REDUCING THE ENVIRONMENTAL IMPACT OF DAIRY FARMING ON WATER AND SOIL QUALITY

A CASE FOR MAIZE SILAGE

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Raewyn Densley graduated from Massey University with a Bachelor in Agricultural Science with Honours in 1990. For the last 24 years she has been working for Genetic Technologies Limited in a range of roles assisting livestock farmers to profitably integrate Pioneer® brand maize silage into their farming systems. She has co-authored 11 peer reviewed scientific papers and written hundreds of technical bulletins and editorial articles on all aspects of maize silage growing, harvesting and feeding.

**Ian Williams**

For the last 14 years Ian Williams has been working as a forage and dairy specialist for Genetic Technologies Limited. Over this period he has had the privilege of working with many of New Zealand’s top dairy farmers as they have profitably introduced maize silage into their farm systems. During this time he has gained a critical understanding of the key management factors needed to make higher input dairy systems profitable and environmentally sustainable. Ian holds a Bachelor in Agricultural Science from Lincoln University and a Masters in Development Management (with Distinction) from the Asian Institute of Management.

**Jakob Kleinmans**

Dr. Jakob Kleinmans is a farmer’s son from North-West Germany. He graduated with a degree in Agricultural Science from the University of Bonn, where he majored in animal production. He then went on to complete a Doctorate in Animal Nutrition, with his dissertation investigating the effect of supplementation on the performance of dairy cows. After completing a three year postdoctoral fellowship at the United States Dairy Forage Research Center in Madison, Wisconsin, Jakob was employed by Pioneer Hi-Bred Northern Europe. In his role as head of nutrition and forage conservation, he was responsible for Pioneer technical support to nutritionists and livestock farmers throughout Northern Europe. Jakob immigrated to New Zealand in 2005 to take up the position of Forage Products Manager with Genetic Technologies Limited. In this role he is responsible for ensuring that users of Pioneer® brand products maximise their forage investment by building systems that are profitable as well as sustainable into the future.

**Greg Edmeades**

Dr. Greg Edmeades completed a Bachelor and Masters of Agricultural Science at Massey University. He graduated from the University of Guelph, Canada with a PhD in Crop Physiology in 1976. Throughout his extensive agricultural career, Greg has held various research and leadership roles in North America and Africa. Much of his career was spent working with tropical maize at the International Maize and Wheat Improvement Centre (CIMMYT) in Mexico. Greg’s role of agronomist and physiologist/breeder focused on the issues in the Third World, particularly focusing on drought and low nitrogen. Up until his retirement in 2004, Greg was a Research Fellow for Pioneer Hi-Bred International based in Hawaii. He was responsible for developing tolerance to drought and improved nitrogen use efficiency. Greg has authored or co-authored 52 refereed papers and 63 publications in conference proceedings, and is a Fellow of the Crop Science Society of America. He is currently consulting both in New Zealand and internationally.

**Barry McCarter**

Barry McCarter has over 30 years’ experience in the seed sector which includes active involvement in crop breeding, cultivar evaluation, agronomic research and seed production of a range of crops. In 1986 Barry was appointed Research Manager for Pioneer Overseas Corporation where he initiated a maize breeding programme and developed a number of hybrids still sold in Southern Africa. For 10 years Barry was Executive Director of Seed Co Ltd, a regional seed business that exported seed to approximately 20 countries. Barry immigrated to New Zealand in 2002 and was appointed Executive Director of the New Zealand Grain & Seed Trade Association and New Zealand Plant Breeding and Research Association. He is currently Maize Product Manager for Genetic Technologies Limited. In this role Barry has responsibility for the sourcing, evaluation and introduction of new maize hybrids. Barry holds a Bachelor of Agricultural Science with honours from the University of Zimbabwe.

**Genetic Technologies Limited** is the New Zealand producer and distributor of Pioneer® brand products including maize and forage sorghum hybrids, lucerne varieties and microbial silage inoculants. Pioneer Hi-Bred International, Inc is the world’s leading developer and supplier of advanced plant genetics to farmers worldwide.
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## Abbreviations

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<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
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<tbody>
<tr>
<td>ANZECC</td>
<td>Australian and New Zealand Environment and Conservation Council</td>
</tr>
<tr>
<td>BOD</td>
<td>biological oxygen demand</td>
</tr>
<tr>
<td>CP</td>
<td>crude protein</td>
</tr>
<tr>
<td>cm</td>
<td>centimetres</td>
</tr>
<tr>
<td>DCD</td>
<td>dicyandiamide</td>
</tr>
<tr>
<td>DM</td>
<td>drymatter</td>
</tr>
<tr>
<td>FAR</td>
<td>Foundation for Arable Research</td>
</tr>
<tr>
<td>ha</td>
<td>hectare</td>
</tr>
<tr>
<td>kg</td>
<td>kilogram</td>
</tr>
<tr>
<td>kgDM</td>
<td>kilogram of drymatter</td>
</tr>
<tr>
<td>L</td>
<td>litre</td>
</tr>
<tr>
<td>MJME</td>
<td>megajoules of metabolisable energy</td>
</tr>
<tr>
<td>mg</td>
<td>milligrams</td>
</tr>
<tr>
<td>mm</td>
<td>millimetre</td>
</tr>
<tr>
<td>MPa</td>
<td>mega pascals</td>
</tr>
<tr>
<td>MS</td>
<td>milksolids</td>
</tr>
<tr>
<td>N</td>
<td>nitrogen</td>
</tr>
<tr>
<td>NI</td>
<td>nitrogen intake</td>
</tr>
<tr>
<td>NO</td>
<td>nitrogen output</td>
</tr>
<tr>
<td>NUE</td>
<td>nitrogen use efficiency</td>
</tr>
<tr>
<td>P</td>
<td>phosphorus</td>
</tr>
<tr>
<td>PKE</td>
<td>palm kernel extract</td>
</tr>
<tr>
<td>K</td>
<td>potassium</td>
</tr>
<tr>
<td>RED</td>
<td>Resource Efficient Dairying Trial</td>
</tr>
<tr>
<td>RML</td>
<td>Restricted Maximum Likelihood Analysis</td>
</tr>
<tr>
<td>tDM</td>
<td>tonnes of drymatter</td>
</tr>
<tr>
<td>tDM/ha</td>
<td>tonnes of drymatter per hectare</td>
</tr>
<tr>
<td>WUE</td>
<td>water use efficiency</td>
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During the past two decades there has been a substantial rise in the size of the national herd with more hectares being committed to dairying and more cows per hectare. The dairy industry has become an increasingly important contributor to the national economy generating $12.7 billion in export earnings in the year ending June 2012.

