi which cause these diseases include *Pythium*, *Diplodia* and *Fusarium* species. These diseases are largely controlled by fungicidal seed dressing and good agronomic management.

Drought, waterlogging, late rain at maturity and nutrient stress predispose crops to disease. Irrigated dry season maize should not be subjected to these conditions so as to minimise disease. Planting the best disease-resistant varieties, adopting good agronomic management and controlling insect pests will minimise the incidence of disease.

Insect pests multiply and develop faster in the tropical Top End than in southern environments because of higher temperatures and humidity. As such, the management of insects and diseases should be a high priority. An **insect management plan** should be in place before planting. The plan should consider potential pests, beneficial insects, appropriate chemicals, pest control and application options.

SOIL INSECTS

Soil insects can cause up to 30 % plant loss and are potentially more damaging than pests which attack aerial parts. Soil insects are harder to detect and damage may only be seen as poor plant establishment. When damage is severe, re-planting is sometimes the only option.

There is a range of soil insects that attack maize seed and seedlings including **black field earwigs, false wireworms, cutworms and wireworms**. These insects damage germinating seeds and seedlings by chewing young roots and shoots below or on the surface of the soil.

The occurrence of soil pests may increase under minimum and zero-tillage practices because of a more favourable environment for both insects as well as plants. The absence of tillage and the maintenance of mulch results in fewer insects being killed and desiccated, increasing the potential for damage in conservation farming. However, a number of control options are available including insecticidal grain baits, in-furrow chemical applications, or seed treatments.

Developments in systemic insecticidal seed treatments have greatly improved the control of soil-borne insects and other pests such as mites, aphids and leafhoppers, which attack young crops. New seed treatments protect the seed and seedling for several weeks, allowing the plant to develop without damage. Gaucho® (imidicloroprid), Cruiser® (thiamethoxam) and other registered seed treatments are recommended for the control of soil pests and some above-ground insects. There are several advantages to seed treatment. The crop is protected from the time it is planted, chemical use is greatly reduced as it acts specifically on pest insects and the treatment eliminates the need for handling and applying pesticides for soil insects.

High quality treated seed is available from most reputable seed companies. Some market their products under specific brands such as Elite® (Pacific Seeds) and Betta Strike® (Pioneer Brand Seeds), to distinguish their highest quality seed. Seed treatment should be carried out under strict guidelines set down by chemical manufacturers to ensure quality, consistency and efficacy.

OTHER MAJOR PESTS

Leafhoppers are a serious economic threat to irrigated maize in the Top End if not controlled. Leafhoppers are one of the largest families of plant-feeding insects and are endemic in the Top End. They have piercing sucking mouthparts and feed on plant sap. The species which attacks maize (*Cicadulina bimaculata*) transmits wallaby ear virus (WEV).

WEV stunts maize plants and can reduce yields by over half. Leaves are characterised by having erect growth with pronounced veins. In severe cases, the crop may have to be ploughed out. Prior to the development of insecticidal seed treatments, the only option was to spray the insects. Several applications were often necessary. However, control of leafhopper can now be achieved with systemic insecticidal seed treatments such as Gaucho®.

Armyworms, heliothis (*Helicoverpa* spp.) and the green vegetable bug (GVB) can cause significant damage to irrigated maize, especially when they occur at the same time. Chemical control may be required in some seasons when pests reach damaging levels. Other insects include the corn aphid, mites, cutworms and various beetles, but these have not been of economic importance in the NT up to now.

Armyworms usually occur mid season when the crop is still vegetative. They feed in the whorl of the plant on emerging leaves, and it can be difficult for insecticides to reach them. Large maize plants can sustain considerable leaf damage before control is required. Armyworms can strip leaves back to the mid-rib and may have to be controlled if damage occurs to the tassels. Armyworms are best controlled in conjunction with other pests, such as heliothis and GVB.

Heliothis caterpillars usually invade the crop at silking. Moths lay pin-head sized white eggs on the silks and tassels. As the larvae grow, they feed on the tops of the young ears and work their way into the sheath, feeding on immature grain. Heliothis are generally more damaging than armyworms because they feed directly on the silks and immature grain. Priority should be given to controlling heliothis if there are more than two small larvae per cob. Caterpillars need to be controlled before they become too large. The ideal target size for control is when caterpillars are 3 mm to 7mm long.

GVB can be an economic pest of irrigated maize in some seasons. When wet season Cavalcade (legume hay) crops are harvested, GVB migrate into maize and other irrigated crops. GVB adults and nymphs feed on immature grain by piercing the seed with their proboscis (sucking mouth tube). When in large numbers, GVB distort the ears and prevent the grains from maturing.

Figure 12. Potato leafhopper adult and nymph, similar to the maize leafhopper
Photo by: Steve L. Brown, University of Georgia, www.forestryimages.org

Figure 13. Effects of WEV

Figure 14. Healthy plants on left and stunted plants on right, affected by WEV

Figure 15. Heliothis caterpillar

Figure 16. Green vegetable bug and eggs on maize

Figure 17. Northern armyworm damage

Figure 18. Heliothis (left) attacking ear and armyworm feeding on leaf

Figure 19. Trichogramma wasp parasite on heliothis egg (Photo, Brad Schultz, QDPIF)

Figure 20. Spider predating an insect

Figure 21. Assassin bugs feed on caterpillars

Figure 22. Ladybirds feed on aphids and other soft pests

CHEMIGATION FOR PEST CONTROL

Chemigation is the application of pesticides (insecticides, fungicides, herbicides etc) through irrigation water. A chemigator is a purpose-built device which accurately measures and injects the desired amount of pesticide through irrigation water on to the crop. It consists of a chemical tank and a precision pump, which is preset to a required dose per hectare. It has valves to prevent backflow and contamination of water supplies.

Chemigation is an effective way of applying certain pesticides and eliminates the need for expensive aircraft application. It allows the application of pesticides when insects are at an optimum size, thereby maximising control and minimising pesticide use. It also allows the use of 'softer' control options (biological insecticides such as Gemstar®) which target pests such as heliothis while minimising the impact on beneficial insects. In areas where aerial application is not an option, chemigation is probably the only effective late-season pest management option in maize.

The installation of chemigation units must meet relevant **environmental (water authority and pesticide-use) legislation.** Issues such as drift and volatilisation of chemicals must be managed appropriately. Legislation regarding chemical use and application methods changes from time to time. Therefore it is the responsibility of the operator to check local legislative requirements and label recommendations before applying any pesticide through an irrigation system.

Chemical and/or fertiliser injection systems in the NT shall not be installed into bore discharge lines without prior approval from the Controller of Water Resources.

Figure 23. Chemigation unit used for applying pesticides through irrigation water

Crop scouting

Crop scouting is essential for effective insect management and is required to identify the presence and size of both pests and beneficial insects. There is a range of predatory and parasitic insects which reduce pest numbers. Spiders, lacewings, ladybugs, shield bugs and predatory wasps play a role in regulating pest populations. In some seasons pests are controlled by beneficial insects without the need for chemicals. It is also important to detect pests before they become too large as small immature insects are easier to control and require less pesticide.

Scouting needs to be carried out every week and up to three times per week at silking and early grain fill. Silking is the most susceptible period because damage to silks reduces pollination and seed set. It is necessary to walk through the crop and inspect leaves, ears, silks and tassels at several locations.

The presence of insects does not necessarily mean the crop requires spraying. Insect numbers need to be sufficiently high and at a critical or threshold level (i.e. approaching economic damage) before spraying is warranted. The threshold level for specific pests is hard to determine at times as injury will depend on stage of crop growth and the presence or absence of other pests and beneficial insects. Developing experience with insect identification and damage is necessary. Assistance with insect management can be sought from a consultant, entomologist or Departmental agronomist.

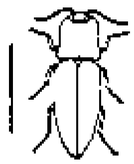
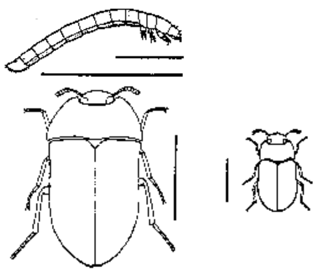
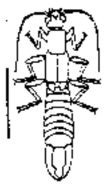
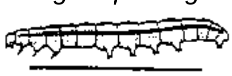
Figure 24. Insect scouting is an essential part of pest management in cropping systems

INTEGRATED PEST MANAGEMENT (IPM)

IPM is a strategy of pest management which uses a combination of biological, cultural and chemical methods to keep pests below economic injury levels, while reducing pesticide use and its impact on the natural environment. IPM includes selecting the best adapted varieties with resistance to insect and diseases, using protective seed dressings, planting optimum populations in narrow rows for weed suppression and monitoring the crop closely for pest and beneficial insects.

Using biological insecticides (Gemstar®) and pheromone traps to monitor pest populations (i.e. heliothis moths), and spraying only when pest levels approach economic injury level will assist in more efficient pest management. Relying on several integrated practices to control pests will give better results and improve overall crop performance.

Table 4. Insect pests of irrigated maize in the NT

Insect pest	**Growth period and damage**	**Comment and control**
Soil insects: wireworm, (click beetles) (Family Elateridae)  False wireworm, (pie dish) (*Gonocephalum* spp., *Pterohelaeus* spp.),  Earwigs*(Nala lividipes)* 	From planting until full emergence. Insects chew young roots, shoots and can prevent germination of seeds and reduce establishment in severe infestations. Soil insects can dramatically reduce plant populations if in high numbers. To detect them in the soil, grain baits are used to estimate numbers prior to planting. For more information on control of specific soil insects, see QDPI&F publication "Managing insects & mites in field crops, forage crops and pastures; Information Series QI92004."	Commonly used methods of control include **insecticidal grain baits** for control of adults, **seed treatment** and in-**furrow spraying** for control of larvae (and adults in some cases). *Germinating grain bait technique* Soak insecticide-free crop seed in water for at least 2 hours to initiate germination. Bury a small handful of the seed at shallow depth and cover it lightly with 1 cm soil Choose five widely spaced sites in each 100 ha; at each site, bury seed on the corners of a 5 m x 5 m square. Check for seedling emergence - once emerged, leave seedlings overnight. Dig up the entire plants the next day and put the plants on a tray to count insects. **If there are one or more insects (or five earwigs) per bait, then control is required.**
Leaf hoppers (various) *Cicadulina bimaculata* possibly *Chiasmus* sp. and *Orosius* sp. See text for damage caused.	From emergence through to week 5 or 6. Causes wallaby ear i.e. stunting and distortion and thickening of leaf and veins.	Seed treatment with a protective systemic insecticide (Gaucho®). Spraying insects one to two weeks after crop emergence is less effective.
Armyworms (*Mythimna separata)*	Late vegetative stage to silking. Defoliate plants and can damage flag leaf and silks.	Monitor population and natural biological agents. Apply registered insecticide or biocide.
Green vegetable bug *(Nezara viridula)*	Heavy infestations cause distortion of cobs and damage to individual kernels.	Monitor population and predation. Apply registered chemical when required. Time application to control other pests if possible.
Heliothis *(Helicoverpa armigera/punctigera)* 	Damage to silks and cobs.	Monitor presence and population. Apply registered insecticide or biocide and apply at appropriate growth stage.

Adapted from QDPI&F Summer Crop Management Notes 2005

Table 5. Insecticides registered for use in maize

Pest	Insecticide (active ingredient)	Trade name examples	Withholding period in days	
			Grain	Grazing
Armyworm	chlorpyrifos	Lorsban	10	2
	methomyl	Lannate L, Marlin	14	14
	trichlorfon	Dipterex	2	2
Heliothis	Gemstar	Nuclear polyhedrosis virus	ns	ns
	alpha-cypermethrin	Dormex	7	ns
	methomyl	Lannate L, Marlin	14	14
	trichlorfon	Dipterex	2	2
	cypermethrin	Cypermethrin 200	7	ns
	deltamethrin	Ballistic ULV	7	ns
	thiodicarb	Larvin 375	7	7
Green vegetable bug	deltamethrin	Ballistic ULV	7	ns
Cutworm	chlorpyrifos	Lorsban	10	2
	trichlorfon	Dipterex	2	2
Wireworm, other soil insects	chlorpyrifos	Lorsban in furrow spray or grain bait	10	2
	terbufos	Counter 150 g granular insecticide/nematicide	ns	ns
	Seed dressing	Seed dressing with Gaucho® Cruiser®		
Maize Leafhopper*	dimethoate	Rogor®	28	1
	Seed dressing	Seed dressing with Gaucho® or similar systemic insecticides.		

Adapted from QDPI&F Summer Crop Management Notes 2005 and APVMA web site: www.apvma@gov.au (ns = not specified)

- Gaucho is registered for soil and sucking pests in maize but also controls leafhoppers which transmit WEV.
- Always refer to the APVMA site for current registrations, products and labels as details may be subject to change and withholding periods can vary between crops. The use of a trade name as an example is not an exclusive recommendation of that product.

PESTICIDE USE AND CHEMICAL REGISTRATION

Due to continual changes in pesticide technology, use and legislation it is imperative to keep up to date with new developments and requirements. There are a number of databases which contain information on agricultural and veterinary chemicals. **The Agricultural Pesticides and Veterinary Medicines Authority (APVMA)** is an Australian government authority responsible for the assessment and registration of pesticides and veterinary medicines. It administers the National Registration Scheme for Agricultural and Veterinary Chemicals (NRS) in partnership with the States and Territories. The web site is www.apvma.gov.au The **APVMA** database is linked to the **Infopest** database which is operated by the Queensland Department of Primary Industry and Fisheries.

Infopest is a computerised database of all nationally registered agricultural and veterinary chemical products. It is available on CD ROM and is currently being developed for the web. The CD is produced by and available from QDPI&F GPO Box 46, Brisbane, Qld. 4001, email infopest@dpi.qld.gov.au

Key points:

- **Have a pest management plan prior to planting**
- **Buy seed treated with a systemic insecticide for leafhopper and soil insect protection**
- **Scout crop regularly to determine pest level, damage and beneficial insects**
- **Have ready access to suitable control measures**
- **Use the correct/registered chemical at the optimum time and consult national databases.**

WEED CONTROL IN MAIZE

Weeds compete for light, water and nutrients and can dramatically reduce yields. The type of crop and mulch level which precedes maize will determine the cultivation method, land preparation, sowing technique and weed control strategy. Weeds can either be managed by herbicides, cultivation or a combination of both. Herbicides combined with conservation tillage are an integral part of modern farming. Herbicides offer greater flexibility and more options for weed control. Conservation farming allows for timely planting and eliminates the need for cultivation. Continuous cultivation consumes considerable energy and leads to a decline in soil structure, a depletion of organic matter and predisposes the land to erosion. Soil conservation and organic matter preservation is a high priority in NT farming systems.

Conventional tillage systems use a combination of cultivation and herbicides to control weeds. Once weeds are killed with cultivation, the crop is planted into a clean seedbed. Pre-emergent, soil residual herbicides such as metolachlor (Dual®), pendimethalin (Stomp®), flumetulam (Broadstrike®), propachlor (Ramrod®), atrazine (Nu Trazine®, Gesaprim®, Atrazine®) can then be applied immediately after planting to control broadleaf and grass weeds. The choice of herbicide will depend on the weed spectrum. In many cases two herbicides will be used in combination to give a broader spectrum of control. An irrigation of 6.0 mm to 10.0 mm immediately after application will incorporate and activate the chemical while enhancing crop germination. The combination of metolachlor and atrazine in a commercial product (Primextra®) provided excellent weed control in maize trials at DDRF.

Inter-row cultivation or inter-row spraying with post-emergent herbicides such as picloram, 2,4-DB, dicamba, fluroxypyr are other options for in-crop weed control in conventional tillage systems. Post-emergent herbicides need to be applied at the correct crop and weed growth stages to prevent crop damage and achieve optimum weed control. There are specific restrictions and application procedures which need to be followed for each chemical. Inter-row cultivation also needs to be undertaken early to prevent damage to the roots and the crop. Using narrow row spacing (75 cm) also results in quicker canopy closure, better weed suppression and can, in some cases, enhance yield.

In **minimum or zero-tillage systems** (also called conservation tillage) crops are sown with minimum soil disturbance and herbicides replace cultivation as the primary means of weed control. Glyphosate is the principal knock-down herbicide in conservation tillage and one or two applications may be required to ensure all emerged weeds are controlled before planting. Glyphosate may be mixed with other herbicides to increase the spectrum of control. Once the crop is planted, post emergent herbicides are usually necessary for extended weed control. The choice of herbicide combination will depend on the weed spectrum.

Mulch management is a major consideration in conservation farming. Excessive mulch levels will interfere with the efficacy of herbicides and cause blockages at planting. Mulch “ties up” soil applied herbicides and nitrogen, especially when partially broken down. Managing mulch levels to allow ease of planting, maximise weed control and crop nutrition is critical to the success of conservation farming systems.

A relatively recent development in weed control in maize (and many other crops) is the introduction of the **CLEARFIELD®** production system. Clearfield Technology is a **system of weed management** which combines the use of imidazolinone-tolerant maize varieties and commercially-formulated herbicides. Maize varieties have been developed which are tolerant to imidazolinone herbicides. These are highly active residual herbicides which provide effective and extended control of many perennial grasses, broadleaves and nutgrass. Lightning® (imazethapyr + imazapyr), is the herbicide specifically registered for use in the Clearfield® system. The system is ideal for conservation tillage systems where broad spectrum, post-emergent weed control is required.