However, the rise in dairying has not been without cost. To support the nutritional requirements of more cows, farmers have augmented feed supplies by using more nitrogen fertiliser, growing supplementary crops for silage or grazing on-farm and/or procuring feed supplements off-farm. This, combined with the increased stocking rate, has increased the rate of nutrient cycling through the soil-plant-animal system and raised concerns as to the impact of dairying on the environment.

Some of the issues of concern are elevated levels of nitrate in aquifers as well as lakes and rivers, soil compaction and increased soil phosphorus levels. Furthermore, many areas are seeing depleted aquifers, reduced river flows, and a drop in lake levels.

The challenge currently facing industry leaders is how to increase profitability without compromising environmental quality.

Maize silage has become widely used in New Zealand for the past two decades. It is a popular dairy farm supplement that has been proven both on commercial farms and in a number of independent farm system trials and analysis. Most farmers from Northland to Canterbury can grow a maize silage crop that yields 18-26 tDM/ha for 15-22 cents per kilogram of drymatter (c/kgDM).

Planted in October to December and harvested in February to April, maize silage is an excellent part of a pasture renovation programme. When combined with a winter crop, maize silage can be grown as a continuous cropping system or it can be purchased from an off-farm source.

Maize silage offers a win-win solution for farmers and environment councils by increasing farm production and profitability in an environmentally sustainable manner.

Advantages of maize include:

1. The ability to stop excess nutrients: Because of its high drymatter yields, the maize crop has significant requirements for nitrogen (N), phosphorus (P) and potassium (K). Recent research has shown maize silage crops can strip nutrients from dairy farm paddocks that have dropped below the root zone of shallow rooted pasture species. As well as delivering an environmental benefit, crops grown in paddocks with a history of effluent application may require no additional fertiliser saving the farmer $440 - $640 per hectare in fertiliser costs.

2. Highly efficient use of nitrogen and water: Research has shown maize silage has a nitrogen use efficiency approximately three times greater than that of pasture. Maize has an effective rooting zone of 100-150 cm (substantially greater than pasture species) and a water use efficiency (WUE) at least twice that of perennial ryegrass on an annual and up to three times greater on a summer seasonal basis.

3. Ability to reduce urinary nitrogen: Maize is a low crude protein feedstuff (average 7.5% crude protein). Feeding maize silage dilutes dietary protein levels and reduces the excretion of nitrogen, especially urinary nitrogen. This is important because it is estimated 69% of the nitrogen loss on a typical Waikato dairy farm is in the form of cow urine.

4. Reduce risk of phosphorous run-off into waterways: It is estimated around 40% of the phosphorus entering streams in the Waikato region comes from dairy farms. An analysis of
the nutrient use efficiency for the Resource Efficiency Dairying (RED) trial farmlets showed the fertiliser P per tonne of milksolids was least for the maize silage supplemented farmlet because of the relatively lower P requirement for maize and its lower P concentration compared to pasture. The conversion of fertiliser P into milk and meat P was greatest for the maize silage farmlet.

Environmentally, maize silage stacks up well when compared to other commonly used dairy farm supplements.

- Maize silage stack effluent losses are usually negligible because maize does not need to be wilted and is harvested at reasonably high (>30%) drymatter contents. In contrast, pasture must be wilted and, as a consequence of poor spring weather conditions, is often ensiled too wet, resulting in a higher volume of effluent run-off.

- Greenfeed crops (such as brassicas and cereals) which are direct grazed by highly stocked animals can damage soil structure and are often associated with high nutrient (especially N) losses particularly when ground conditions are wet.

- Palm kernel extract (PKE and PKE blends) bring additional nitrogen and phosphorus onto New Zealand dairy farms. These concentrates are often fed in the farm dairy and most of the additional effluent and nutrients excreted are deposited on the paddock.

We believe maize silage offers the ideal solution for both farmers and environment councils. The councils can achieve a number of their nutrient leaching and water use efficiency objectives by promoting the use of maize silage, especially if it is grown on-farm and fed on a stand-off pad.
There is increasing pressure on New Zealand’s dairy farmers to intensify production so they can maintain or increase returns from land, which is by far their largest on-farm capital item.

During the past two decades the size of the national dairy herd has increased from 2,438,641 cows to 4,634,226 cows (an increase of 90%). This rise in cow numbers has been accompanied by a significant rise in land area with 1,638,546 ha currently dedicated to dairying (Dairy Statistics, 2012). Dairy cow stocking rates have increased by 20% and the national average stocking rate is currently 2.83 cows/ha.

The dairy industry has become an increasingly important contributor to the New Zealand domestic economy as well as being a key export earner. In the June 2012 year, dairy products accounted for 27% of total merchandise exports and contributed $12.7 billion to the New Zealand economy (Statistics NZ, 2012).

This rise in dairying has not been without cost. As well as increasing stocking rates, farmers have been augmenting available feed through nitrogen (N) applications, growing supplementary crops for silage or grazing on-farm and/or procuring feed supplements off-farm. This, combined with the increased stocking rate, has increased the rate of nutrient cycling through the soil-plant-animal system and raised concern as to the impact of dairying on the environment.

While nitrogen run-off which creates elevated nitrate levels in our lakes and rivers and leaching which lifts the nitrate levels in our aquifers have been key focuses in recent years, other areas for concern include:

- Soil compaction
- Increased soil phosphorus levels

An Environment Waikato (2008) report states: “Monitoring shows that important aspects of soil and water quality are deteriorating across the intensively farmed areas of the region. In particular, nutrient concentrations in water are increasing. Sediment and faecal levels remain high in a large number of waterways. There are also indications that soil compaction is a common issue under intensive land use and that some contaminants are building up in soils in parts of the region.”

The problem is not just confined to the Waikato, which is the country’s largest dairying region. Other regions are experiencing similar trends in water quality and soil health. For example:

- **Manawatu**: Research indicates significant to highly significant increases in the concentration of nutrients (i.e. a degradation of water quality) at a number of sites within the Manawatu catchment. No significant improvements were observed (Aussel et al, 2006).

- **Taranaki**: Nitrate levels have been deteriorating in Taranaki and the increasing use of nitrogenous fertilisers (particularly urea) in the region in the last few years is likely to be a contributing cause of the deterioration. (Taranaki Regional Council, 2006).

- **Canterbury**: From 2001 to 2006, nitrate-N concentrations measured in Canterbury groundwater ranged from less than 0.25 mg/L to 24.6 mg/L. Concentrations as high as 3 mg/L could be natural, but concentrations greater than that are probably the result of contamination from livestock farming and other human activities (Environment Canterbury, 2008).

- **Northland**: Soil chemical properties at 25 sites sampled in 2007 were generally good. However, the physical properties at about half of the 25 sites indicated soil compaction was occurring (Northland Regional Council, 2007).
Decreases in water quality and soil health are not the only problems that have been potentially linked to the intensification and increase in dairying. Many areas are seeing decreases in groundwater levels as well as the water volume in lakes and rivers. The need for a plentiful supply of high quality water and healthy soils underpins not only the success of farming but also healthy ecosystems which provide a haven for our native flora and fauna. Wasteful use of water for agricultural purposes can result in a shortage of water for household and industrial use and may place the agriculture sector in direct conflict with hydroelectricity generators who need high water flow rates to generate power as well as the large number of New Zealanders who are involved in water-based leisure pursuits.

The challenge currently facing industry leaders is that of increasing profitability without compromising environmental quality. We believe hybrid maize harvested for silage can deliver a viable solution for both commercial farmers seeking to maintain their profitability and environment councils charged with protecting the environment in which they farm.

This report outlines how maize silage can be used to increase farmer profitability while at the same time mitigating some of the potential environment downsides associated with the expansion and intensification of dairying.
Summary

- New Zealand maize silage yields more than trebled in the period 1961 – 2012.
- Most New Zealand dairy farmers can grow a maize silage crop yielding 18 – 26 tDM/ha on-farm. Assuming total costs (planting to feed-out) of $3,877, this translates to a cost of just 15–22 c/kgDM.
- Maize silage is an excellent complement to New Zealand pasture. In addition to providing a relatively inexpensive source of energy, maize silage lowers dietary crude protein levels and is a good source of carbohydrates, in the form of starch.
- Farmers can grow maize silage on-farm (or a dairy run-off) as either part of a pasture renovation programme or a continuous cropping system.
- Buying in maize silage allows farmers to increase the milksolids production on their milking platform while at the same time diluting dietary crude protein levels.
- The productivity, profitability and sustainability of maize silage has been demonstrated in a range of dairy farm trials and economic analysis as well as on a large number of commercial dairy farms throughout the country.
- Maize silage offers a win-win solution for farmers and environment councils because it can increase farm production and profitability in an environmentally sustainable manner.

3.1 History of maize silage

Maize was first hybridised in 1908, primarily through the innovative research of Dr George Harrison Shull who recognised the higher yield potential and uniformity hybrid maize could deliver. The transition from open pollinated maize to hybrid maize was rapid. In Iowa the proportion of hybrid maize grew from less than 10% in 1935 to well over 90% four years later (Crow 1998).

The size of the global hybrid maize seed market and the fact growers must purchase new seed each season led to a huge investment in maize plant breeding. This in turn has driven fast genetic progress. For example, American research shows that since the mid-1930s, maize silage yields have increased at a rate of 128 – 164 kgDM/ha per year (Lauer et al. 2001).

Maize has been grown in New Zealand for more than 40 years. In the early 1990s coordinated trial programmes were established to advance the commercial potential of hybrid maize for silage.

As a consequence of improved crop management techniques and improved maize genetics, New Zealand maize silage yields more than trebled in the period 1961 – 2012 (Figure 1).
3.2 Current costs and yields

Modern maize hybrids offer high yield potential combined with exceptional drought tolerance and disease resistance. The record maize silage yield in the Pioneer Maize Hybrid Evaluation Programme was 36.3 tDM/ha harvested from a strip of Pioneer® brand 33G26 in the Bay of Plenty. Most New Zealand dairy farmers can grow a maize silage crop yielding 18 – 26 tDM/ha on-farm. Assuming total costs (planting to feed-out) of $3,877 (Pioneer Maize Silage, 2012), this translates to a cost of 15 – 22 c/kgDM.

3.3 Nutritional analysis

In nutritional terms, maize silage has proved to be the ideal complement to pasture in New Zealand dairy farm systems. In addition to providing a relatively inexpensive source of energy, maize silage lowers dietary crude protein levels and is a good source of carbohydrates, in the form of starch.

Table 1: Typical nutritional analysis of New Zealand maize silage (DairyNZ, 2009)

<table>
<thead>
<tr>
<th>Nutritional parameter</th>
<th>Low grain maize silage</th>
<th>High grain maize silage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metabolisable energy (MJME/kgDM)</td>
<td>10.3 - 10.5</td>
<td>10.8 - 11.0</td>
</tr>
<tr>
<td>Crude protein (%)</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Neutral detergent fibre (%)</td>
<td>49</td>
<td>42 - 45</td>
</tr>
<tr>
<td>Water soluble carbohydrate (%)</td>
<td>30.0</td>
<td>35.1</td>
</tr>
</tbody>
</table>
3.4 Growing maize silage on-farm

Farmers can grow maize silage on-farm (or a dairy run-off) as either part of a pasture renovation programme or a continuous cropping system.

3.4.1 Pasture renovation programme

Pasture persistence is a major issue for many NZ dairy farms. DairyNZ research has shown the best yielding paddocks on a dairy farm produce double the annual pasture drymatter yields of the worst paddocks (Romera et al., 2008). Many farmers could benefit from renewing their pastures, and maize silage can be used to help improve pasture persistence (Densley et al., 2011).

Paddocks are sprayed out of pasture in the spring and planted in maize for silage in September to early December. The paddocks are direct drilled with permanent pasture species immediately after maize silage harvest in February to April.

Planting 15% of the farm in maize silage as part of a pasture renovation programme can lift total drymatter yields and farm milksolids (MS) production by more than 10% (Table 2).

**Table 2.** Total drymatter and milksolids yields from a 70 ha farm using maize silage grown on-farm (15% of farm area) compared to an all-grass system.

<table>
<thead>
<tr>
<th>Farm system</th>
<th>Farm DM yield (tDM/ha/year)</th>
<th>Milksolids yield (kgMS/ha/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permanent pasture (100% of area)</td>
<td>15.0</td>
<td>1,200</td>
</tr>
<tr>
<td>Maize silage followed by permanent pasture (15% of area) + permanent pasture (85% of area)</td>
<td>16.5</td>
<td>1,324</td>
</tr>
</tbody>
</table>

1 Assumes a maize silage yield of 22 tDM/ha.
2 Assumes that 68% of the annual pasture DM yield will be forfeited while the maize silage crop is in the ground.
3 Assumes a milksolids response of 80 gMS/kgDM fed.