Figure 25. Conventionally tilled maize with pre-emergent herbicide showing excellent weed control

Figure 26. Row sweepers on a conservation tillage planter, which "sweep" the row clean of mulch to allow the seed to be planted without obstruction

WEEDS OF SIGNIFICANCE

The major weeds in irrigated maize crops include summer grasses (*Brachiaria*, *Digitaria* sp.), crowsfoot grass (*Eleusine indica*), *Pennisetum* sp. and barnyard grass (*Echinochloa colona*). Grasses compete strongly for water and nitrogen and will reduce yields if unmanaged. Grasses are best controlled with pre-emergent herbicides such as atrazine and metolachlor formulations i.e. Atrazine®, Dual® or Primextra® or by using Lightning® with varieties with the Clearfield Technology®. Inter-row spraying with shielded sprayers or cultivation is also an option.

Major broadleaf weeds include caltrop (*Tribulus terrestris*), senna (*Senna obtusifolia*) and *Sida* sp., *Hyptis*, nutgrass (*Cyperus rotundus*) and pigweed (*Portulaca* sp. and *Trianthema* sp.) A number of herbicides (atrazine, Starane®, Tordon 75-D® etc) are effective in controlling a range of broadleaves post-emergent. The timing of post-emergent herbicides is critical to achieve effective weed control and to prevent crop damage. Applying certain herbicides (2,4-D, dicamba) past a specific growth stage will result in permanent crop damage and significant yield reduction. Follow recommendations on timing of herbicide application to avoid crop injury.

Weed spectrum and weed dynamics are likely to change depending on farming practice, herbicides used and rotations. Minor weeds may become economically significant over time and some weeds may develop herbicide resistance. Rotating crops, herbicides and cultivation practice to manage herbicide resistance is a major challenge and should be a high priority in farming systems in the NT.

Table 6. Herbicides registered for post-sowing, pre-emergence weed control in maize

Chemical	atrazine	pendimethalin	s-metolachlor	s-metolachlor + atrazine	flumetsulam	propachlor	linuron
Trade name	Gesaprim	Stomp	Dual Gold	Primextra Gold	Broadstrike	Ramrod	Linurex

Adapted from QDPI&F Summer Crop Management Notes 2005

Table 7. Common herbicides registered for post-emergence broadleaf weed control in maize

Chemical	atrazine + wetter	atrazine + picloram (add wetter)	atrazine + fluroxypyr	picloram	picloram+ 2,4-DB amine	fluroxypyr	dicamba	mcpa	imazethapyr + imazapyr (see notes)	flumetsulam
Trade name	Gesaprim and other products	Gesaprim + Tordon 75-D	Gesaprim Starane and other products	Tordon 75-D	Tordon 75D + Amicide 625	Starane	Dicamba 500	MCPA 250	Lightning	Broadstrike

Notes: Lightning Herbicide must only be applied to maize varieties with **CLEARFIELD® Technology**
Adapted from QDPI&F Summer Crop Management Notes 2005 and APVMA web site: www.apvma@gov.au

Always refer to the container label for current registration and safety information. These details may be subject to change. Withholding periods can vary between crops. Check container labels for details.

Current national information on agricultural chemicals registered for use in maize is available on the Infopest CD-ROM. Write to GPO Box 46, Brisbane, Qld. 4001, email infopest@dpi.qld.gov.au

Key points:

- **Control weeds early and sow crop into a moist, weed-free seedbed**
- **Use correct herbicide and rate for weed spectrum and soil type**
- **Use optimum nutrition, plant population and narrow rows to suppress weeds**
- **Weed spectrum will change and resistance to herbicides will become more prevalent**
- **Be prepared to rotate herbicides and adapt management.**

IRRIGATION MANAGEMENT

The arable red earths of the Top End are suited to sprinkler systems (centre pivot/lateral move etc) due to their high infiltration rates (up to 180 mm/hour initially), low water-holding capacities and deep percolation. Flood irrigation on these soils results in erratic wetting and poor water distribution, causing unsustainable water loss due to deep drainage through the profile. There are several areas of black and grey clay soils in the NT which are suitable for flood irrigation. However, these are largely undeveloped for agriculture. Irrigated maize will be produced predominantly on the lighter soils under sprinkler systems until such time as the heavier soils are developed for agriculture.

An irrigated maize crop in the dry season will require between 5.0 and 7.0 ML/ha of water, depending on planting time, cultivar, soil type, seasonal conditions and irrigation efficiency. This equates to 500 mm to 700 mm of water applied through the growing season.

A crop sown in March will require less water than that sown in May because of lower evaporative demand in the earlier planted crop. Maize takes approximately 100 to 120 days to reach physiological maturity depending on variety and will usually require about 100 days of irrigation. Underestimating water demand will stress the crop and reduce yield, while overestimating water demand results in nutrient leaching, water logging and a waste of water and money. The full potential of maize will only be achieved when it is grown without stress throughout the season.

USING A WATER BALANCE APPROACH TO SCHEDULE IRRIGATION

Irrigation scheduling is the process of calculating the timing and volume of water required to meet crop demand and yield expectations. The simplest method to schedule irrigation is to calculate crop water requirement using a water balance technique similar to a check-book (i.e. with debits and credits). This method calculates water losses through evapo-transpiration and gains through irrigation and rainfall.

To use a water balance approach the following information is needed:

- Soil water-holding capacity and starting soil moisture.
- Daily evaporation rates.
- Effective crop root zone.
- Allowable soil moisture depletion.

Soil water-holding capacities for different soil types are usually provided by agriculture and natural resource agencies. Estimates of plant water use are commonly obtained using evaporation (referred to as pan evaporation) figures from a specifically designed US Class A evaporative pan. Pan evaporation measurements are recorded in **mm of evaporation** per day by weather stations and departments of agriculture. Douglas Daly Research Farm records daily evaporation.

Crop water demand is driven by temperature, humidity, solar radiation and wind speed. The combined evaporation from soil and transpiration from leaf surfaces is termed ***evapo-transpiration.*** High temperatures, clear sunny days and strong wind will cause high evapo-transpiration and thus a high crop water requirement.

Evaporation from a Class A pan closely approximates the evaporation rate from a reference crop. The reference crop usually refers to a well-watered, full-canopy grass sward. The daily evaporation figures are then used in conjunction with a **crop factor** to estimate daily crop water use. A crop factor is a fraction or ratio which estimates the difference between pan evaporation and the actual crop evapo-transpiration.

Young crops with a small leaf surface area use only a fraction of the daily pan evaporation rate and therefore have low crop factors (i.e. 0.2 to 0.5), reflecting low water use. A mature or fully vegetative crop will be assigned a higher crop factor (i.e. 0.9 to 1.1), to reflect higher water use. Crop factors of 1.0 or higher indicate that evapo-transpiration (crop water demand) is now equal to or greater than the daily pan evaporation. Water requirement can be estimated by:

Crop water requirement (mm) = Pan evaporation (mm) x crop factor (evapo-transpiration)

Example:

Pan evaporation per week = 49 mm (i.e. 7.0 mm/day)
Crop factor for maize not at full canopy = 0.7
Water requirement is 49 mm x 0.7 = 34.3 mm/week.

Crop water use will vary from week to week in line with variations in the weather. Evaporation rates can range from 5.0 mm to over 10 mm/day in September to November (Figure 23). When scheduling irrigation, take into account the variation in daily evaporation rates. The use of an average weekly evaporation figure can result in over or under estimating water demand. Tabulating daily evaporation is necessary to determine weekly crop use and to calculate the amount of water that needs to be replaced at the next irrigation.

Average evaporation rates in September to November appear moderate but daily temperatures are generally over 36°C. Evaporation rates range from 6.0 to almost 12.0 mm/day in the Katherine-Daly Basin. In contrast, temperatures from May to August are usually 33°C or less, with an evaporation range of 4.0 to 9.0 mm/day. One of the major considerations for irrigated crop production is the total number of days with temperatures over 35°C later in the dry season. From September to November, 23 days per month on average will have temperatures of 35°C or higher, which is above the optimum temperature range for maize production (25 to 32°C).

The Bureau of Meteorology provides comprehensive data on climatic characteristics for a number of locations in the NT.

Table 8. Crop factors for maize at different stages of growth

Days from planting	**Ave crop factor for the period**	**Physiology of the crop**	**Comment**
5 to 15	0.23	Early seedling growth, small leaves	Low moisture requirement
15 to 25	0.30	Increasing leaf and root extension	Increasing water demand and growth
25 to 40	0.5	Initiation of tassel and rapid leaf expansion. Initiating grain numbers	Rapid leaf and root growth and increased water demand
40 to 60	1.0	Formation of ear and tasselling	Full canopy cover and approaching maximum water use
60 to 95	1.1	Silking, fertilisation and early grain fill	Peak water demand and maximum shoot and root development. **Stress at this time will have more impact on yield than at any other time in the crop's life**
95 to 110	0.9	Grain filling and maturation	High water demand to fill grain
110 to 120	0.5-0.35	Late grain fill	Water requirement declining as grain reaches maximum dry matter

Figures adapted from FAO Irrigation and Drainage Paper 56

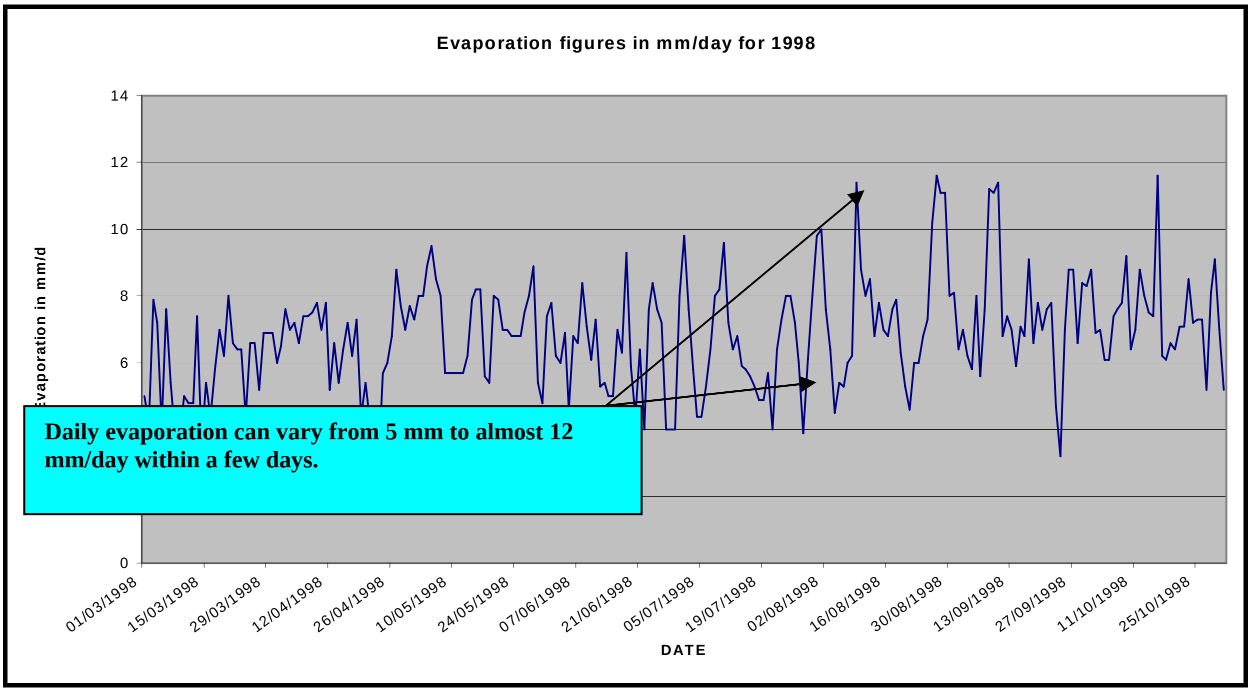


Figure 27. Daily evaporation rates (mm/day) from March to October 1998 at DDRF

Table 9. Average monthly evaporation at Douglas Daly Research Farm latitude 13°50'04"S, longitude 131°11'14"E, elevation 42.8 m

Month	Average daily pan evaporation (mm)	Average daily maximum temperature (ºC)	Average monthly evaporation (mm)
January	5.7	33.8	175.2
February	4.7	32.9	145.4
March	5.5	33.7	170
April	6.0	34.5	181
May	6.4	33.0	199
June	6.2	31.5	185
July	6.4	31.7	199
August	7.2	33.6	223
September	7.6	36.5	227
October	7.6	36.6	235
November	6.8	36.7	204
December	6.1	34.7	188

Data: Climate and Consultancy Section, Northern Territory Regional Office of the Bureau of Meteorology, 27 July 2004
Start of records 1/8/1968

Table 10. Estimated soil-moisture availability for different soils in the Top End

Soil type	Plant avail. water- moisture holding capacity/m (difference between field capacity* and wilting point**)	Allowable deficit (allowable depletion before irrigation)	Readily available water/m (50%of total water available)
Blain (sandy loam)	40 to 75 mm	40 to 50%	20 to 35 mm
Oolloo	60 to 80 mm	40 to 50%	30 to 40 mm
Tippera (clay loam)	75 to 140 mm	40 to 50%	37 to 70 mm

Note: *Field capacity = drained upper limit **Wilting point = drained lower limit. Field capacity is amount of water held in the root zone after the soil has been saturated and allowed to drain for 24 to 48 hours. Data adapted from Dilshad et. al. 1996.

The effective rooting depth for maize is over 1.5 m. However, irrigating to 70.0 to 80.0 cm is sufficient using sprinkler irrigation in the NT, as most of the moisture will be taken up from within this zone. The allowable soil moisture depletion is usually set at 40% to 50% in line with good irrigation practice. Drying the soil down to more than 50% depletion increases the risk of stress and yield reduction, especially if it suddenly turns hot or if a problem develops with the irrigation system.

When maize reaches full canopy closure (i.e. crop factor 1.0) in June/July it will require on average 35.0 mm to 45.0 mm of irrigation water per week, depending on location and environmental conditions. This could increase to about 70.0 mm per week in October for late crops. Applying such quantities of water by sprinkler irrigation (centre pivot or lateral move) will usually require two to three irrigations per week at peak times. Large irrigations (i.e. over 30.0 mm at one time) on the red earths can cause temporary ponding, runoff and deep drainage. Applying two small, rather than one large application will reduce water losses and improve water-use efficiency.

USING SOIL MOISTURE SENSORS TO SCHEDULE IRRIGATION

There is a wide range of sensors that directly or indirectly measure soil moisture. These vary in price from a few hundred dollars (i.e. tensiometers) to sophisticated electronic sensors costing several thousand dollars (i.e. capacitance probes). Tensiometers are the simplest and most economical soil moisture sensors.

Tensiometers are porous ceramic tipped tubes fitted with a vacuum gauge. They measure the tension with which moisture is held in the soil. Upon drying, the soil moisture tension increases so that water is “pulled” from the tensiometer into the soil creating a vacuum which is registered on the gauge. The reading will indicate when irrigation is required. The higher the reading on the vacuum gauge the dryer the soil.

Electronic equipment such as capacitance sensors (i.e. Enviroscan®, C-Probe®, Gopher®) measure volumetric moisture at predetermined depths throughout the profile. This equipment has the capacity to continuously log moisture content at any depth at which sensors are placed. Information can be graphed to visually illustrate moisture at various depths. Fully automated systems can be set up to monitor and control irrigation applications when moisture levels reach predetermined settings.

The advantage of capacitance soil monitors is that they continuously measure moisture levels, extraction rates and drainage throughout the profile and present it in a visual format. Knowing what is happening below the soil surface allows more precise irrigation management. Issues of under or over watering and nutrient leaching are minimised resulting in better water use efficiency, improved crop performance and enhanced natural resource protection.

There are many other types of monitors available than discussed here. Irrigation consultants and retailers can recommend alternative types.