3.4.2 Maize silage as part of a continuous cropping programme

Under this scenario a designated part of the farm is planted in maize for silage followed by a winter silage crop (usually oats, triticale or winter ryegrass).

A replicated small plot trial conducted over two seasons on a farm near Te Awamutu showed a late maturity maize silage crop followed by either Monster triticale or Feast II™ Italian ryegrass yielded a combined total of 38.8 and 32.5 tDM/ha per year respectively (Figure 2).
Since maize silage is a deep rooting crop, it is an ideal sink for dairy shed effluent. Maize silage crops grown in paddocks with a history of dairy effluent application may require no additional fertiliser (Johnstone and Arnold, 2008). This reduces the cost per kgDM grown and has obvious environmental benefits (see Section 4 for more details).

### 3.5 Buying in maize silage

Maize silage can easily be grown and harvested in one district and trucked to another for stacking and subsequent feeding. Buying in maize silage allows farmers to increase the milk solids production on their milking platform while at the same time diluting dietary crude protein levels (see Section 5.1).

Maize silage contract growing (i.e. growing a crop which is sold and trucked into dairy districts) may be an option for sensitive catchment areas. However, the rate and timing of nitrogen applications must be closely matched to crop requirements.

### 3.6 Maize silage in dairy farm systems

Maize silage has played an increasingly important role in New Zealand dairying over the past two decades. It is estimated there are currently 72,000 ha planted in maize for silage each year (Booker, 2009).

The productivity, profitability and sustainability of maize silage have been demonstrated in a range of dairy farm trials and economic analysis as well as on a large number of commercial dairy farms throughout the country. These include:
- **Waimate West Demonstration Farm Trial.** In the 1997-98 trial the maize silage fed in autumn treatment produced an EFS 28% higher than the all-grass control (Deane, 1999).

- **Resource Efficient Dairying (RED) Trial.** The moderate supplement treatment (2.5 tDM/cow maize silage) produced 2,122 kgMS/ha which was 84% higher than the all-grass control herd (Glassey et al, 2007).

- **Dairy 3 paper by Hedley et al.** A paper presented by Hedley et al at Dairy 3 (2006) identified five principal pasture-based systems in the Waikato region and described key factors for high performance and financial returns for each system at $4.00/kgMS. Farmers that used the most supplements (System 5) were the most profitable because they milked more cows per hectare, produced more milk, grew and harvested more pasture and had a higher milk response to feed.

- **Fonterra Westpac Dairy Excellence Awards.** In the period 2001-05, in those areas where maize silage could be grown (i.e. north of Dunedin) 19 of the 23 (83%) regional winners of the Fonterra Westpac Dairy Excellence Awards were feeding maize silage.
Summary

- Maize silage has high drymatter yields and as a consequence the maize plant has a high requirement for nutrients especially N, P and K.

- Maize has an effective rooting zone in unimpeded soil of 150-180 cm depth. This allows it to capture nutrients from depths 2-3 times greater than most C3 grasses.

- Maize silage crops grown in paddocks with a history of farm dairy effluent application may require no additional fertiliser.

- The nitrogen use efficiency of maize is approximately three times greater than that of pasture.

- Maize has up to twice the water use efficiency of perennial ryegrass on an annual basis and up to three times greater on a summer seasonal basis.

- Nitrogen leaching is not a major problem under maize crops providing excess N is not applied. FAR research has shown a heavy simulated rainfall event after a large amount of N has been applied will move very little of the applied N beyond the rooting zone of the crop (taken as 180 cm).

- Maize management plays a major part in minimising nitrate leaching. Cultivation in mid-winter should be avoided. Match the rate and timing of N applications to crop requirements. A ryegrass or triticale crop should be sown when maize silage is harvested in April to remove excess N left behind by the maize crop.

The next two sections will examine the environmental benefits of growing (Chapter 4) and feeding (Chapter 5) hybrid maize for silage. While these chapters will largely discuss the benefits of maize silage in a dairy farm context, it is important to note maize silage can play an important role in improving the profitability and environmental stability of a range of livestock systems.

The results of a beef farm modeling study (Carracelas et al, 2008.) showed feeding maize silage at two different proportions (5% or 10%) in the winter or summer increased beef production by an average of 36% over an all-grass control. Farm profitability was increased by feeding maize silage in the winter and spring. The authors concluded: “Appropriate use of maize silage in beef production systems can substantially improve animal performance and farm profitability.”

Maize silage has been used by a limited number of sheep farmers in New Zealand. However, overseas (especially in North America) maize silage is widely used in sheep diets. It has also been used successfully by a number of deer and dairy goat farmers in New Zealand.
4.1 Maize nutrient removal

Because of its high dry matter yields, the maize plant has a significant requirement for nutrients especially nitrogen (N), phosphorus (P) and potassium (K). Assuming that maize silage contains 7.5% crude protein (1.2% N), 0.26% P and 1.20% K (NRC, 2001), each tonne of maize silage dry matter removes around 12 kgN, 2.6 kgP and 12 kgK.

Plant species belong to two main groups according to their photosynthetic pathway and their leaf morphology. C4 species, which include maize, sorghum, sudan grass, and paspalum, have photosynthetic systems that are generally more tolerant of high temperatures and high radiation conditions typical of the tropics. C3 plants, which include most of the pasture species (e.g. ryegrass) and cereals such as wheat and rice, are less efficient in using bright sunlight and their photosynthetic rates are reduced more drastically by high temperatures.

Maize (a C4 plant) has an effective rooting zone in unimpeded soil of 150-180 cm depth (Kovacc et al., 1995; Grigani et al., 2007). This allows it to capture nutrients from depths 2-3 times greater than most C3 grasses (Kristensen and Thorup-Kristensen, 2004) and makes it ideal for using soil nutrients that have dropped out of the effective root zone of pasture. For the reasons above, maize is an excellent sink for dairy farm effluent.

A trial investigated whether maize silage could strip nutrients from high fertility soils (Johnstone and Arnold, 2008). Four Waikato sites were planted in maize in spring 2007. All paddocks were coming out of long-term pasture and had been used as effluent application blocks for extended periods. Maize was grown with either full fertiliser (starter and sidedress, FF), reduced fertiliser (starter only, RF) and no fertiliser (NF). No N, P or K base fertiliser was applied at any site. Across all sites the mean silage yield was 25.4 tDM/ha for the NF practice and 25.1 tDM/ha for the fertiliser practices. Across the four sites the nutrient removal was equivalent to 290, 42 and 322 kg/ha of N, P and K respectively for the NF treatment, all of which was supplied from the soil. As an added bonus the NF treatment had reduced maize fertiliser costs by $165-$330 per hectare.

4.2 Nitrogen use efficiency

4.2.1 What is nitrogen use efficiency?

Strictly defined, nitrogen use efficiency (NUE) is the ratio of DM increase per unit of N absorbed by the plant. The N content of the plant is costly to determine, so a more common measure of NUE is crop DM response per unit N applied (kgDM/kgN applied).

In an N-deficient soil, maize crops respond to applied N with a linear increase in DM, but as N becomes less limiting the response of the crop to successive increments of N begins to decline. For many New Zealand soils, this decline will start at 30-50 kgN/ha, and reach a plateau of zero additional response at around 150 kgN/ha. Thus, NUE depends on the degree of N deficiency in the soil, and is usually measured as the DM response to the first 50 kg of applied N.

4.2.2 Maize nitrogen use efficiency

Maize, a C4 plant, is more responsive to N than C3 species, resulting in a NUE of 40-64 kgDM/kg N for the initial 30-50 kgN/ha applied (Binder et al., 2000; Cox and Cherney, 2001). Extrapolating from maize grain trial results (Scharf et al., 2002; Grignani et al., 2007; Worku et al., 2007, Cahill et al., 2007), it would appear silage responses to N for the first 50 kgN/ha are in the range of 25-85 kgDM/kg N, for an average of 55 kgDM/kg N. Turning the numbers around, 55kgDM/kgN equates to a crop nitrogen requirement of 18.2 kgN per 1tDM produced and a 23 tDM/ha maize silage crop will require around 418 kgN.
The NUE of pasture is considerably less. Harris et al. (1996) reported an average response of 17 kg DM/kg applied N. The response of pasture to applied N has been recently summarised by Zhang and Tillman (2008) who examined results from approximately 30 N response experiments on pasture in New Zealand. They noted NUE of pasture has ranged between 0 and 40 kgDM/kgN, but usually falls in the range of 5-15 kgDM/kgN. The best NUE figures they obtained were 31.9 in a wet warm spring while on cold slopes under dry conditions NUE fell to 3 kgDM/kgN applied. Thus, the level of responsiveness of maize is approximately three times greater than that of pasture, due more to the high inherent NUE of C4 species than to a reduction in leaching.

4.3 Water use efficiency

4.3.1 What is water use efficiency?
Crops require water for growth, and a continuous and adequate supply is necessary for maximum yields. Unfortunately water is becoming an increasingly scarce and expensive commodity so the efficiency with which it is used is an important consideration.

Water use efficiency (WUE) is the ratio of drymatter output per unit of water utilised. Ideally, transpired water should be used to estimate WUE, but this is more difficult to measure than the drymatter response to a known quantity of water that is evaporated or transpired from the cropped land area. It is this latter measure of WUE that is used here. Units are typically kg of additional DM per mm of water extracted from the soil. Another measure of WUE is tDM/megalitre, a measure commonly used to describe response to applied irrigation. It includes losses of applied irrigation water as surface runoff and drainage, as well as evaporation from the soil surface.

The quantity of water present in soil is either measured gravimetrically, or by using a neutron probe or a time domain reflectometer. The total amount of water present in soils always exceeds the plant-available water, since plants cannot extract soil water held at water potentials less than approximately -1.5 MPa. Plants cannot extract water at depths greater than their effective rooting zone, and this is usually 30-40 cm for pasture species and 100-150 cm for maize. Thus, maize can access 2-3 times more soil water than pasture species, something that was very evident in the dry summer of 2008.
4.3.2 Maize water use efficiency

C4 species generally have a high WUE, especially in the summer. Studies have shown maize responded to irrigation with a WUE of 20-36 kg grain/mm water applied during the growing season (Rhoads and Bennett, 1990), equivalent to approximately 40-72 kgDM maize silage/mm. Callow and Kenma (2004) compared the WUE of temperate and tropical irrigated species in south Queensland dairying areas. The best WUE of irrigated temperate species was ryegrass at 13-16 kgDM/mm water applied, vs. 43 to 46 kgDM/mm applied for irrigated sorghum and maize. Garcia et al. (2006) compared responses to irrigation in a forage system that included maize, a brassica and a legume vs. a well-managed sward of kikuyu pasture (a C4 species) oversown with Italian ryegrass. The forage system provided a response of 47 kgDM/mm water vs. 24 kgDM/mm water for pasture. Neal et al. (2005; 2007), in a study of WUE in 30 forage species, noted maize has up to twice the WUE of perennial ryegrass on an annual basis and up to three times greater on a summer seasonal basis. The largest WUE observed in these studies was 49 kgDM/ha/mm for maize grown in New South Wales (Neal et al., 2006). Data presented by this group (Table 3) and the overall differences between C3 and C4 plants in WUE under unstressed conditions (Figure 3) suggest C4 species (e.g. maize) are about 80% more efficient in water use than C3 forages (e.g. ryegrass), when considered over different seasons.

The superior WUE of maize over pastures species is an important consideration over the summer, especially as the costs to pump water continue to rise as irrigation expands on dairying land and as easily accessed water resources in New Zealand approach full exploitation for irrigation, energy generation and recreation.

Table 3. Yield and WUE of different forages grown in different seasons in New Zealand and Australia (Neal et al., 2007).