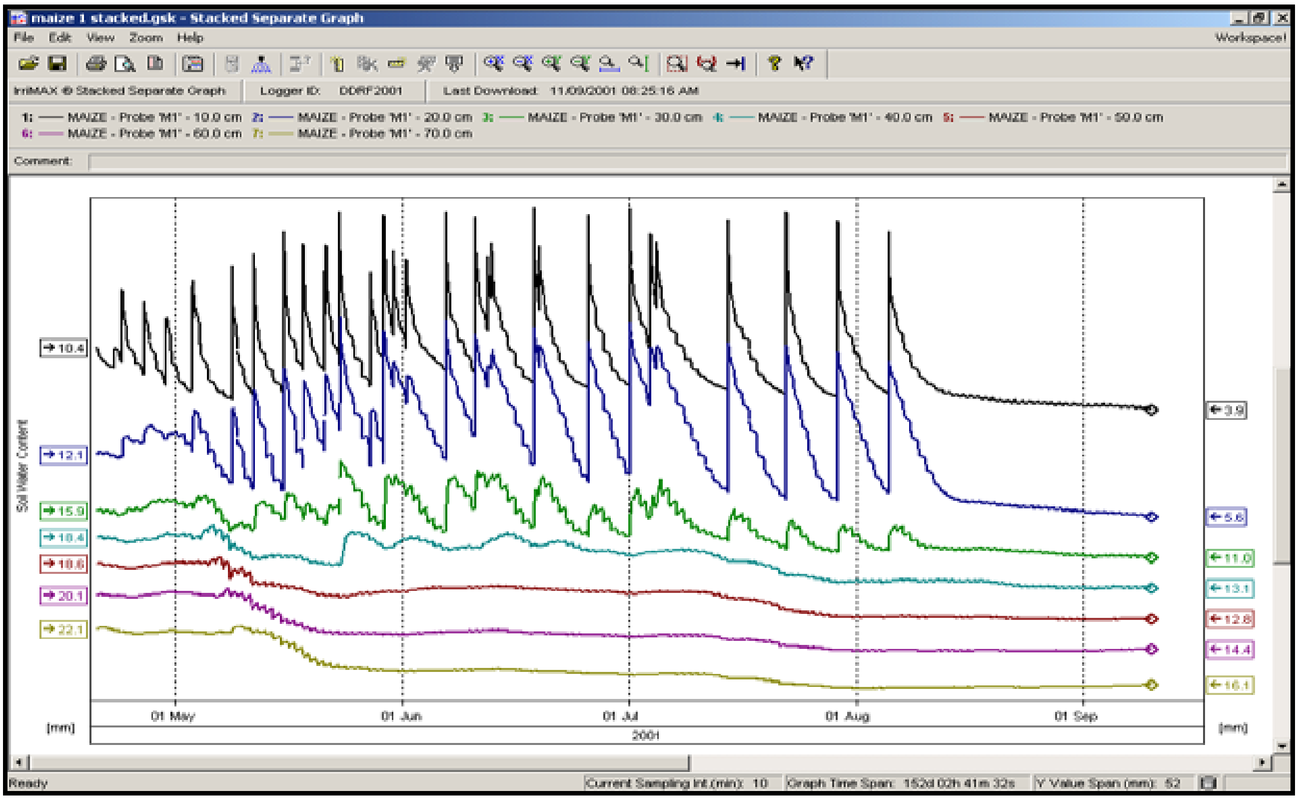


Figure 28. Enviroscan® chart showing moisture extraction at various depths

Figure 29a and b. Enviroscan® capacitance sensors and data logger

Figure 30. Installing an Enviroscan® in a maize crop

Figure 31a. Tensiometers at different depths in a peanut crop and **b.** Tensiometer with gauge

IRRIGATION SYSTEM CAPACITY

The capacity of an irrigation system is determined by the availability of water. Once that is determined the infrastructure can be designed to match the resource. Most field crop irrigation systems in the NT are based on centre pivots supplied by underground aquifers. Bore capacities may be as high as 100 L/second. However, the majority range from 30 to 70 L/second. Good system design, installation and management are critical for viable crop production.

Many irrigation systems are installed without sufficient planning or consideration of the physical environment or available resources. A common mistake is that irrigation systems are too large for the amount of water available. The sustainable yield of a bore should be determined through a pump test before the irrigation system is installed. A pump test is the only way to accurately establish the draw down and recharge rates, yield and the capacity of the bore.

Systems and bores which are subjected to long periods of continuous pumping at maximum rates are likely to fail. Over pumping may result in sand being sucked into the system. This results in premature pump wear and may cause the bore to collapse. Bores require time to recharge and each will vary in draw-down and recharge rates. The NT Department of Natural Resources, Environment and the Arts (NRETA) can advise on bore establishment, testing and maintenance.

Two aspects influence irrigation and crop management in the Top End. First, no useful rainfall occurs for seven to eight months of the dry season. This means total crop water requirement must be supplied by irrigation. Second, the arable red earths and many other soil types have low water-holding capacities and do not store moisture for extended periods.

Bore capacity, flow rate and irrigation systems must match the intended size of the cropping operation. When calculating water required for a particular area, peak and not average evaporative demand should be used. Average figures result in under-estimating what is actually required when evaporative demand is at its highest.

Peak water demand by maize could be as high as 60 to 70 mm per week for periods from August to November. Two to three separate irrigations of 20 to 30 mm will be required, as one heavy application will result in runoff, ponding and deep percolation. The specific soil type (i.e. clay loam or sandy loam) and soil conditions will determine how much water can be applied at once. Tippera clay loams will accept approximately 20 mm to 25 mm and sandy loams 25 to 35 mm before water starts to pond and run off.

With a given bore output, it is possible to work out how long it will take to irrigate the entire area to satisfy crop water demand. This is critical for working out pumping schedules and determining whether the crop can be irrigated sufficiently to avoid stress.

Example:
Assume a bore capacity of 70 L/second and potential area of 50 hectares, total peak crop requirement of 60 mm per week to be applied in two irrigations of 30 mm each.

Information: 70 L/second maximum flow = 252 000 L/hour
30 mm application required
50 ha area to be watered

1. Calculate how long it will take to apply 30mm to 50 hectares.

    - First, calculate how much water is required to irrigate 50 ha.
    - Calculate volume of water required to provide 30 mm over 1 hectare (ha)
    - (i.e. 30 mm deep x 1 ha area = 0.03 m x 10 000 m^2)
    - = 0.03 m x 10 000 m^2
    - = 300 cubic metres (m^3) required to water 1 ha
    - = 300 x 1000 = 300 000 L required to water 1 ha
    - Calculate amount (L) required for 50 ha = 300 000 L x 50 = 15 000 000 L
    - Total water required = 15 000 000 L or 15 mega litres (ML)
    - Time to irrigate 50 ha = Total water required divided by pumping rate
      = 15 ML/252 000 L/hr (i.e. 70 L/sec)
      = 15 000 000 L/252 000 L/hour
      = 59.5 hours

Note: 1 cubic meter (m^3) of water = 1000 L, 1 million litres = 1 mega litre (ML), 1 hectare = 10 000 m^2

It takes 59.5 hours or almost 2.5 days to apply 30 mm to 50 hectares with 70 L/sec

2. Calculate how long to apply 60 mm to total area

Time to apply 30 mm = 59.5 hrs
Time to apply 60 mm = 59.5 x 2
= **119 hrs or almost 5 days**

In this example, 119 hours of pumping is required to apply 60 mm of water. The irrigation system will be operational for five out of seven days. While 40 mm to 50 mm may be required most weeks, the example illustrates how to determine if a system is capable of effectively watering an area during peak water use. The example does not show system losses or inefficiencies such as evaporation from the soil and friction losses which further reduce water availability by 10% to 20%. Determining total water availability and peak crop water demand is necessary to calculate maximum irrigable area, water schedules, pumping periods and operational costs. Information from relevant advisors should be sought in the planning stages of an irrigated cropping enterprise.

WATER PLANNING AND ALLOCATION

The NT Government is in the process of developing and implementing water allocation plans for the Territory. Due to the increasing demand on water resources, allocation plans are necessary to ensure the sustainability and equity of the resource into the future. Commercial irrigators require an extraction licence from NRETA for extraction of 15 L/sec or more for specified agricultural and horticultural uses. There are no charges associated with irrigation at present.

Once water plans are implemented, irrigators will have to apply for an allocation. Bores will need to be metered to determine water use and total ground water extraction. Producers will have to budget to determine how much of the crop can be grown to ensure there is enough water in their allocation to satisfy crop needs. Water-trading, i.e. buying and selling water from other irrigators, is likely to become a feature of irrigation in the Top End as it is elsewhere in Australia.

For example, one producer with an allocation of 1000 ML may budget on 5.0 ML/ha for 200 ha of maize. Another producer may be more conservative and allocate 6.0 ML/ha for the crop reducing the planted area to 166 ha.

If the producer who allocated 5.0 ML/ha finds there is insufficient water towards the end of the season due to unexpected hot weather, he/she may have to consider one of several options. The grower may:

1. Continue watering the entire area at the budgeted rate and incur a yield reduction over the whole crop

2. Sacrifice a portion of the crop and redistribute the available water to maintain full yield potential over a reduced area, or

3. Purchase additional water to finish the original 200 ha of maize with full irrigation.

These are some of the decisions producers will have to make when irrigating in the NT, in future. Management of irrigation and water is the key to profitability and sustainable resource protection. These issues will become more important as demand for water and land grows in the NT.

Planning and developing well designed irrigation systems will pay dividends in terms of water use efficiency and crop performance well into the future.

Figures 32a and b. Different sprinkler heads will give different efficiencies. Wobbler type sprinklers (left) reduce drift and evaporative losses in high winds and hot conditions.

Key points:

- **Maize requires 5.0 to 7.0 ML/ha of water depending on variety, soil type and planting time.**
- **Using crop factors and daily evaporation rates will help determine crop water demand. Soil monitors will help fine-tune irrigation scheduling and conserve water.**
- **Moisture stress at silking to grain fill will result in the greatest loss in yield.**
- **Applications of 25 mm will be more efficient than infrequent large irrigations (>33 mm) on light permeable soils.**
- **Water allocation plans and water budgeting will become an integral part of irrigation management in the NT.**

NATIVE AND FERAL ANIMAL DAMAGE

Damage from galahs, sulphur-crested cockatoos and pigs needs to be considered in small isolated maize plantings. In areas close to water systems such as in Katherine and Douglas Daly areas, damage by birds and pigs can be severe. Pig-fencing may be necessary in some locations. Pigs rampage through the crop knocking it over to access the cobs. White cockatoos can do considerable damage during the seedling stage and when the grain is maturing. They concentrate on the edge of crops, gradually eating their way in. When they are in large numbers, losses can be substantial.

Prior to growing maize, consider the location and the potential damage from wildlife and other pests.

Figure 33. Damage to a maize crop caused by sulphur-crested cockatoos

HARVESTING

Two major issues impact on final crop yield and profitability:

- Correct setting and operation of the combine.
- Timely harvest (not delayed or late).

Maize is easy to harvest provided the combine is fitted with a specialised “corn” front. Maize fronts are either “cutter bar” or “snapper bar” types with large crop dividers matching the crop row width. Cutter bar fronts cut the maize stalks and thresh the whole plant and ear and are mainly used in dryland or low-yielding crops. Snapper bar fronts strip the ear from the plant so that stalks are not taken into the harvester. Snapper bar fronts range in size from four to 12 rows depending on header capacity.

Maize is physiologically mature when a **black layer** appears at the base of the grain where it attaches to the cob. Grain moisture at this stage is around 28% to 32%, which is too high for storage. Grain in the NT is mostly used as stock feed; so it is allowed to dry down in the field to a safe storage moisture content of 14%. Maize can be harvested at higher moisture, but will require artificial drying before storage. As there is little chance of rain and/or high relative humidity during August/September, maize will dry rapidly in the field and artificial drying will usually be unnecessary.

Maize planted at the end of March can usually be harvested in late August when conditions are ideal. Depending on variety, it will usually take between 135 and 160 days from planting to harvest at the correct moisture content.

The adjustment to the front of the harvester is critical for harvest efficiency and for minimising grain loss. The speed of snapper rolls on the front must be compatible with the forward speed of the harvester. A combine which is incorrectly set-up or operated can result in 10% to 20% loss in the field. Delaying the harvest can result in additional losses of 3% to 5%. These losses can be much higher if the crop begins to lodge or is being attacked by birds or other pests. Harvest should commence as soon as the grain approaches 15% moisture. If the crop begins to lodge or is being damaged by pests, it may be necessary to harvest it earlier and artificially dry the grain.

Loss of grain at harvest significantly affects profit. For example, if a 10.0 t/ha crop loses 15% due to harvesting inefficiency and if it takes 6.0 t/ha to cover costs, the loss due to inefficiency actually represents a 37.5% reduction in profit. This is because the loss of 1.5 t/ha (i.e. 10.0 t x 15% = 1.5 t) comes directly from the profit of 4.0 t/ha (i.e. 1.5 t loss/4.0 t profit = 37.5%).

Every effort should be made to minimise harvest losses by ensuring that the machinery is well set up and operated and the crop is harvested at the optimum time.

MAIZE AS A SOURCE OF FODDER AND ENERGY

Maize silage is the most widely grown fodder in the world. **Silage** is basically fodder which is harvested and stored at high moisture (around 60%) and which undergoes fermentation. The fermentation process conserves the fodder and produces a palatable, high energy (9.5 to 11.0 Mega joules of energy per kilogram of dry matter) feed. Silage crops of 40.0 to 60.0 t/ha have been produced in the Top End. Silage crops are produced in the same manner as grain crops but the complete plant is harvested at about 35% dry matter (i.e. 65% moisture) which is approximately two weeks before physiological maturity. At this stage the grain is partially soft and the milk line is about half way along the kernel.

Silage crops are harvested with forage harvesters or precision choppers, which cut the plant into lengths of 1.0 to 2.0 cm. Precision choppers make the best quality silage and the product is easier to compact and conserve. Silage production is a specialized operation and requires specific handling and storage facilities. Silage yields can be estimated by multiplying potential grain yields by 6. A 10.0 t/ha grain crop has the potential to produce 60.0 t/ha of green chop or silage.

Maize can also be harvested as high moisture grain for stock feed. The grain is usually harvested at about 28 to 32 % moisture and ground in a tub-grinder to crack the grain and assist in the fermentation process. It is then stored in specially designed high moisture grain silos or in pits as with normal silage.

‘Earlage’ is made by harvesting only the ears and husks (cobs) (as opposed to the whole plant) with a snapper-bar and ensiled in the same way as silage. The ears are harvested at about 35 to 40% moisture, similar to normal whole plant silage. This results in a high energy feed and most of the stover is returned to the soil.

Maize is also being used increasingly for the production of **ethanol,** as a substitute for fossil fuels. Ethanol production from maize (corn) rose in the US to a record high of 5.9 billion gallons in January 2007 and could rise by as much as 60% by the end of the year. US ethanol consumption increased by 33% in 2006 to 5.4 billion gallons. According to the Renewable Fuels Association, the industry's primary trade organisation in the US, there are now 114 ethanol distilleries, with an additional 80 new plants and seven expansions under construction. A US federal mandate requires that there be a near-doubling in the use of renewable fuels, from 2007 to 2012.

The dramatic increase in the use of grain for ethanol production has resulted in the doubling of the price of corn in the US over the past year. This is a concern for many who believe the use of food crops for energy could cause a shortage of grain for human and animal consumption.

Maize stover also has the potential to be used as a source of ethanol through a process of fermentation and distillation of the cellulose. Cellulose is a major constituent of plant cell walls and is the most abundant form of living biomass. **Cellulose ethanol** is gaining momentum as a viable bio-fuel alternative as companies improve production technology. It may prove to be more environmentally sustainable and energy efficient than ethanol from grain.

Despite the trend of increased bio-fuel use, there are arguments against the production of fuel from food crops, both on environmental and economic grounds. Information on bio-fuels, their use and associated issues is growing rapidly and is available from a wide range organisations and researchers on the internet.

THE ECONOMICS AND FUTURE OF IRRIGATED MAIZE PRODUCTION IN THE NT

Irrigated maize is a high input crop. Seed, fertiliser, fuel and other inputs have a significant freight component which adds to the cost of crop production in the NT. Growing maize in the NT may cost up to 30% more than in Qld or NSW. However, the price of maize may also be higher in the NT than the national average due to the higher costs of production.

Growing costs will largely be determined by the amount of fertiliser and water required. Water and fertiliser account for over 60% of the total variable costs. Nitrogen requirements can be reduced significantly by rotating maize with legume crops such as peanuts, mungbeans or legume pastures. Banding phosphorus and nitrogen at sowing will be more efficient and help to reduce inputs. Using precision planters will reduce seed requirements and ensure optimum seed depth, spacing and establishment. Using the most suitable soils for maize production and avoiding problem areas or soils with low nutritional status will help reduce production costs.

Planting maize at the earliest opportunity in the dry season or even late wet-season will reduce the amount of water required. Using water monitoring equipment will help schedule irrigations more accurately and may potentially save water.

CURRENT AND POTENTIAL MARKET

There is a limited market for maize at present in the NT due to the absence of dairy or feedlot industries. If livestock industries intensify, maize should become more important. Maize has several industrial uses and is being increasingly grown for ethanol production and bio-degradable plastics in Europe and the US. As high yields can be achieved in the NT using irrigation, maize has potential for feedlots, in ethanol production and other industrial purposes provided its cultivation is economical.

GROSS MARGIN FOR A SINGLE IRRIGATED MAIZE CROP

A **gross margin** is the difference between gross income and total variable cost of growing a crop. Gross income is made up of total receipts from the sale of a maize crop. Variable costs, also referred to as running costs, are directly related to growing, harvesting and marketing the crop. Gross margins do not take into account fixed or overhead costs such as capital or interest, permanent labour, insurance, infrastructure and other repairs, maintenance, replacement, depreciation and living or travel expenses. For this reason gross margins are not a measure of the profit but more a measure of relative profitability when compared with a similar enterprise.

Gross margins are useful in comparing different crops which require a similar level of input and resources. However, it is unrealistic to compare gross margins of irrigated crops with those of dryland crops because of the need for extra resources and infrastructure for irrigation. If major changes in the enterprise mix are being considered, more comprehensive budgeting techniques are required.

Crop gross margins are usually based on a return per hectare. However, comparing different enterprises on return per unit of permanent labour, per $1000 capital or per mega-litre of water used, is a worthwhile exercise.

It has been suggested that it is possible to grow two crops per year using irrigation. While this was the premise many peanut growers had in the late 1990s, experience has shown that it is difficult to grow two successful crops in one year. Peanut producers found that delays in one crop exacerbated delays in the following crop, which seriously compromised yield. Maize however, is a shorter season crop and requires less ground preparation and harvesting time than peanuts. The problem with growing a wet season crop is that it cannot be harvested before mid to late April in most instances due to the wet season. This means that planting the following dry season crop has to wait until harvest is complete.

Growing two successful maize crops per year with irrigation may be possible provided stubble management, planting time, pest, weed and disease control, water allocation and irrigation issues are effectively resolved. Managing the soil and water resources in a sustainable way and developing viable markets are some of the challenges for irrigated cropping in the Top End.

The following gross margin is based on a fully irrigated dry season crop on a sandy red earth in which the level of inputs is aimed at achieving 10.0 t/ha. No allowance for residual soil fertility is made. Fertiliser and chemical prices are based on quotes received from agribusinesses in Darwin in January 2007, which are subject to change. Grain price is based on an estimate provided by local growers/buyers.

Table 11. Gross margin for irrigated maize on Blain soil at Douglas Daly/Katherine, NT

						Per hectare	Your estimate
			t/ha	**price/t**			
Yield			**9.5**	**250**		**2375**	
Total Income						**2375**	
Variable Costs							
Land Preparation							
1 disk						10	
1 chisel						9	
2 scarify						15	
Sowing							
Operation						4	
		$/bag	bags/ha	for 78 000 plants/ha			
Seed	Gaucho® treated	264	1.1			290.4	
Fertilizer							
Pre-plant application		by 3				9	
250 kg of DAP/SOA	20:13:0:13		at	900	per ton	225	
250 kg Urea			at	720	per ton	180	
20 kg zinc hepta-hydrate or equivalent			at	1316	per ton	26.32	
200 kg MOP			at	875	per ton	175	
50 kg/ha	DAP plus TE at planting		at	1000	per ton	50	
Fertigation							
200 kg urea			at	720	per ton	144	
10 kg zinc hepta-hydrate			at	1316	per ton	13.16	
Weed Control							
Application		L/ha		$/L		3	
Primextra	Post-plant pre-emergent	5.0	at	13.4		67	
Insect control							
Chlopyrifos		0.9		10		9	
Irrigation		ML		$/ML			
Pumping costs		5.5	at	60		330	
		$/t					
Harvesting		10				100	
Total	**Variable Costs**					**1659.88**	
Gross Margin						**715.12**	
Seed as % of total variable costs:			17				
Fertilizer as % of total variable costs:			49				
Water as % of total variable costs:			20				

Notes:

- DAP/SOA is a di-ammonium phosphate/sulphate of ammonia blend to supply N, P and S.
- Fertiliser may be reduced on soils with good fertiliser history and on heavier clay loams.
- Input costs may be lower with bulk purchases and economies of scale.

Table 12. Effect of price and yield on gross return

Expected on-farm price ($/t)	Expected yield (t/ha)					
	6	8	10	11	12	13
$100	-1076	-876	-676	-576	-476	-376
$150	-776	-476	-176	-26	124	274
$200	-476	-76	324	524	724	924
$250	-176	324	824	1074	1324	1574
$275	-26	524	1074	1349	1624	1899
$300	124	724	1324	1624	1924	2224
$325	274	924	1574	1899	2224	2549

Total variable cost: $1676

WORLDWIDE DEVELOPMENTS IN MAIZE PRODUCTION AND TECHNOLOGY

Maize is one of the world's most important crops and according to the FAO, demand for it as a food and industrial crop will increase dramatically within the next 20 years. FAO predicts that an additional 295 million tonnes (almost half of world's current production) will be needed by 2030. Demand in the US has already surged where competition from the ethanol industry has doubled the price of maize in the past year. Even though maize is a minor crop in Australia, annual production has more than doubled in the past eight years to 530 000 tonnes.

Billions of dollars are spent each year on maize research and development. Those involved include biotechnology, seed and agrichemical companies, universities, state and federal departments of agriculture and development agencies such as the International Maize and Wheat Improvement Centre (CIMMYT).

As a result of the advances in maize research, yields as high as 26.0 t/ha and 21.0 t/ha have been achieved in the US and Australia, respectively.

Major advances in maize and other crop research during the last 10 years have been in **biotechnology and genetic engineering**. This involves the transfer of genetic material and traits (often from other organisms) to plants to improve their quality, yield or resistance to pests. Maize has been genetically engineered to resist attack by a range of economically important pests and to tolerate herbicides such as glyphosate (i.e. Roundup®) to improve crop weed management.

Bacillus thuringiensis (Bt) is a soil bacterium that produces an insecticidal protein. The protein has been genetically transferred to maize with the result that the crop produces a Bt toxin against pests. When attacked by specific insects (i.e. heliothis) the toxin is ingested; feeding stops and eventually the pest dies. Bt corn is now commercially available in a number of countries and in 2006 over 60% of the US corn crop was genetically modified. This trend is increasing as the benefits of genetic engineering technology are being realised through better yields, improved insect and weed management, reduced pesticide usage and improved grower returns.

Maize is available now in the US which has been "stacked" with genetic material conferring several traits. *Monsanto* markets "triple trait" maize varieties which are genetically modified (GM) to resist rootworms and other soil insects, corn borers and is also glyphosate tolerant. The GM maize is marketed as YieldGard®Plus with Roundup Ready® Corn 2.

Biotechnology has its critics and many countries and jurisdictions are still resisting the push to adopt GM crops. However, GM crops are commercially proven across millions of hectares worldwide and are increasing at such a rate that some predict 95% of the US maize crop will be GM in the next few years. The European Community is also embracing some aspects of GM agriculture.

Biotechnology is destined to play an even greater role in improving the efficiency of generating bio-fuel from maize and other crops. It is predicted that within 10 years GM maize will provide double (i.e. 600 US gallons per acre of ethanol from grain and 200 US gallons per acre from stover) the amount it now produces per hectare. Genetic engineering is being used to improve the nutritional and industrial qualities of maize, develop specialty products and is destined to play an ever increasing role in world agriculture.

The use of GM crops comes with an obligation of managing the crop and surrounding area in a specific manner. There are strict guidelines about the use of GM crops and the requirement to implement an insect resistance management (IRM) program to help to protect the longevity of the technology.

Other advances in plant genetics which are enhancing traditional breeding and maize improvement include in-vitro culture and selection, genomic analysis and molecular breeding, or marker assisted selection. Advances have been made in maize tissue culture which have enabled more detailed study of the genetic make-up of plants and accelerated genetic manipulation, selection and regeneration of transgenic plants.

Mutagenesis, which is recognized as a traditional breeding technique, is used to develop maize which has specific traits. The Clearfield® technology system is an example of where herbicide-tolerant maize is specifically developed for an integrated weed management system using imidazolinone herbicides.

Other advances include new age polymers, seed coatings and insecticidal/fungicidal seed dressings. *Landec Ag* has developed the Intellicoat® patented seed coat which stimulates seeds to germinate once the soil reaches a prescribed temperature. This is used in the US and Europe where farmers want to plant earlier in cool soil and require the crop to germinate once temperatures become favourable.

New low-toxicity, low rate, systemic seed dressings (such as Gaucho® and Cruiser® which have been described) have been developed to protect the seed and young plants from a range of economically damaging diseases and insect pests. The benefit of this technology is that the pesticide is applied directly to the seed and eliminates the need to handle or apply multiple in-crop pesticides. The chemical is systemic and protects the plant for several weeks and acts specifically on the target pest.

There is an increasing trend of agrichemical, seed and biotechnology companies combining to develop new technology. In the US when farmers purchase GM seed they are buying a complete crop management system and a licence to use the technology according to specific production guidelines.

Maize technology is advancing at a rapid rate due to the worldwide importance of the crop. Improvements will continue to come from traditional breeding while biotechnology will play an increasing role in trait identification and selection.

GLOSSARY

ADMA	Agricultural Development and Marketing Authority, established in 1980 by the NT Government to assist with agricultural development in the Top End.
Banding (fertiliser)	Applying fertiliser in a "band" or strip below or beside seed at planting.
Blain soil	Dark reddish-brown sand to loamy sand. Profile graduates to sandy loam to sandy clay loam at 30 cm. Easy to cultivate and is not hard setting.
Buffering capacity	The ability of soils to resist changes in pH.
Chemigation	The application of chemicals in irrigation water.
Cob	Term used for the ear of corn.
Conventional cultivation	The use of heavy machinery such as ploughs to cultivate and prepare land for crops.
Corn	Term used to describe the major cereal (maize), largely used in the US
Crop factor	An estimate of the ratio of plant water use to pan evaporation, (usually between 0.3 and 1.2). A crop factor of 0.7 estimates that the plant is using 70% of pan evaporation.
Drained upper limit	The volume of water a soil can hold two to three days after saturation and when free drainage has practically ceased, also termed field capacity.
Drained lower limit	The moisture content of a soil at which plants wilt and fail to recover, also called wilting point.
Fertigation	The application of fertiliser through the irrigation system.
Ethanol	A flammable, colourless alcohol produced through the fermentation of plant sugars for use in alcoholic beverages and industrial purposes such as the production biofuel. Also known as ethyl alcohol, drinking alcohol or grain alcohol.
Enviroscan®	A capacitance probe which measures soil moisture.
Ear	Synonymous with cob.
Evapo-transpiration	The combined evaporation from a crop surface and surrounding soil surface.
Genetically modified organism (GMO)	An organism whose genetic material has been altered using genetic techniques generally known as recombinant DNA technology.
Infiltration	The rate at which water enters the soil before it begins to run off or pond on the surface, measured in mm per hour.
Lodging	Crop falling over due to wind, disease or weak stalk.
Maize	Native American name for the crop.
Mega litre	One million litres (of water).
Nutrients	Elements necessary for plant health and growth supplied by the soil or in applied fertiliser.
Oolloo soil	Dark, reddish-brown sandy loam, graduating to sandy clay loam, to clay loam at 30 to 40 cm. Its intermediate texture is between Tippera and Blain soils.
Pan-evaporation	The amount of daily evaporation from a specially designed and located pan (US Class A pan).
Percolation	The movement of water downwards within the soil profile.

Physiological maturity	When grain has reached maximum dry matter and its development is complete.
Red earths	A diverse group of arable, well drained soils under the Great Soil Group Classification (Stace et al. 1968) with characteristics which determine their use and productivity. Colours range from deep red to reddish-brown. They are common agricultural soils in the Katherine Daly Basin. They are known as Kandosols under the Australian Soil Classification.
Respiration	The uptake and storage of carbon dioxide in the process of converting it to carbon through photosynthesis.
Soil pH	The relative acidity or alkalinity of the soil.
Silage	Conserved and fermented high moisture plant material used for stock feed.
Silking	The emergence of silks (female reproductive part) from the top of the immature ear.
Standability	The ability of the crop to stand and resist lodging.
Stover	Stalk or mulch left over after harvest.
Systemic (as in pesticide)	An insecticide whose mode of action is via uptake into a plant, entering the pest when the plant is consumed.
Tasseling	When the tassels (male reproductive part) emerge from the top of the maize plant to release pollen.
Tensiometer	A vacuum tube fitted with a gauge used to measure soil water tension.
Tippera soil	Dark red to reddish-brown, hard loam soils. Soil profile increases in clay at 30 to 40 cm. Sets hard on drying and forms soil surface crust under conventional tillage.
Top End	The northern most area of the Northern Territory (north of latitude 15° South)
Trace element	Elements essential to plant growth which are taken up in minute quantities, such as zinc, copper, boron etc.
Transgenic plants	Plants that possess genes that have been transferred from a different species. Today the term refers to plants produced in a laboratory using recombinant DNA technology in order to create plants with specific characteristics by artificial insertion of genes from other species.
Zero-till	Establishing crops without any preliminary cultivation and controlling weeds with herbicides.

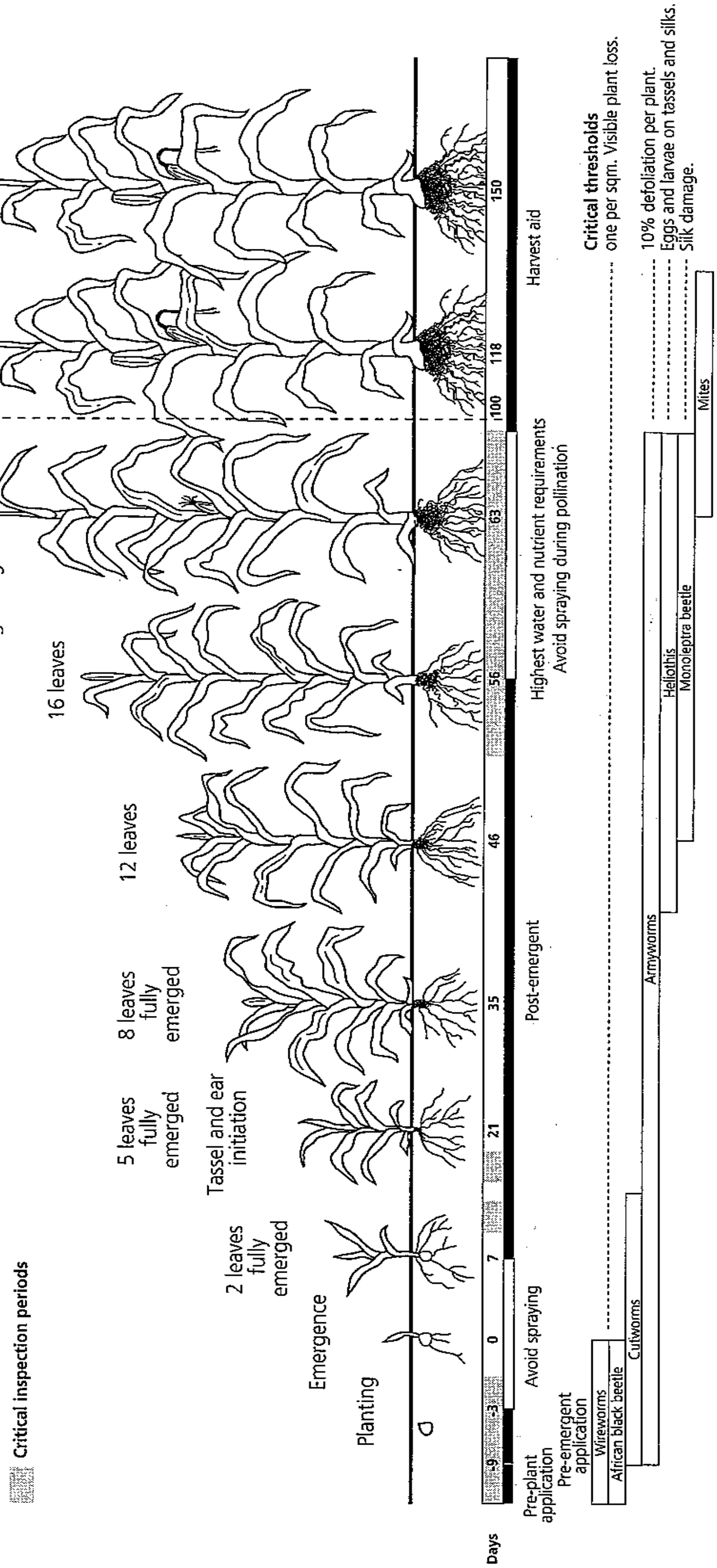
APPENDICIES

APPENDIX 1. USEFUL WEBSITES

Organization	Web Site
Australian Centre fro International Agricultural Research (ACIAR)	www.aciar.gov.au
Australian Pesticides and Veterinary Medicines Authority	www.apvma.gov.au
Council for Biotechnology Information	www.whybiotech.com
CSIRO	www.csiro.com.au
Farm Industry News	www.farmindustrynews.com
Farmers Info Australia	www.nswfarmers.org.au
Farmlink Research	www.farmlink.com.au
Fat Cow Farming	www.fatcow.com.au
Food and Agriculture Organisation of the UN	www.fao.org
Grains Research and Development Corporation (GRDC)	www.grdc.com.au
InfoPest database	www2.dpi.qld.gov.au/extra/asp/infopest
International Maize and Wheat Improvement Centre (CIMMYT)	www.cimmyt.org
Kondinin Group	www.kondinin.com.au
Maize Association of Australia	www.maizeaustralia.com.au
National Corn Growers Association of the US	www.ncga.com
NSW Department of Primary Industries	www.dpi.nsw.gov.au
NT Department of Primary Industry, Fisheries and Mines	www.nt.gov.au/dpifm
Queensland Department of Primary Industries and Fisheries	www.dpi.qld.gov.au
Rural Industries Research and Development Corporation	www.rirdc.gov.au
University of Queensland	www.uq.edu.au
Victorian Department of Primary Industry	www.dpi.vic.gov.au

APPENDIX 2. MAIZE CROP GROWTH STAGES AND MANAGEMENT GUIDE

(Courtesy NSW Department of Primary Industries)



Stage and Duration	Management
Sowing to seedling emergence (4-5 days) Seed reserves provide energy for the emerging seedling. The primary root develops and the shoot emerges from the soil. Leaves appear at the rate of one leaf every three days. The growing point remains below the soil for about three weeks after sowing.	Starter fertilizer (NPK with trace elements) should be banded below and to the side of the seed. Seed (treated with registered fungicide and insecticide) should be planted at a uniform depth and spacing into moist soil. Monitor seedlings for insect damage. Apply pre-emergent herbicide.
Early vegetative (seedling emergence to tassel initiation – 5 weeks) Two weeks after emergence the secondary root system takes over from the primary roots. At about day 20 the potential ears are starting to form. Leaf formation is at its most rapid stage. At week five the plant has 8 fully emerged leaves and the tassel starts to develop in the growing point.	The secondary roots can be damaged by cultivation. Post emergent herbicides can be applied until the crop becomes too tall.
Late vegetative stage to tassel emergence (3-4 weeks) At about six weeks, the plant has 10 leaves and is growing rapidly and taking up nutrients and water in large quantities. Kernel number and ear size are being determined. At the 12th to 17th leaf stage (day 40-55) the number of potential kernels and the size of the ears will be set.	Nutrients and water must be freely available. N can be applied by side-dressing or through the irrigation water. Ensure all “top-up” nutrients are applied at this time in advance of flowering and pollination. Ensure all of K has been applied.
Flowering (pollination & fertilisation, 3-8 days) At about week 9, tassels emerge and shed pollen 2 to 3 days before silks emerge. Silking occurs at about day 65. It takes another 2 to 3 days for all of the silks to be exposed and pollinated. Two weeks after silking, nutrients are being relocated from leaves and stems to the ear and seed.	Stress at this time will cause poor pollination, barren tips and have the biggest impact on yield. Monitor the crop for insect pests and protect the silks from damage. The two weeks prior to pollination (about day 50) and two weeks after pollination (about day 75) is the most critical period for determining maize yield. Ensure water and nutrients are adequate.
Grain filling - physiological maturity (8-9 weeks) Ears have developed 12 days after silking and the grain starts to fill. N and P uptake continues at a rapid rate. Denting of grain occurs 35-40 days after silking. Physiological maturity occurs 55-65 days after silking. A black layer develops at the tip of the seed where it joins the husk, indicating physiological maturity.	Moisture and nutrient stress will result in small grain and reduced yield. Stress may pre-dispose the plant to disease and lodging. Bird and pig damage may be an issue in some areas and preventative measures may need to be taken.
Grain drying (35 days depending on conditions) Grain gradually dries and leaves hay off. Harvest occurs at about 150 – 160 days after emergence when the grain has reached 14 % moisture and is safe for storage.	Artificial drying is usually un-necessary in the NT unless the crop starts to lodge or there is the threat of damage by birds or pigs. Harvest the crop as soon as it reaches a safe moisture level.
Maize yield is enhanced by long, warm days and cool nights. High temperatures will hasten maize development reducing the time for dry-matter and yield accumulation. Crops which mature in mild rather than hot conditions will have a higher potential yield.	