<table>
<thead>
<tr>
<th>Forage</th>
<th>Yield (tDM/ha)</th>
<th>WUE (kgDM/ha/mm)</th>
<th>Plant type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perennial Ryegrass</td>
<td>18.7</td>
<td>16.2</td>
<td>C3</td>
</tr>
<tr>
<td>Australia, NZ, 6 estimates</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fescue</td>
<td>21.2</td>
<td>20.0</td>
<td>C3</td>
</tr>
<tr>
<td>Australia, 4 estimates</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lucerne</td>
<td>20.3</td>
<td>18.8</td>
<td>C3</td>
</tr>
<tr>
<td>NZ, Australia, 4 estimates</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clover (red, white, Persian)</td>
<td>14.8</td>
<td>18.5</td>
<td>C3</td>
</tr>
<tr>
<td>NZ, Australia, 4 estimates</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maize</td>
<td>25.5</td>
<td>34.5</td>
<td>C4</td>
</tr>
<tr>
<td>Australia, two estimates</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kikuyu</td>
<td>25</td>
<td>32</td>
<td>C4</td>
</tr>
<tr>
<td>Camden, NSW, Australia</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sorghum</td>
<td>18</td>
<td>28</td>
<td>C4</td>
</tr>
<tr>
<td>Camden, NSW, Australia</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 3. Maximum WUE estimates from C3 and C4 forage species observed under non-limiting conditions in Australia. Actual values could be less than this if affected by high temperatures, agronomic management, pests and diseases (Neal et al., 2007).

Figure 3 shows that to grow 15,000 kgDM of a C3 forage would require more than 600mm of water. The same amount of water could be used to grow close to 30 tDM of a C4 forage such as maize.

4.4 Impact of maize cropping on groundwater N

Leaching generally increases as fertiliser N applied to the crop or pasture increases (Ledgard, 2001; Ledgard et al., 2006a). In general however, leaching is not a major problem under maize crops providing excess N is not applied. The Foundation for Arable Research (FAR) has conducted a number of leaching studies in maize in different parts of New Zealand, both during the maize growing season and over the winter (FAR, 2001; 2005b; 2006a; 2006b; 2007a; 2007b; 2007c). In general these studies have shown a heavy simulated rainfall event after a large amount of N has been applied will move very little of the applied N beyond the rooting zone of the crop (taken as 180 cm).

4.5 Managing maize to reduce N leaching

The foundation of good fertiliser stewardship rests on the principles of using the right source, at the right rate, at the right time, with the right placement (Roberts, 2007).

Maize is easily over-fertilised because it shows no symptoms of excess N. A survey conducted in 2000 indicated 20% of maize crops were in this category (FAR, 2001). Soil samples used to determine N status prior to sowing are often taken only in the top 15-30 cm, and do not account for partially leached N lower in the profile below the reach of pasture roots. The amount of N supplied by a previous pasture is often underestimated (e.g. Pearson and Arnold, 2008), and farmers respond to visual deficiency symptoms in a few low-fertility areas in the field by increasing application rates. Consequently, winter leaching under bare soil following maize harvest can be high, and averaged 60 kgN/ha over winter when measured at over 50 sites (FAR, 2001). N leaching from land allocated to maize silage production was estimated at 109 kgN/ha in the Resource Efficient Dairying (RED) Trial treatments 3 and 4 (see Table 5 for farmlet details, Ledgard et al., 2006a). This level of N loss is wasteful as well as environmentally damaging.
Maize management plays a major part in minimising nitrate leaching. Cultivation in mid-winter should be avoided. Leaching is further reduced by careful timing of N applications to match peak demands in N uptake, by splitting applications to ensure applied urea is soil-incorporated (FAR, 2006), and by using urease or nitrification inhibitors and slow release forms of N (de Klein et al., 2001). A number of management tools are available to avoid excess N fertilisation in maize. A sensible appraisal of the likelihood of a response to fertiliser on paddocks coming out of permanent pasture is a first but important step. N applications can be further fine-tuned based on results from deep soil sampling (Pyke et al., 2008), and the use of models such as OVERSEER® or AmaizeN to predict N status following pasture and mineralisation during the season.

Finally, a ryegrass or triticale crop sown when maize is harvested in April can remove excess N (see Fowler et al., 2004; Grignani et al., 2007), and frequently does not need additional fertiliser (Thorup-Kristensen et al., 2004; Densley et al., 2006).
Summary

- Grass and legumes selected for temperate grazing systems frequently contain excess crude protein relative to animal requirements and this is made worse by the application of nitrogenous fertilisers to boost pasture growth particularly in the spring and autumn.
- When dietary N exceeds animal requirements, a high proportion (typically 60-70%) of the excess N intake is excreted in the urine.
- It is estimated that on most Waikato farms, the majority of N entering water from grazed farmland comes from stock urine.
- Feeding a low protein feed such as maize silage (7.5% crude protein) in conjunction with high protein pasture dilutes dietary protein content and reduces N excretion by the cow.
- Feeding maize silage can reduce the N content of urine by 70% and sharply reduce leaching losses from urine patches.
- Quantities of N leached per kgMS in the Resource Efficient Dairying (RED) trial farmlets with maize supplements were 21-32% lower than the all-grass control.
- Point sources of urine deposition can be further reduced by feeding cattle on a feed pad that doubles as a stand-off pad and distributing accumulated effluent uniformly over the pasture when the soil is not saturated.
- Maize silage is a low phosphorus feedstuff containing around 0.25% which is substantially lower than pasture (0.30 – 0.45%P) and well below the requirements of lactating dairy cows (0.32 – 0.38%).
- An analysis of the nitrogen use efficiency for the RED trial showed the fertiliser P requirement per tonne of milksolids was least for the low supplement maize silage farmlet because of the relatively lower P requirement for maize and its lower P concentration compared to pasture. The conversion of P fertiliser into milk and meat P was greatest for the maize silage farmlet.

5.1 Reducing nitrate leaching

During the period 1991-2002, the amount of urea fertiliser per hectare applied to dairy farms rose by 162% (Williams and Richardson, 2004). Grass and legumes selected for temperate grazing systems frequently contain excess crude protein relative to animal requirements (Brookes and Nicol 2007) and this is made worse by the application of nitrogenous fertilisers to boost pasture growth particularly in the spring and autumn (Pacheco and Waghorn, 2008).

When dietary N exceeds animal requirements, a high proportion (typically 60-70%) of the excess N intake is excreted in the urine (Figure 4).
Figure 4. The relationship between daily total N intake (NI) and N output (NO) in dung (NO = 76.7 +0.16 NI), milk (NO = 38.2 + 0.19 NI) and urine (NO = 0.003 NI^{1.8}) (Kebreab et al., 2001).

Cows urinate at random on pasture as they graze and the N deposit under each urine patch may exceed 1,000 kgN/ha. Nitrates can be relatively quickly leached beyond the reach of pasture roots at 30-50 cm depth. It is estimated that on most Waikato farms, the majority of N entering water from grazed farmland comes from stock urine (Figure 5).

Figure 5: Sources of N loss on a typical dairy farm (Environment Waikato, 2008)*.