Appendix 3. Evaluation of Irrigated Maize on Blain Soils, Douglas Daly Research Farm, 1999 to 2002

Abstract

Formal research into rain-fed maize in the NT began in 1954. The Animal Industry and Agriculture Branch of the Northern Territory Administration conducted trials at Berrimah Farm, Batchelor and Tortilla Flats (Muchow 1985). Trials continued until 1963 but yields were disappointing due to weed infestation, waterlogging, drought and diseases, including “Wallaby Ear” virus. Trials were also conducted at Tipperary in the 1970s where the best plot yields were 5.2 t/ha.

With the implementation of the Agricultural Development and Marketing Authority (ADMA) at Douglas-Daly in the early 1980s, maize was commercially grown for about 12 years. Plantings peaked in 1987/88 when 1725 hectares (ha) were sown. Yields reached 4.0 to 5.0 t/ha, but the average district yield was less than 3.0 t/ha (Price 1982 and 1983, Garside and Price 1984, Price 1985 to 1988). Airey (1972) and Roberts (1986) reviewed early maize research in the NT. Airey suggested that maize had a limited potential as a dryland crop and Roberts suggested that the highest priority for research was the nutritional requirements of the crop.

In the mid 1990s interest in irrigation increased and several commercial irrigated peanut operations were established in Katherine and Douglas Daly. Maize was seen as an ideal rotation crop; however, there was little experience or data on growing irrigated maize on sandy surfaced soils. In 1999 the Department of Primary Industry, Fisheries and Mines (DPIFM) began evaluating commercial and experimental maize lines to assess their productivity under irrigation on Blain soil at Douglas Daly Research Farm (DDRF).

Over four years (1999 to 2002), the average maize yield for all varieties was 9.3 t/ha. When the 2000 season results are excluded, due to incomplete pollination, the average yield for all varieties and for the best four varieties was 10.3 t/ha and 11 t/ha, respectively.

Introduction

In the late 1990s DPIFM and the newly-formed NT Irrigation, Grain and Fodder Producers Association (NTIGFPA), promoted irrigated agriculture in the Top End. Irrigation was seen as a means to increase viability and decrease risks associated with wet season production. However, there was little data on irrigated crop production in the Top End as most of the research had been conducted under dryland conditions.

Despite this lack of knowledge, a number of interstate and local producers installed centre pivots specifically to grow peanuts. Wet season grown peanuts had shown potential (Price 1985 to 1988) and it was believed that peanuts would also perform well under irrigation. Friable, free-draining, sandy red-earth soils (Blain and Ooloo soil types) were selected for peanut production. The soils are easy to cultivate and allow peanuts to be dug and harvested efficiently.

Due to the high cost of establishing irrigation infrastructure, it is necessary to assess alternative crops and develop a viable crop rotation. Maize was chosen as one possible option because of its high yield and market potential. A maize-peanut cropping system is potentially a good rotation because the nitrogen fixed by the legume can be utilised by the maize crop and pests, disease and weeds can be managed more effectively.

However, there was no information available on the performance of irrigated maize on sandy soils. Past experience with maize on sandy soils in the wet season, indicated the crop suffered from a range of nutritional disorders and yields were low (Roberts 1986, Price 1985 to 1988).

The performance and agronomic requirements of maize grown on light soil needed to be assessed before recommendations could be given to growers. Commercial hybrids also required evaluation to determine the best varieties for the Top End. DPIFM evaluated irrigated maize on Blain soil at DDRF for four years (1999 to 2002) to determine the crops potential. The evaluation was conducted using centre-pivot irrigation and the maize was grown in rotation with peanuts and green manure crops. The results and conclusions from this evaluation are outlined in the following report.

Objectives

- To assess the nutritional, water and pest management requirements of irrigated maize crops on light soils in the NT.
- To determine yield potential, production costs and viability of irrigated maize in the NT.
- To identify suitable and adapted commercial hybrids for NT conditions.
- To develop and document recommendations for irrigated maize production in the NT.

Location and soil type

The research was undertaken at DDRF, near the junction of the Douglas and Daly Rivers, (13º50´ S, 131º45´ E, altitude less than 200 m), 220 km south-west of Darwin. The soil type is a **Ruby-Blain**, red earth (Figure 1) under the Great Soil Group classification (Northcote 1979). It falls in the sandy subgroup along with Venn and Oolloo soil types of the Top End. These soils are classified as **Kandosols** under the Australian Soil Classification system (Isbell 2003). Blain soils are well drained and have a pH of 6.0 to just below neutral. They are massive in structure and have a dark reddish brown sand or sandy loam profile to about 40.0 cm. The soil profile graduates to a dark-red sandy loam to sandy clay loam below 40.0 cm. Clay content in the surface layers (0-20 cm) is around 7% and may increase to 50% at depths of 80.0 to 90.0 cm (Lucas 1983).

The dominant clay material is kaolinite and fine sand accounts for 50 to 70% of the particle size analysis. Blain soils have a low cation exchange capacity, low organic matter content, are low in all the essential elements and have low water holding capacities (Lucas 1983, Aldrick and Robinson 1970, Williams, Day, Isbell and Reddy 1985). Volumetric available water holding capacity of Blain soils varies from 4.0 to 7.5 % (i.e. 40.0 to 75.0 mm/m of soil depth) depending on soil condition and clay content (Dilshad et. al. 1996).

DRY SEASON 1999

Materials and methods

The trial site consisted of 5.0 ha on one side of a 10.0 ha centre pivot on Circle 2 at DDRF. The area was sown with a mungbean green manure crop in December 1998. The mungbeans were disk-ploughed and incorporated in late February 1999. The area was cultivated twice with a scarifier to prepare a friable seedbed. The area was soil sampled to a depth of 150.0 mm in February and analysed for nutrient content (Table 1). The trial was sown on 25 March 1999.

Nine varieties of maize were evaluated (Figure 5) in a randomised complete block design experiment with four replicates. Blocks consisted of four rows by 100.0 m of crop (Figure 2). The design was maintained over the four years of evaluation; however, the number of replicates, the number of rows and plot sizes varied depending on the number of cultivars evaluated in a particular season.

The varieties were sown with an eight-row “Mason Maxi-Strike” planter. The planter components consisted of twin opening disks. Seed dropped between the disks into the open furrow and two inclined press-wheels close the furrow. The aim was to plant 7 to 8 seeds/m at a 75 cm row spacing to achieve a population of around 75 000 plants/ha. However, the planter could only be calibrated to around 10 seeds/m resulting in a population of over 91 000 plants/ha.

This population was between 17 and 22% higher than recommended by the seed companies. To assess whether the higher population influenced yield, plots measuring 2.0 m by four rows were hand-thinned three weeks after establishment to the recommended population of between 75 000 and 80 000 plants/ha. Hand harvests were taken from the thinned plots and from equivalent areas in un-thinned crops to determine if either population influenced yield.

Pre-plant fertiliser was broadcast and worked into the soil at the rate of 130.0 kg of nitrogen (N), 26.0 kg of phosphorus (P), 20.0 kg of sulphur (S), 150.0 kg of potassium (K), and 81.0 kg of magnesium (Mg)/ha. Zinc (Zn) and boron (B) were applied through the fertigator (dissolved in water and injected through the irrigation system) at the rate of 10.5 and 1.5 kg/ha, respectively. About 100 kg/ha of MAP Sulcote® +TE (mono-ammonium phosphate plus trace elements i.e. 9% N, 19% P, 12% S, 2.5% Cu and 2.5% Zn) was applied through the planter and dropped on top of the row and partially incorporated by the opening disks on the planter. Approximately 92 kg/ha of N (as urea) was split-applied through the fertigation system at 30 and 55 days after sowing (DAS). Total nutrients applied are presented in table 2.

Primextra® herbicide (277 g/L a.i. metolachlor and 223 g/L a.i. atrazine) was applied at 5.0 L/ha immediately after planting followed by 10.0 mm of irrigation to control broadleaf and grass weeds. On 10 April 3.0 L/ha of Nutrazine® (500 g/L atrazine a.i.) was applied in conjunction with Lorsban® insecticide (1.0 L/ha of 300 g/L a.i. chlorpyrifos) to provide additional residual weed control and to control leafhoppers. Rogor® insecticide (0.5 L/ha of 400 g/L a.i. dimethoate.) was applied on 17 April to control leafhoppers and Larvin® insecticide (2.0 L/ha of 375 g/L a.i. thiodicarb) was applied by helicopter on 8 May to control armyworms, heliothis and green vegetable bugs (GVB).

Tissue samples were taken 30 DAS and at silking and analysed by the chemistry laboratory at Berrimah Farm to determine nutrient status. Samples were taken in accordance with recommendations in Reuter and Robinson (1997). Whole plant tops were analysed at 30 DAS and the leaf blade opposite and below the cob (bobc) at silking (see Table 3).

The crop was irrigated using a centre pivot and received approximately 4.8 ML/ha of water. Jetfill® tensiometers were used to assist with irrigation scheduling and total water consumption was recorded on a bore metre.

Hand harvests from the two population areas were undertaken on 20 August and the ears were threshed and weighed; grain moisture was recorded using a grain moisture meter. The main trial was harvested on 26 August, with an International® 1420 axial flow header fitted with a four-row snapper-bar maize front. Plot yields were measured and nutrient composition of the grain and stover was assessed. Weight of grain was corrected to 12% moisture. Krondomic (kg/hectolitre) weight was also measured for each variety.

Table 1. Indicative soil nutrient levels prior to the 1999 planting

	Nutrients					
	K	**Mg**	**P**	**S**	**Zn**	**Cu**
Available levels	80.0 mg/kg	50.0 mg/kg	15.0 mg/kg	2.1 mg/kg	1.7 mg/kg	1.3 mg/kg

Table 2. Fertiliser applied during the 1999 maize evaluation at DDRF

Timing	kg/ha	Type	N (kg/ha)	P (kg/ha)	K (kg/ha)	S (kg/ha)	Cu (kg/ha)	Zn (kg/ha)	Mg (kg/ha)	B (kg/ha)	$/Ton*	$/ha
Preplant	200	**19:0:13:10**	38	26	0	20	0	0	0	0	665	133.0
Preplant	200	**Urea**	92	0	0	0	0	0	0	0	702.5	140.5
Preplant	300	**MOP**	0	0	150	0	0	0	0	0	555	166.5
Preplant	150	**Granomag**	0	0	0	0	0	0	81	0	852	127.8
Fertigate	50	**Zinc Sul Hepta**	0	0	0	0	0	10.5	0	0	810	40.5
	7.5	**Solubor**	0	0	0	0	0	0	0	1.5	3000	22.5
At Planting 9:19:0:12	100	**MAP. Sulcote+ TE**	9	19	0	12	2.5	2.5	0	0	881.5	88.2
		Sub total	139	45	150	42	2.5	13	0	0		719
Fertigation	30 Urea	**Urea plus Zinc**	13					9				57.45
Fertigation	100	**Urea 30 DAS**	46	0	0	0	0	0	0	0	702.5	70.25
Fertigation	100	**Urea 55 DAS**	46	0	0	0	0	0	0	0	702.5	70.25
		Total	244	45	150	42	2.5	22	81	1.5		916.95

Note: *1999 fertiliser prices

Figure 1. Ruby Blain, sandy red earth at DDRF

Figure 2. Maize evaluation plots under centre pivot irrigation at DDRF

Results and discussion

Establishment and nutrition

Eight out of nine varieties established well and achieved an average population of 91 500 plants/ha which is approximately 17% to 22% higher than recommended by commercial seed companies. Pacific 338 was the only variety with low establishment due to poor seed quality and vigour. It achieved only 52 000 plants/ha, which is 30% lower than the recommended population. Consequently, Pacific 338 had a significantly lower yield than all other varieties.

Figure 3. Commercial header used to harvest maize evaluation plots at the DDRF.

Within a week of emergence, N and P deficiency was evident in sections throughout the trial. The deficiency was traced back to a design fault in the fertiliser metering system on the planter. Fertiliser was applied intermittently instead of in a continuous stream with the result that sections of the crop completely missed out on fertiliser giving a "patchwork" deficiency pattern throughout the trial area (Figure 4). Analysis at 30 DAS confirmed that the crop was low in N and marginal for P (Table 3).

Figure 4. N deficiency due to poor distribution of fertiliser at planting time

On 9 April the crop was fertigated with 30.0 kg/ha of N as urea and 9.0 kg/ha of Zn as zinc sulphate heptahydrate. Early N deficiency will limit the leaf and cob size and reduce potential yield. Mg concentration at silking was a little lower than recommended and Zn was considerably higher. The crop eventually recovered from the initial N and P deficiency. Plant tissue analysis revealed that nutrients were adequate at silking and within the range specified by Reuter and Robinson (1997).

Table 3. Average nutrient concentration of irrigated maize and recommended ranges* for different stages of growth

	Nutrient levels									
Growth stage	**N %**	**P %**	**K %**	**S %**	**Ca %**	**Mg %**	**Zn ppm***	**Cu ppm**	**Fe ppm**	**B ppm**
30 DAS*** (measured)	2.7	0.36	3.59	0.21	0.38	0.19	79.7	7.7	107	7.09
Recommended range*	3.5-5.0	0.30-0.5	2.5-3.0	0.2-0.3	0.3-0.7	0.15-0.45	20-50	7-20	50-300	7-25
Silking (measured)	3.3	0.32	2.3	0.22	0.46	0.13	153	10.5	89.8	6.2
Recommended range*	2.7-3.3	0.27-0.62	2.1-3.0	0.15-0.5	0.21-0.5	0.2-0.5	25-70	6-20	20-200	6-25

* Recommended ranges derived from Reuter, D.J. and Robinson, J.B. 1997(eds) Plant Analysis 2nd Edition.

** ppm = parts per million, *** DAS = days after sowing.

Total applied N was 244.0 kg/ha. At an average yield of 9.5 t/ha (average of all varieties) the crop took up 180.0 kg of N, leaving a residual of 64.0 kg N, some of which is lost or immobilised by micro-organisms. This N would allow an additional yield potential of about 3.0 t/ha if all applied N was utilised. However, some varieties yielded 11.0 t/ha and utilised over 200.0 kg of N, equivalent to 85% of applied N. Had the application of fertiliser at planting been more efficient, the recovery of N and yield may have been higher.

Table 4. Nutrients taken up by a 10.0 t/ha irrigated maize crop at DDRF in 1999

Plant part	N kg	P kg	K kg	S kg	Ca kg	Mg kg	Zn grams	Cu grams	Fe grams
Nutrient removed per tonne of stover	6.0	0.42	15.1	0.48	2.5	1.6	27	4	34
Nutrient removed per tonne of grain	13	2.3	2.75	0.91	0.04	0.88	18	2	12
Total nutrients removed in 10 t of grain	130	23.0	27.5	9.1	3.8	8.36	171	19	114
Total nutrients taken up in grain and stover*	190	27.2	178.5	13 .9	27.5	23.5	441	57	454

* The total nutrient taken up in a 10 t/ha grain crop with 8.0% protein. A 10 t/ha grain crop produces an equivalent amount of stover. Nutrients in the stover are returned to the soil when it is ploughed back.

Variety performance and plant population

The trial crop was harvested on 26 August, 153 DAS when grain moisture was below 15%. Grain moisture was recorded and grain weight was corrected to 12% moisture.

PIONEER 3237 was the best performing variety at 11.09 t/ha and was significantly better than five other varieties. HYCORN 75, PIONEER 31M10 and DK 689 were the next best yielding varieties (Figure 5). All varieties yielded 9.0 t/ha or higher except PACIFIC 338 which had a significantly lower yield due to poor seeding vigour and emergence. It also had significantly lighter grain than most of the other varieties. The trial area averaged 9.40 t/ha. The poor fertiliser distribution at planting may have reduced overall yield potential.

A comparison of the high and low populations (i.e. the thinned and un-thinned) showed there was no significant difference in yield or grain density (i.e. kg/hectolitre) between or within varieties, when variety Pacific 338 was excluded from the analysis (Tables 5 and 6). While the yield of individual varieties varied, it was not influenced by either population in this trial. Pacific 338 had a significantly lower yield and this was due to its poor establishment, low population and lighter grain. This showed that when populations are significantly lower (i.e. 30% lower) than recommended, there will be a big yield penalty. For all other varieties, 75 000 to 80 000 plants/ha gave an equivalent yield to that of 91 000 + plants/ha. This illustrates that there is a tolerance to slightly higher plant populations (17 to 22%) than recommended but no yield advantage or penalty. However, in commercial practice higher populations than recommended will result in unnecessary seed costs and may induce lodging (due to thinner stalks) at the end of the season.

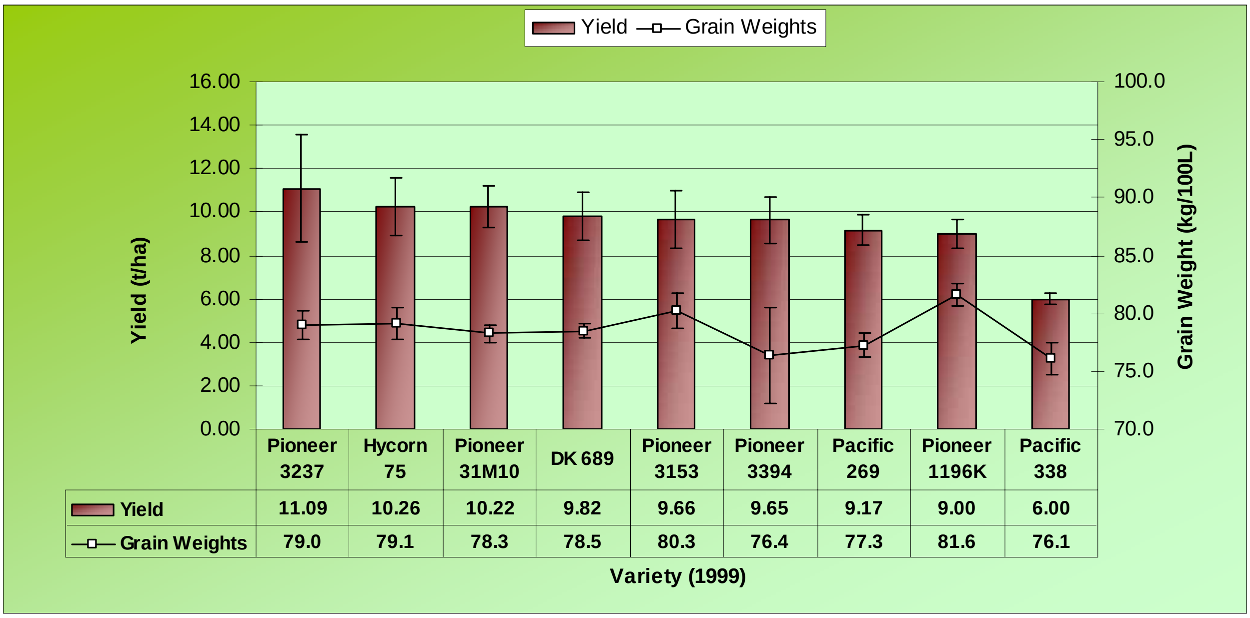


Figure 5. Yield and grain weights for the 1999 maize variety evaluation at DDRF with 95% confidence intervals

Table 5. Plot yield (kg/plot) analysis of varieties in thinned and un-thinned maize populations

Variety	Weight - mean	
Thinned	6.600	a
Unthinned	6.445	a
LSD (p<0.05)	0.3467	
p-value	0.368 (not signif)	
CV (%)	11.0	

Means with a common letter are not significantly different
Thinned = 78 000 plants/ha. Unthinned 91 500 plants/ha

Table 6. Plot grain density (kg/100 L) analysis for thinned and un-thinned maize populations

Variety	Original scale	
Thinned	77.300	a
Unthinned	76.746	a
LSD (p<0.05)		
p-value	0.146 (not signif.)	
CV (%)	0.5	

Means with a letter common letter are not significantly different
Thinned = 78 000 plants/ha. Unthinned 91 500 plants/ha

Weeds, pests and diseases

The application of Primextra® provided excellent control of broadleaf and grass weed. Nutgrass (*Cyperus rotundus*) was the only weed not controlled. Nutgrass is becoming an increasing problem on the experimental areas at DDRF.

Insect pressure was high throughout the 1999 dry season. Large populations of leafhoppers, (*Circadulina bimaculata),* heliothis (*Helicoverpa* spp.), Northern Armyworm, (*Mythimna separata)* and the green vegetable bug (GVB) (*Nezara viridula*) were present and required control on three occasions. GVB can build-up to extremely high populations, feeding on and shrivelling the developing kernels and distorting the ears. This allows heliothis to enter the ear sheath and cause further damage (Figures 7 and 8).

Leafhoppers are small mobile insects which are difficult to detect. They are a serious pest because they transmit WEV which stunts and renders maize plants unviable (Figure 6). They were present in the crop from the first week after emergence. Their eradication within the first 14 days is critical for disease control. If not managed, WEV is one of the most severe diseases affecting irrigated maize in the NT. Leafhopper infestation in irrigated maize is a constant threat because the crop is usually the only alternative source of food available in the dry season.

The chemical applications were effective in protecting the crop; however, by harvest, GVB had re-established in large numbers (two to four insects per plant) from adjoining legume pastures. An integrated pest management program should be an integral part of commercial maize production in the NT.

Note enlarged veins and upright growth

Figure 6. (a and b) Symptoms of wallaby ear virus transmitted by leafhoppers

Figures 7a and b. (a) Helicoverpa larva feeding on young maize ear. **(b)** Green vegetable bug and egg raft on maize leaf

Figures 8a and b. (a) Northern armyworm damage in maize **(b)** Armyworm larva

Irrigation requirements

The trial area received approximately 4.8 ML of irrigation. Applied water was recorded on a water meter at the bore and tensiometers were used to monitor soil moisture. Irrigation scheduling was based on weekly pan evaporation and crop factors. The crop was planted in a full profile of moisture and received 10.0 mm of irrigation to enhance germination and activate the herbicide. Intermittent showers in late March and early April reduced the need for irrigation until 9 April. Irrigation continued until 12 July, 109 DAS at which time the crop was physiologically mature. Crop water requirement will vary each year depending on time of planting, cultivar, amount of residual soil moisture and seasonal evaporative demand.

Figure 9. Jetfill® tensiometer used to assist in scheduling irrigation for maize

Irrigating crops on light soil without monitoring equipment requires a degree of “guess work”. It is difficult to determine the depth of water infiltration as water and nutrients can be pushed beyond the root zone. Using pan evaporation is only partially accurate as evaporation rates can vary widely over a few days. With wide fluctuations in evaporative demand it is difficult to maintain optimum irrigation schedules. In practice, relying solely on pan evaporation often leads to under-or-over-watering, which results in a reduction in yield and/or an increase in the cost of production.

Summary

The 1999 maize evaluation demonstrated that commercial hybrids are capable of producing 9.0 to 10.0 t/ha on Blain soils under irrigation in the Daly Basin. Pioneer 3237 achieved almost 11 t/ha which was not significantly different from DK 689, Hycorn 75 or 31M10. Pacific 338 had a significantly lower yield due to poor establishment, demonstrating the need to have optimum plant populations for viable yields.

Populations of 70 000 to 80 000 plants/ha are adequate for optimum yields of the varieties evaluated. There was no advantage in increasing the seed rates beyond that recommended by seed companies.

The N deficiency (caused by uneven fertiliser distribution at planting) demonstrated the need to have good nutrition early in the crop’s life. This is particularly important for maize on light soils. Zn and B applications prevented some of the nutrient disorders commonly seen in maize grown on sandy soils in the Douglas Daly region in the past.

Insect pressure in 1999 was high and is a major concern. The incidence of leafhoppers, GVB, armyworms and heliothis is a threat to the viability of commercial maize production unless effectively managed. WEV is a serious threat and an effective, integrated pest management strategy should be developed.

Water management and water use efficiency was adequate in 1999 but could be improved with the use of soil moisture sensors.

DRY SEASON 2000

Materials and methods

The maize trial was repeated in 2000 using the best performing varieties of 1999 plus Hycorn 90, 32P75, Cracker Jack, Genex 2 and Pacific 53IT. Eleven hybrids were planted on 28 April 2000 on Circle 2 centre-pivot at DDRF in a randomised complete block. Only one population was evaluated. A Nodet Gougis precision, vacuum planter (Figure 1) was used instead of the Mason Maxi Strike planter. The planter has the capacity to band fertiliser beneath and to the side of the seed. This ensured that nutrients were available immediately and eliminated the nutrient deficiency which occurred in 1999. A basal fertiliser was banded at planting at the rate of 100.0 kg/ha consisting of 9.0 kg N, 19.0 kg P, 10.0 kg S, 2.5 kg Zn and 2.5 kg Cu/ha.

A plant population of 86 000 plants/ha was established at a row spacing of 75 cm. The crop received approximately 250, 40, 150, 81 and 15 kg/ha of N, P, K, Mg and Zn, respectively in total. Soil water and irrigation applications were monitored with “Jet-Fill” tensiometers set at 15, 30, 45 and 60 cm.

Insect control was carried out on five occasions. Two Rogor® (0.5 L/ha of 400.0 g/L a.i. dimethoate) and one Lannate® (1.5 L/ha of 225.0 g/L a.i. methomyl) treatments were applied between week three and week five to control leafhoppers and prevent WEV. Armyworms, heliothis and GVB were present in high numbers at silking. Two aerial applications of insecticide were carried out, one prior to silking and one during silking. Rogor® (800.0 mL/ha of 400.0 g/L a. i. dimethoate) and Lorsban® (2.0 L/ha of 300.0 g/L a. i. chlorpyrifos) were tank mixed and applied by helicopter on 10 July to control a heavy infestation of GVB, *Helicoverpa* spp. and armyworms during pollination. The trial crop was harvested with the same commercial header as in 1999.

Figure 10. A Nodet Gougis vacuum planter, capable of banding fertiliser below and beside seed

Results and discussion

All varieties established well. Banding fertiliser below and to the side of the seed improved the nutrient status, appearance and early vigour of the maize. There were no visible nutrient deficiencies.

Leafhoppers required control on three occasions due to the high numbers and the speed of reinfestation. GVB adults, nymphs and egg rafts were evident in the crop throughout the season. GVB populations can increase rapidly in the presence of Cavalcade, which is a host of GVB in the district. Once Cavalcade is harvested in April and May, GVB migrate to maize and other irrigated crops. It is interesting that GVB were in higher numbers in the maize crop than in the adjoining peanut crop. Due to the high numbers of insects the trial area was sprayed with a combination of Rogor® (800.0 mL/ha of 400.0 g/L a. i. dimethoate) and Lorsban® (2.0 L/ha of 300.0 g/L a. i. chlorpyrifos) at silking time to try and prevent damage to reproductive parts.

Table 7. Insect pests on irrigated maize at DDRF, 2000

Insect pest	Growth period and damage
Leafhoppers (various) *(Cicadulina bimaculata)* Possibly *Chiasmus* sp. and *Orosius* sp.	From emergence through to week 5 or 6. Hoppers transmit 'wallaby ear' i.e. stunting and distortion and thickening of leaf and veins.
Armyworms (*Mythimna separata)*	Late vegetative stage to silking. Defoliate plants and may damage flag leaf and silks.
Green vegetable bug *(Nezara viridula)*	Heavy infestations cause distortion of cobs and damage to individual kernels.
Heliothis *(Helicoverpa amrigera/punctigera)*	Damage to silks and cobs.

Prior to the application of Rogor® and Lorsban® in July the crop appeared to be in excellent health with no apparent disorders. After spraying, it was apparent that normal pollination was not occurring (Figures 12 and 13). A large proportion of plants in all varieties produced multiple and partially-pollinated ears. Stem distortion was also evident and some plants produced up to five barren ears. The severity of damage varied throughout the varieties and no distinct pattern could be identified.

The damage to each variety in each replication was rated on the number of plants with partially- pollinated cobs. The two earliest varieties (32 P75 and X32 J55) and one of the latest maturing varieties (Pioneer 3237) had the highest yields and the least amount of damage. These varieties may have escaped the effect of the chemical while the intermediate flowering lines had more damage and lower yields. Figure 11 shows that the varieties with the lower degree of damage produced the best yields.

The exact cause of the damage and poor pollination has not been ascertained. One possibility is that the combination of Rogor® and Lorsban® applied at tasselling reduced the viability of the pollen, damaged the silks or physiologically interfered with the fertilisation process. Another is that the spray vat was contaminated with herbicide. Information was sought from maize specialists in Australia and the US but no satisfactory explanation could be found. Insecticides are regularly used in sweet corn crops during silking with no phyto-toxic effects reported. Avoiding the use of insecticides at silking may prevent such occurrences.

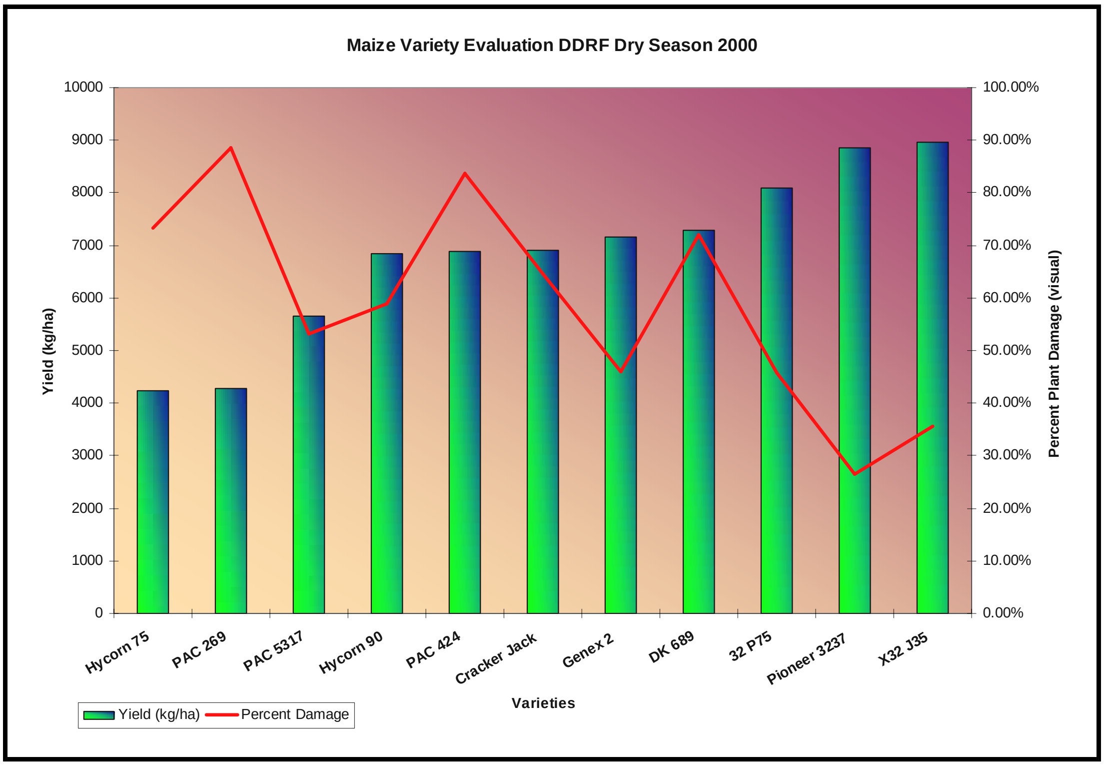


Figure 11. Yield and proportion of physiological damage in maize varieties in 2000

Variety performance

The crop was harvested on 3 September 128 DAS. Yields in 2000 were reduced as a result of the physiological damage and the incomplete pollination. In 1999 the site mean yield was 9.4 t/ha. In 2000 it was only 6.8 t/ha, a 28% reduction from the previous year. The yields are presented in Table 8. No statistical analysis was undertaken due to the variable damage throughout the trial.

Figures 12a and b. (left) Characteristic stem bending evident in 2000. (right) Un-pollinated ear. The damage coincided with an insecticide application between tasselling and at silking.

Figures 13a and b. (left) GVB nymphs on maize and (right) typical cob distortion caused by bugs feeding on outer kernels

Table 8. Maize variety yield, 2000

Variety	Name	t/ha 12% moisture
1	PAC 442	6.8
2	Hycorn 75	4.2
3	Hycorn 90	6.8
4	DK 689	7.2
5	PAC 269	4.2
6	Pioneer 3237	8.8
7	X32 J55	8.9
8	32 P75	8.0
9	Cracker Jack	6.9
10	Genex 2	7.1
11	PAC 53IT	5.6
	Mean	6.77

Average machine harvested yield from 4 replications

Summary

The 2000 trial had a high level of insect infestation as in 1999 and required multiple insecticide applications. The level of control required will reduce the economic viability of maize production unless alternative cost-effective pest management strategies are employed. The 2000 trial identified a possible hazard with trying to control insects at pollination. The chemicals or their combination (Rogor® and Lorsban®) while not conclusively proven, may have interfered with the pollination process and reduced yield. The other possibility is herbicide contamination of the spray vat. The frustrating aspect is that the cause of the damage remains unknown.