*Agresearch data (for a dairy farm producing 850 kgMS/ha, using 100 kg fertiliser N, effluent applied to land).

Pacheco and Waghorn (2008) state: “In systems in which supplementary feed is used, the target should be to reduce the amount of rapidly degradable protein and provide energy for both the microbes and the ruminant to promote the conversion of dietary N into animal product.”
Feeding a low protein feed such as maize silage (7.5% crude protein) in conjunction with high protein pasture dilutes dietary protein content and reduces N excretion by the cow (Table 4). This strategy has been a major focus for improving N efficiency and reducing N loss in Europe (e.g. Aarts et al 1999; Kebreab et al, 2001). Feeding maize silage can reduce the absolute N content of urine by 70% (Table 4) and sharply reduce leaching losses from urine patches.

Of the total N excreted in the dung and urine, cows fed pasture excreted a greater proportion of surplus N in the urine than cows fed maize silage (Table 4). However the total amount of N excreted (dung + urine) was relatively small for cows on the maize silage diet because of its low crude protein content (Ledgard 2006).

Table 4. Effect of feed source on N output in milk, dung and urine in absolute and relative terms \((in \ parentheses)\) (Ledgard, 2006).

<table>
<thead>
<tr>
<th>Type of silage</th>
<th>N intake(^a) (kgN/cow)</th>
<th>N output (kgN/cow) (% intake)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Milk</td>
<td>Dung</td>
</tr>
<tr>
<td>Lucerne</td>
<td>37</td>
<td>6 (16)</td>
</tr>
<tr>
<td>Pasture</td>
<td>24</td>
<td>6 (25)</td>
</tr>
<tr>
<td>Cereal</td>
<td>16</td>
<td>6 (38)</td>
</tr>
<tr>
<td>Maize</td>
<td>12</td>
<td>6 (50)</td>
</tr>
</tbody>
</table>

\(^a\)Based on 1 t DM/cow

The Resource Efficient Dairying (RED) Trial was established to evaluate the environmental implications of the intensification of dairying. Pastures for the four relevant treatments (Table 5) received 170 kgN/ha as urea to boost annual pasture production from around 15 to 17.5 tDM/ha. The stand-off treatment used a pad to keep cows off pasture in winter, reducing soil damage and excreta return to pasture during the period when N leaching was high. Maize silage (grown off-farm) was used to significantly increase production of milksolids on a total hectare basis.

Table 5. Performance parameters for four of the RED trial farmlets, 2002-2005 (Clark and Ledgard 2006).

<table>
<thead>
<tr>
<th>Farmlet</th>
<th>Stocking rate (cows/ha)</th>
<th>Target pasture production (tDM/ha/yr)</th>
<th>Maize silage fed (tDM/ha/yr)</th>
<th>Milksolids (kg/ha)</th>
<th>Milksolids (kg/total ha(^a))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Control</td>
<td>3.0</td>
<td>17.5</td>
<td>0.0</td>
<td>1,112</td>
<td>1,112</td>
</tr>
<tr>
<td>2. Stand-off</td>
<td>3.0</td>
<td>17.5</td>
<td>0.0</td>
<td>1,080</td>
<td>1,080</td>
</tr>
<tr>
<td>3. Low supplement</td>
<td>3.8</td>
<td>17.5</td>
<td>5.5</td>
<td>1,509</td>
<td>1,349</td>
</tr>
<tr>
<td>4. Mod. supplement</td>
<td>5.3</td>
<td>20.5(^b)</td>
<td>13.3</td>
<td>2,175</td>
<td>1,520</td>
</tr>
</tbody>
</table>

\(^a\)Includes farmlet area plus area needed to grow maize silage at 24 tDM/ha.

\(^b\)Pasture irrigated on an “as required” basis.

Quantities of N leached per kgMS on the farmlets with maize supplements were 21-32% lower than the all-grass control. However, on a whole area basis, N leached per kgMS exceeded the control (Figure 6) by 7% and 15% as the maize silage feeding level increased from 5.5 to 13.3 tDM/ha/yr due to N leaching on the cropping area. If maize silage practices were aimed at reducing losses by 50% (see section 4.5), then the corresponding values would be efficiency gains of 8 and 10% respectively when compared to an all-grass control (Williams et al, 2007).
Figure 6. Nitrogen leaching losses from RED farmlets alone, and the farmlet plus the area used to rear replacements or grow maize silage (based on Ledgard et al 2006a). Dotted bars in the maize farmlets assume optimum maize management to halve measured N leaching in the maize growing areas (Williams et al, 2007).
5.2 Utilising a stand-off pad to further decrease N leaching

In the RED trial maize silage was fed in the paddock. Point sources of urine deposition can be further reduced by feeding cattle on a feed pad that doubles as a stand-off pad and distributing accumulated effluent uniformly over the pasture when the soil is not saturated. Stand-off pads are particularly beneficial over winter months when soil is saturated and pugging can occur in grazed paddocks. They can be used to their best advantage when they are coupled with feed bins, a plentiful supply of high quality forage that can be fed as required and a good effluent storage and dispersal system. In this situation, animals can be kept off pasture for significant periods when ground conditions are wet.

When low crude protein, high carbohydrate maize silage is fed to dairy cows over the winter on a feed pad that doubles as a stand-off pad (which is equipped with an effluent reservoir and a uniform effluent dispersal system), a considerable reduction in nitrate leaching and soil pugging damage can be expected. De Klein and Ledgard (2001) estimated the use of stand-off pads in winter can reduce N leaching in pasture by 40%. Data from the winter stand-off and control RED farmlets suggest the use of stand-off pads in winter can reduce N leaching losses by 25% provided effluent can be dispersed over a sufficiently large area to eliminate surface ponding which can also result in significant leaching of nitrates (Di et al., 1998; Dexcel, 2007).

A second approach being adopted by a number of farmers is a more elaborate enclosed version of the feeding pad (e.g. Herd Homes®). Cows are allowed limited access to the paddock especially when ground conditions are wet and the risk of pugging is high. For the rest of the time they are housed under cover and fed conserved feeds (e.g. maize silage) in the herd home. Waste is stored in a bunker under a slatted floor and allowed to partly dry out before being cleaned and spread (Longhurst et al., 2006). Early evaluations show winter feed requirements are reduced due to a combination of less feed wastage (less pugging, less grazed crop wastage, less waste of conserved supplements) and lower maintenance requirements of animals due to the warmer microclimate in the Herd Home®. This represents a new environmental initiative to control nitrate. A Herd Home® is being deployed as part of Dairy NZ’s “tight N” management initiative (Clark and Ledgard, 2006).
5.3 Soil phosphorus levels

Soil samples from Waikato farms show that in some cases more phosphate fertiliser is being added than plants can absorb. On dairy farms many soil samples (44 to 50%) from volcanic and sedimentary soils show excessive phosphorus (P) fertility. This has increased markedly between 1996 and 2001 (Environment Waikato, 2008).