The positive aspect of the 2000 trial was the success of banding fertiliser below the seed at planting time which resulted in improved uniformity, early vigour and enhanced the nutritional status of the crop. There were no visible nutritional disorders in the 2000 crop and N status at 20 DAS was within the recommended range i.e. 3.5 to 5% N.

Improving pest management in irrigated maize production is a high priority.

DRY SEASON 2001

Materials and methods

Nine commercial varieties of maize were sown in a conventionally prepared seedbed under the centre pivot at DDRF on 10 April 2001. The varieties and yields appear in Table 1 and Figure 3. The trial crop was planted with a Nodet Gougis vacuum planter with basal fertiliser banded beneath the seed. Mungbeans (cv Putland) were grown during the previous wet season and ploughed in prior to planting. The trial was a randomised complete block with four replicates, with plots 150 m long by four rows. The plots were surrounded by maize to protect the trial crop from bird damage. The total planted area was approximately 5 ha. Leaf samples were taken 35-40 DAS and at silking to determine nutritional status. Hand harvests were taken and total plot yield was measured using a commercial International 1420 header.

Fertiliser was applied pre-planting, at planting (banded) and by fertigation. The trial crop received 250.0 kg N, 40.0 kg P, 150.0 kg K, 33.0 kg S, 64.0 kg Mg, 20.0 kg Zn and 1.5 kg B. The established plant population was between 75 000 and 84 000 plants per/ha (recommended by seed companies) at a 75 cm row spacing.

An Enviroscan® soil moisture sensor and Jet-Fill® tensiometers were used to monitor irrigation and soil moisture content. The crop received approximately 5.0 ML/ha of water. Weeds were controlled by a post-planting, pre-emergent application of Primextra® at 5.0 L/ha (277 g/L a.i. metolachlor and 223 g/L a.i. atrazine).

An Insectigator III® chemigation unit (Figure 1) was installed on the centre pivot in 2001 to evaluate the efficacy of pesticides applied through the irrigation water. The unit injects precise amounts of chemical directly into the irrigation water. A non-return valve was fitted to the delivery line at the pivot to prevent back-flow and chemical entry into the supply line.

Figure 14. Insectigator III® chemigation unit showing tank and pump

In 2001 Gaucho® (imidacloprid), a systemic seed dressing in the nitroguanidine group of chemicals, was evaluated for the control of leafhoppers and WEV. Gaucho® is a low-toxicity chemical which was introduced in 1997 and has been successfully used in cotton to control thrips, aphids and wireworms. All of the varieties were treated with Gaucho®. An untreated (un-replicated) observation area was established adjacent to the main trial to compare the effect of Gaucho® on leafhopper numbers.

Seed treatments reduce the amount of chemical needed, act specifically on pests, are safe to beneficial insects and reduce the need for handling and spraying insecticides. Gaucho® -treated seed is available from seed companies for the control of a range of soil insects and sucking pests.

Soil moisture was monitored using an Enviroscan® soil moisture sensor (Figure 2). An Enviroscan® is a capacitance sensor which continuously measures volumetric soil moisture at defined depths in the profile.

The measurements are stored in a data logger which is down-loaded to a computer software package. Graphs are generated which show soil water content, drainage and crop water use (Figures 18 and 19).

Figure 15. Installing an Enviroscan® soil moisture monitoring probe

Results and discussion

Analysis of variance showed a significant difference between varieties. Q81 yielded significantly less than all other varieties. Yields from DK 689, (which averaged nearly 11 t/ha), Pacific 424, Hycorn 75 and Pioneer 3335 were not significantly different. Most of the other varieties (excluding Q81) did not differ significantly from Pioneer 3335, which had a yield of over 10.0 t/ha.

Hand-harvests produced yields of over 14.0 t/ha in some varieties but on average machine harvested yields were 22% lower. This highlights the importance of large machine harvested plots in assessing the true commercial potential of a particular crop. This trial indicated that many commercial varieties are capable of producing 10 t/ha on Blain soil in the Top End. DK 689, Pioneer 3237 and Hycorn 75 have provided consistently high yields over the past three years.

Lodging was visually rated from 1 to 5 (i.e. from mild to severe). Cracker Jack had the highest lodging score of 2.6 followed by DK689 and Pioneer 3237 at 1.63. Most of the other varieties had low ratings for lodging.

Table 9. Variety yields, 2001

Varieties	Hand-harvested yield (kg/ha*)	Machine-harvested yield (kg/ha)	Difference between hand and machine harvested yields (%)
Pac 53IT	12.9	9.59	25.7
Hycorn 75	13.1	10.79	17.6
Pac 424	14.2	10.86	23.5
Pioneer 3335	12.1	10.19	15.8
Pioneer 3153	14.3	9.54	33.3
Q 81	9.9	7.60	23.2
Cracker Jack	11.9	9.71	18.4
Pioneer 3237	13.3	9.61	27.7
DK 689	12.9	10.99	14.8
Site mean	12.7	9.87	22.3

*Yield is the average weight from ten hand harvested plants from each replication converted to t/ha

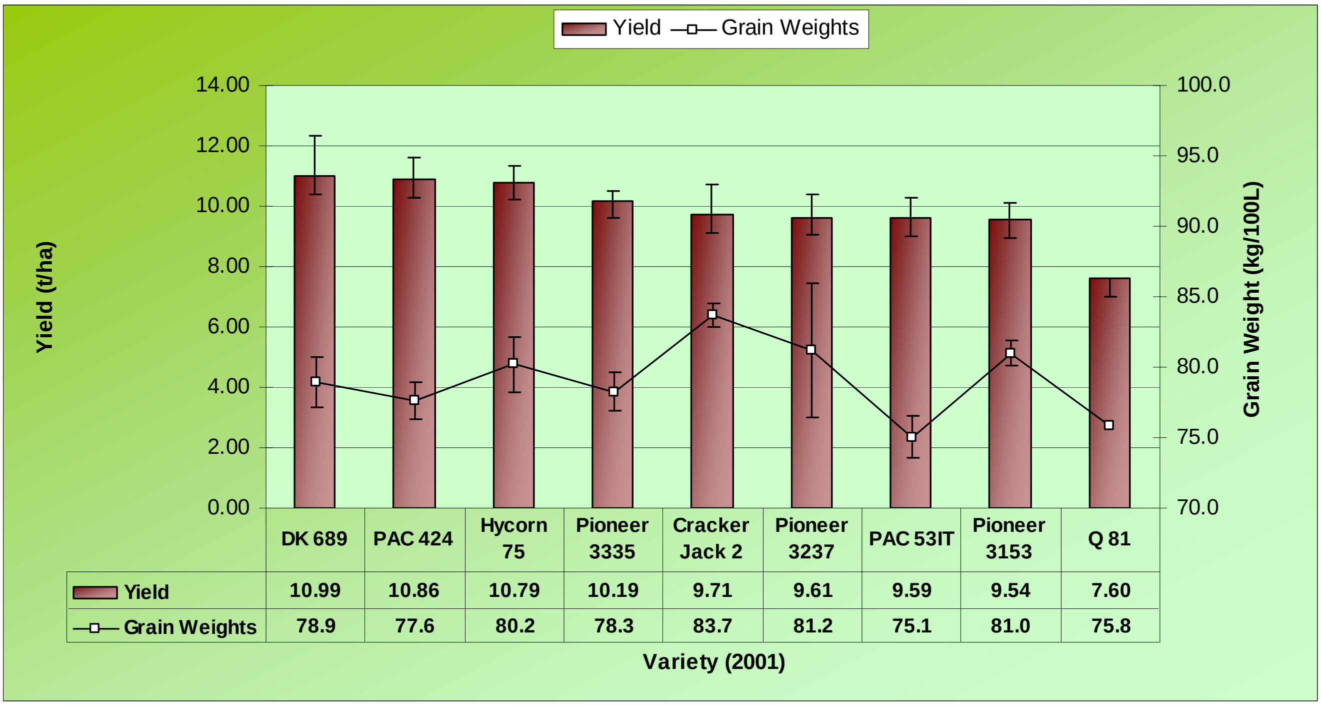


Figure 16. Yield and grain weights for 2001 maize variety evaluation at DDRF at 95% confidence intervals

Gaucho® effectively controlled leafhoppers and WEV. The non-treated area was severely affected by WEV, where plants were stunted, had shorter stalks, smaller leaf area and poor root development. The treated area had a lower number of leafhoppers and no visible disease symptoms. Gaucho® eliminated the need to apply insecticides for leafhopper control in 2001 whereas three chemical applications were required in previous seasons. Yield from the affected area varied from 2.6 to 5.8 t/ha compared with an average of 9.8 t/ha from the treated area (Table 10).

Table 10. Effect of Gaucho® on leafhopper numbers

	Control (non-treated)	**Gaucho-treated**
Leaf-hopper numbers (insects /10m row*)	94	5
Yield	2.6**to 5.8 t/ha	9.8 t/ha mean of all treated varieties

*Average number from multiple vacuum samples from 10 m row
**Yield from the most severely affected area

The Insectigator III® chemigation unit was used to apply insecticides and biocides to control a range of pests. Gemstar® at 500 mL/ha (a. i. Nuclear Polyhedrosis Virus) and DiPel Forte at 500 g/ha (a. i. *Bacillus thuringienesis* var *kurstaki*) were applied to control armyworms and Helicoverpa spp. Gemstar® appeared (observation only) to be more effective in reducing larvae numbers than Dipel®. Biological insecticides need to be applied when the larvae are very small. Monitoring and identification of eggs and small larvae is necessary to determine the optimum time for application.

GVB infested the crop in large numbers. Dipterex® at 1.1 L/ha (500 g/L trichlorfon a.i.) was applied prior to silking and Decis Options® (synthetic pyrethroid) was applied at 2.5 L/ha (deltamethrin 27.5 g/L a.i.) at early grain fill to control Helicoverpa sp. GVB.

The combination of Gaucho® and chemigation was more efficient and cost effective in reducing pest populations and disease than applying chemicals either by ground-rig or by aircraft.

Figures 17a and b. (a) Maize (top right hand corner) was Gaucho® treated and grew normally. Maize in foreground (un-treated) and was stunted by WEV. (b) Plants on the left were treated with Gaucho® and show normal growth. Stunted plants (un-treated) on the right are the same age and cultivar and severely affected by WEV.

An Enviroscan® moisture meter was used to monitor soil water in the 2001 season. Moderate evaporation rates in April and May, low soil-moisture holding capacity and low initial crop water demand dictates that the crop receives frequent but light irrigations. A schedule of 15.0 mm of water was applied about every three days (i.e. 35.0 mm/week) for the first six to seven weeks. This kept the soil surface and upper profile moist to enhance rapid and uniform germination. Moisture gradually drained down to 70.0 cm by week four (Figure 18) and to 100.0 cm by week five (Figure 19). This indicated that the water application was heavier than the rate of crop uptake. However, lighter or less frequent irrigations risked drying of the seed-zone which may have affected crop emergence.

The Enviroscan® graphs showed that by week four to six the maize was extracting water from 70 cm. There was also evidence of root activity at 100.0 cm (Figure 19). Between weeks 4 and 5 the crop began to rapidly use moisture from the 40.0 to 70.0 cm depth. This period coincides with rapid plant development and when the number of kernels and the size of the ear is being determined. By week six the crop had largely used most of the moisture from below 40.0 cm and there appeared to be little root activity below this zone.

At week seven the irrigation schedule was increased 20.0 to 25.0 mm applied every four days (i.e. 35.0 to 43.0 mm/week) in line with crop water requirements. This was sufficient to keep the profile full to 40 cm without causing drainage to lower levels. By late May the Enviroscan® showed there was little moisture available for extraction between 50.0 and 70.0 cm. However Figure 19 shows that there was some water extraction at 100.0 cm during week 6 to 9 while moisture was available at this depth. After week 9 there appeared to be little root activity at 100 cm due to declining moisture availability. From late May onwards, the majority of active water extraction was in the 10.0 to 40.0 cm zone where there was ample soil moisture available.

From July to August irrigations were reduced to 20.0 mm every five days (28.0 mm/week) as the crop approached maturity. The crop received approximately 5.0 ML of water for the season giving an average water use efficiency (WUE) of 1.96 t/ML. This equates to 19.6 kg of grain/mm of water applied which compares favourably with figures in the literature of 16.0 to 18.0 kg of grain/mm of water applied (Brown 1997).

The Enviroscan® assisted in scheduling irrigation more accurately and prevented moisture and nutrients being leached below the root zone. Learning to install and interpret soil moisture data accurately is critical in using monitoring equipment and improving water management. The graphs illustrated that the early irrigation was probably too heavy (resulting in drainage to 100.0 cm), while the schedule in the middle of the season was probably too light (depletion of the 50.0 to 70.0 cm zone). One or two heavier irrigations in June would have improved moisture availability lower in the soil profile, decreasing the risks of moisture stress.

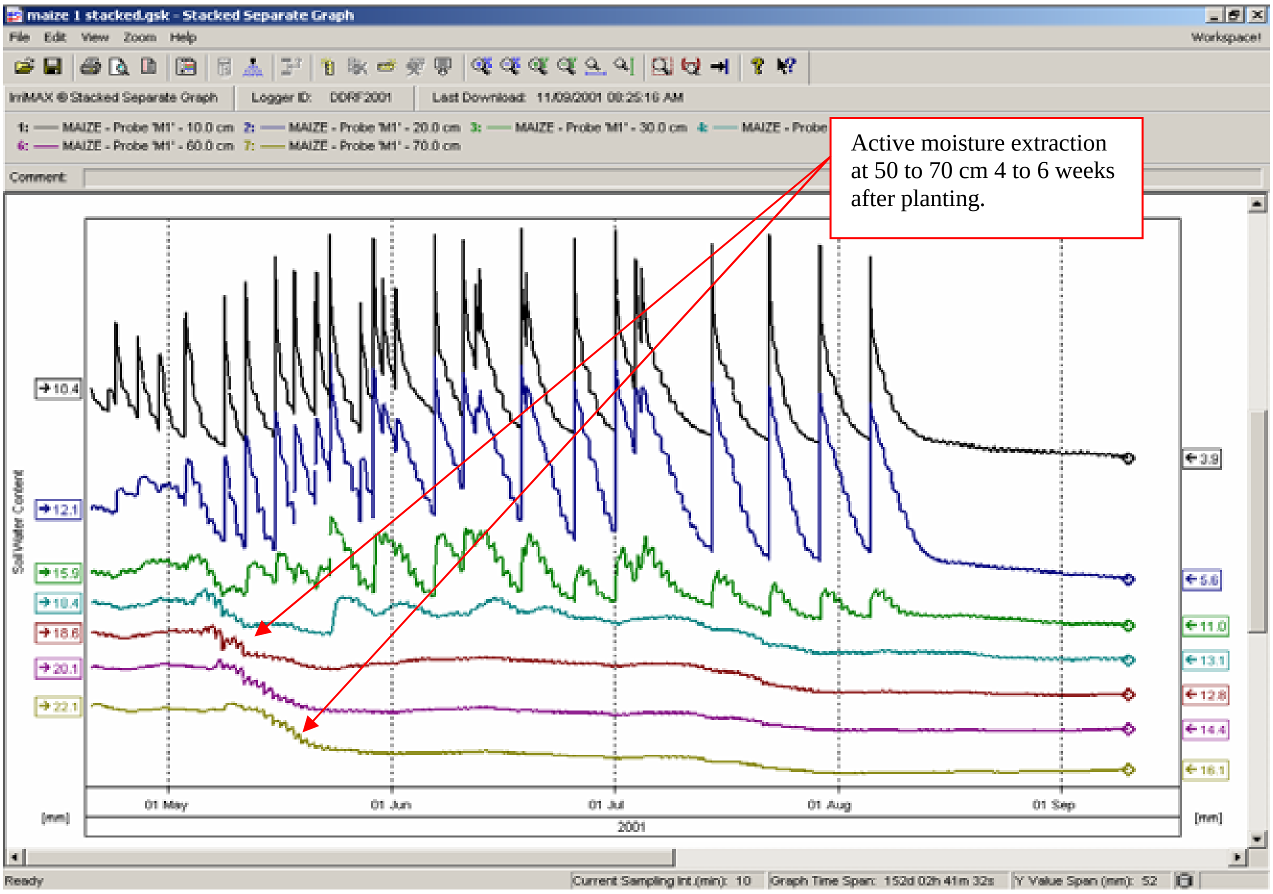


Figure 18. Enviroscan® readings from 10.0 to 70.0 cm levels in the 2001 maize trial

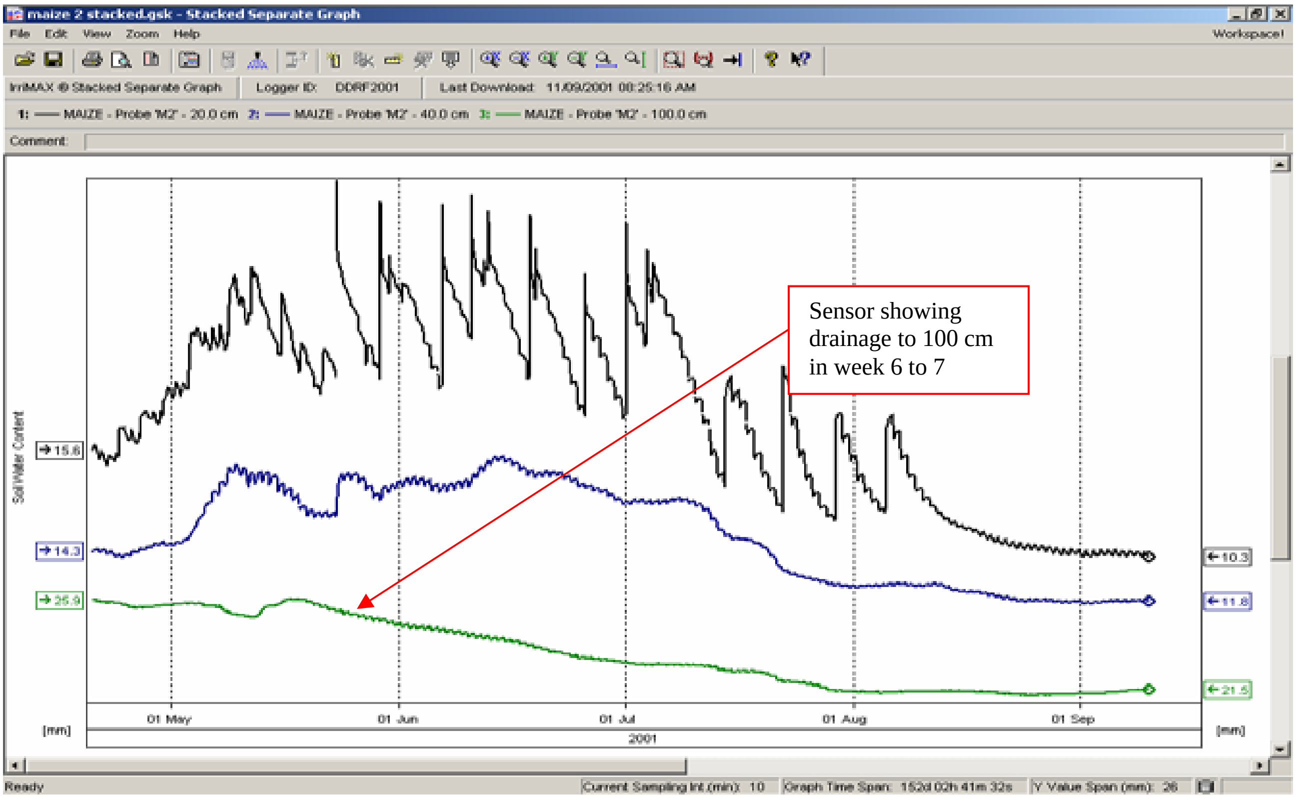


Figure 19. Enviroscan® readings for 20.0, 40.0 and 100.0 cm levels

Summary

The 2001 trial confirmed that commercial maize hybrids are capable of producing yields in excess of 10.0 t/ha on light soils in the Katherine-Daly basin. Four varieties produced over 10.0 t/ha and the combined trial averaged 9.8 t/ha.

The systemic seed dressing and chemigation greatly improved pest management and reduced overall chemical usage. Gaucho® provided excellent control of leafhoppers and WEV and eliminated the need for insecticides in the early vegetative period. Chemigation proved successful in controlling pests during tasselling and grain fill, and eliminated the need for aerial application. The efficacy of Gemstar®, Dipel® and similar products needs further evaluation under NT conditions. Unfortunately, these products do not control GVB, which can be a serious pest in irrigated maize.

Irrigation scheduling in 2001 was improved by using an Enviroscan® and a high WUE was achieved. However, allowing the profile to dry below 40 cm means there is no reserve of soil moisture at depth. Filling the profile to 60.0 to 80.0 cm, prior to silking and pollination will ensure moisture is available during the critical growth phase and will reduce the risk of moisture stress if something goes wrong with the irrigation system. Maintaining good soil moisture in the lower profile is desirable but difficult to achieve in light soils of high permeability. Due to the low water holding capacity of Blain soils, water which is not taken up by plants, will drain to lower levels in the profile and eventually pass beyond the root zone.

Moisture meters will certainly assist in fine tuning irrigation schedules on light soils.

DRY SEASON 2002

Materials and methods

Four of the most consistent varieties from previous trials (DK 689, Pioneer 3153, Pioneer 3237 and Hycorn 424), three new commercial varieties (Hycorn 449, Hycorn 901and Pacific 675) plus an experimental variety (Pioneer X1180) were evaluated in 2002. The trial was sown into a conventionally prepared seedbed on 26 March using a Nodet Gougis precision vacuum planter. A mungbean green manure crop (cv. Putland) was grown over the wet season and ploughed in, four weeks prior to sowing. The average plant population over the trial was 69 642 plants/ha with a low of 65 000 and a high of 74 600 plants/ha.

The trial was a randomised complete block with three replicates and plot sizes of 120.0 m long, by eight rows. The trial crop was harvested on 6 September, 164 DAS. The trial was harvested with an International 1420 header.

An Enviroscan® was used to monitor soil moisture content and assist in irrigation scheduling. The crop received approximately 5.5 ML/ha of water. Weeds were controlled by a post-plant, pre-emergent application of Primextra® at 5.0 L/ha.

An Insectigator III® chemigation unit was used to apply insecticides and biocides to control armyworms, *Helicoverpa* spp. and GVB. A low tolerance of insect pressure was maintained to ensure maximum yield. Lorsban® was applied pre-tasselling and Dipel® and Gemstar® were applied during pollination to control armyworms and *Helicoverpa* larvae. Seed was treated with Gaucho® to control leafhoppers and WEV.

Fertiliser was applied pre-plant, at planting (as a band beside and below the seed) and through the fertigation system. A total of 330.0, 40.0, 250.0 and 30.0 kg/ha of N, P, K and S, respectively was applied during the life of the crop. Mg, Zn and B were also applied at the rate of 50.0, 5.0 and 1.5 kg/ha, respectively.

Results and discussion

Yields in 2002 were higher than in the previous three seasons (Figure 1). Lower insect pressure, improved varieties and increased N and water may have contributed to higher yields in 2002.

The average yield of all the varieties was 11.7 t/ha. Pacific 675, yielded 12.7 t/ha and was significantly better than all varieties except Pioneer 3237. Hycorn 449 gave a significantly lower yield than the other varieties but still produced 10.0 t/ha. There were no significant differences in yield between Hycorn 901, Hycorn 424, DK 689, Pioneer 3237, Pioneer X 1180 and Pioneer 3153. Yields are presented in figure 20.

The crop received 5.5 ML/ha of irrigation in 2002 compared with about 5.0 ML/ha in 2001 in spite of being planted two weeks earlier than the 2001 crop. Pre-plant watering was carried out to fill the top 30.0 cm of the soil and to promote good germination. Irrigation rates were on average higher than in 2001 to allow moisture to penetrate to below 50 cm. Despite the increased water usage in 2002, WUE was marginally higher at 2.12 t/ML (21.2 kg/mm) compared to 1.96 t/ML (19.6 kg/mm) in 2001.

Based on the average site yield of 11.7 t/ha, the crop (including stover) took up a total of 266.0 kg/ha of N, 31.0 kg/ha of P, 183.0 kg/ha of K, 15.0 kg/ha of S and 0.4 kg/ha of Zn. Between 190.0 and 207.0 kg/ha of N was taken up in the maize grain, depending on variety and yield.

Hand harvests were taken from different populations in the surrounding bulk area to estimate potential silage yields. Table 16 lists a range of plant populations with corresponding oven-dry weights. Weights were converted to an equivalent silage yield (t/ha) at 40% dry matter (DM). While no conclusion can be drawn (due to the small sample) biomass increased with increasing plant densities up to a maximum population of 170 000 plants/ha. Populations over 80 000 plants/ha is likely to give optimum dry matter yields. However, plant population for silage production will depend on agronomy, planting time, variety, soil type, row-spacing and many other variables. Commercial companies will recommend optimum population for specific varieties and uses.

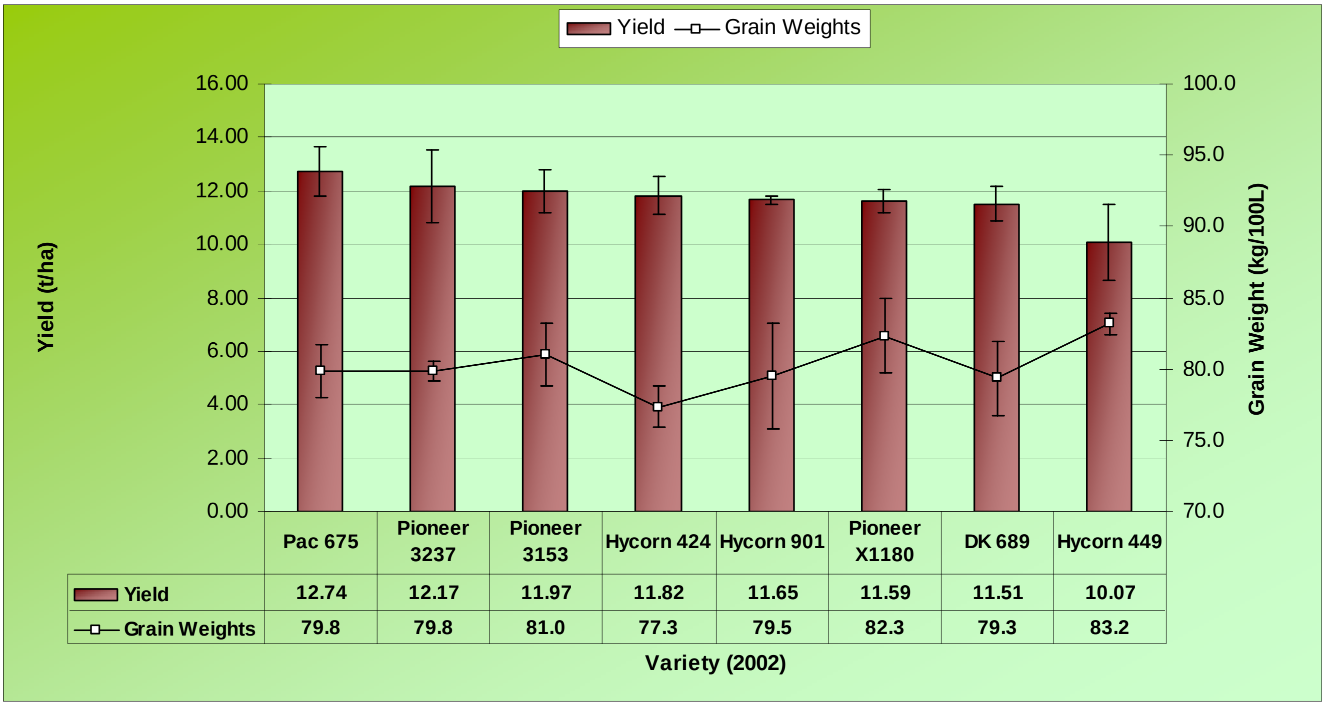


Figure 20. Yield and grain weight for the 2002 maize variety evaluation crop at DDRF, at 95% confidence intervals

Table 11. Hand harvest biomass yields of irrigated maize 2002, DDRF

Average plants/ha	Total oven dry biomass (t/ha)	Equivalent silage yield (t/ha) (40% DM)
170 000	24.5	61
156 660	23.6	59
140 000	20.6	51.5
86 664	20.3	50
83 331	19	47.5
81 664	21.2	53
73 331	18.1	45.3
61 665	18.33	45.8

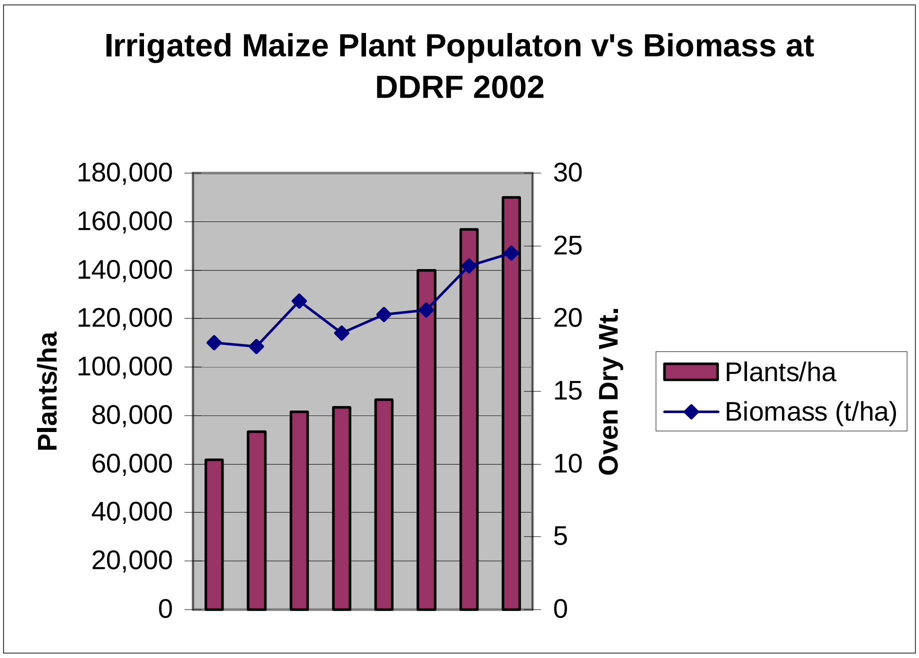


Figure 21. Plant population and oven dry yield (t/ha) of irrigated maize at DDRF in 2002

Resistance to lodging, stem strength and resistance to disease are important aspects of maize production in the tropics. Maize stalks tend to collapse relatively quickly after physiological maturity. Lodging is usually more severe in thin stalked varieties.

Lodging was not severe in 2002. However, varieties Pac. 424 and DK 689 tended to lodge more than other varieties in previous years. Pioneer X1180, Pioneer 3153 and Pacific 675 have thick robust stalks and are less likely to lodge. High daytime temperatures and moisture (from dews) seems to exacerbate the breakdown of stem material under tropical conditions.

Conclusion

The four year evaluation indicated that maize yields of 9.0 to 12.0 t/ha are achievable on Blain soils. The evaluation highlighted the need to get the nutrition, pest management and water scheduling right in maize production. In 2002 when nutrition, water and insect pests were well managed, yields approached 13.0 t/ha for the best varieties. The average yield for all varieties over four years was 9.3 t/ha. Excluding the 2000 season results (crop damage and incomplete pollination), the average yield for all varieties and for the best four varieties was 10.3 t/ha and 11.0 t/ha, respectively.

Higher yields may be possible on heavier clay loam (Tippera) soil types due to better moisture and nutrient retention, and good commercial yields have being reported on clay-loams at Katherine.

The trial also highlighted the importance of larger scale, machine-harvested plots in determining commercial potential. Small plots are useful for direct varietal comparison, but give artificially high estimates of field performance. Information provided to growers and agribusiness needs to be based on realistic and achievable yields obtained from commercial sized trials.

Varieties DK 689, Hycorn 75 and Hycorn 90 have been replaced by new lines. New hybrids are continually being developed and will need to be evaluated prior to broad-scale plantings in the NT. At the time of writing, varieties which could be recommended include Pioneer 3237, Pioneer 3153, Hycorn 424, Hycorn 901 (replaces Hycorn 90) and Pacific 675 (replaces Hycorn 75).

Insect and disease management are high priorities in irrigated maize in the NT. Leafhoppers and WEV are the biggest economic threat. However, Gaucho® effectively controlled the insect vector in this evaluation. Dry season maize seed should be treated with Gaucho® or an equivalent registered systemic chemical. Other systemic seed treatments should be evaluated for leafhopper control and other insect pests.

Armyworms, heliothis and GVB have the potential to cause economic damage. Crops may require insecticide treatment if pests reach threshold levels. Chemigation has proven effective and eliminates the expense of aerial application. Chemigation allows more precise timing of pesticide application which is the key to controlling insects. It also allows the use of 'softer' control options such as Gemstar®, which targets caterpillar pests while minimising the impact on beneficial insects. However, chemigation must be carried out in accordance with the relevant legislation and only with chemicals which are registered for the purpose.

Birds, pig and wallaby damage is a major consideration in isolated crops especially near river systems. The trial area was protected from pigs and wallabies but damage from sulphur crested cockatoos occurred. Cockatoos completely strip cobs but generally concentrate on the edge, gradually eating their way in. Pigs damage much more than they consume and pig-proof fencing will be required in many areas.

Maize is an expensive crop to produce in the NT due to high fertiliser, freight and fuel costs. Optimum plant populations, adequate water and nutrition, good weed, insect and disease management and adapted high yielding hybrids are the keys to viable maize production. Maize will only be viable at the highest levels of production.

Further R&D is needed to refine water and nutrient use in maize in the tropics. The N contribution of green manure and legume rotation crops should be quantified, as N constitutes one of the highest production costs. Identifying varieties with greater yield potential and pest and disease resistance will also enhance the crop's viability.

Insect pests are a constant threat in tropical farming systems. Developing effective integrated pest management systems for maize and other irrigated crops and keeping abreast of new developments in crop production, nutrient and water management is imperative for long term sustainability.

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