Currently it is estimated around 42% of the phosphorus entering streams in the Waikato region comes from dairy farms (Figure 7).

Figure 7. Sources of P entering streams in the Waikato region (Environment Waikato, 2008).

Maize silage is a low phosphorus feedstuff containing around 0.25% P (NRC, 2001) which is substantially lower than pasture (0.30 – 0.45%P, Holmes and Wilson, 2002) and well below the requirements of lactating dairy cows (0.32 – 0.38%, Powell and Satter 2009).

An analysis of the nitrogen use efficiency for the RED trial (Ledgard et al, 2006b) showed the fertiliser P requirement per tonne of milk solids was least for the low supplement maize silage farmlet (see Table 5 for farmlet details) because of the relatively lower P requirement for maize and its lower P concentration compared to pasture (Table 6).

Similarly, the efficiency of conversion of P fertiliser (maintenance) into milk and meat P was greatest for the maize silage farmlet. This decreased on a whole system (milking platform plus cropping land, assuming maintenance P for the forage cropping area was 70 kgP/ha/yr). This greater efficiency for the maize silage farmlet would be more evident on farm systems where the farm dairy effluent was returned to land because of greater nutrient cycling in farm dairy effluent with increased intensification.
Table 6. Dairy farm and whole-farm efficiency of P use (Ledgard et al, 2006b).

<table>
<thead>
<tr>
<th>Farmlet</th>
<th>kg P fertiliser* per t milksolids</th>
<th>Product P**/maintenance fertiliser P (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dairy farm</td>
<td>Whole system</td>
</tr>
<tr>
<td>Low input</td>
<td>49</td>
<td>49</td>
</tr>
<tr>
<td>Control</td>
<td>42</td>
<td>45</td>
</tr>
<tr>
<td>Low suppl. maize silage</td>
<td>27</td>
<td>43</td>
</tr>
</tbody>
</table>

*Maintenance P fertiliser requirements.
**Milk and meat P.
Summary

- A market research survey of dairy farmers located from Northland to Canterbury would suggest 99% are feeding some type of supplementary feed. Commonly used supplements include pasture silage, maize silage, greenfeed crops, palm kernel extract or palm kernel extract blends.

- Pasture must be wilted before it is harvested and as a consequence of poor spring weather conditions, is often ensiled too wet. An analysis of 1,207 pasture silage samples (Feedtech, 2002) showed 524 (43%) were less than 28% drymatter. The lower the silage drymatter at harvest, the higher the volume of effluent run-off from a silage stack.

- Silage effluent is an environmental concern because it contains highly soluble nutrients and has a biological oxygen demand 170 times greater than untreated human sewage.

- Maize silage increases in drymatter as it matures in the field and does not need to be wilted. The effluent loss from well-managed maize silage is negligible.

- High stock density of animals grazing greenfeed crops can lead to soil physical damage and nutrient losses especially when ground conditions are wet.

- Palm Kernel Extract (PKE) is a by-product of the palm oil industry and a significant dairy supplementary feed.

- PKE contains an average of 14% crude protein and this translates to an average N intake of 22 kgN/tDM fed. The N excretion rates for cows fed PKE would be similar to those of pasture silage and significantly higher than for cows fed maize silage.

- PKE also contains an average of 0.65% phosphorus which is more than 2.5 times the amount contained in maize silage and around double the requirement of lactating cows.

- Blends containing palm kernel extract) are often fed through meal feeding systems which do not enable farmers to capture the majority of the additional effluent produced by better fed cows.

6.1 Pasture silage

Pasture surplus to animal demands is usually harvested as pasture silage in the spring. At this time pasture is normally in the range 12-16% drymatter (DM) and so it must be wilted prior to ensiling. Typically pasture is cut in the morning and wilted for 12-36 hours depending on weather conditions. Ideally, once it has reached the ideal harvest DM (28% +) it is ensiled in either bales or a silage stack or bunker.

Spring weather conditions can be extremely variable and this often makes it difficult for farmers to get pasture silage wilted adequately. An analysis of 1,207 pasture silage samples (Feedtech, 2002)
showed 524 (43%) were less than 28% DM. The lower the silage DM at harvest, the higher the volume of effluent run-off from a silage stack (Table 7).

Table 7. Estimation of effluent losses in a silage bunker (Bastiman and Altman, 1985).

<table>
<thead>
<tr>
<th>Silage DM content (%)</th>
<th>Volume of effluent (L/tonne of silage)</th>
<th>Loss of silage DM (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>203</td>
<td>8.70</td>
</tr>
<tr>
<td>16</td>
<td>152</td>
<td>5.70</td>
</tr>
<tr>
<td>18</td>
<td>109</td>
<td>3.63</td>
</tr>
<tr>
<td>20</td>
<td>73</td>
<td>2.19</td>
</tr>
<tr>
<td>22</td>
<td>45</td>
<td>1.23</td>
</tr>
<tr>
<td>24</td>
<td>25</td>
<td>0.63</td>
</tr>
<tr>
<td>26</td>
<td>11</td>
<td>0.25</td>
</tr>
<tr>
<td>28</td>
<td>6</td>
<td>0.13</td>
</tr>
</tbody>
</table>

Effluent losses occur even in baled silage if pasture silage is harvested below 25%. About 75% of the effluent is lost in the first 45 days after ensiling and effluent production is not affected by whether the bales are stored end-on or lengthwise (Dürr, L. 2004).

Silage effluent is 95% water. However, the solids portion (5%) is composed of soluble, highly digestible nutrients. As a result, the effluent has a very high oxygen demand. In fact, the biochemical oxygen demand (BOD) of silage effluent is reported to be 60,000 mg/L. This compares to untreated human sewage at 350 mg/L (Merrington et al, 2002).

In contrast, maize silage is a self-wilting crop which means that as the plant matures, it increases in DM percentage. Maize silage does not need to be field wilted; instead it can be directly harvested at an ideal harvest drymatter of 30-38%. For these reasons, the effluent production from well-managed maize silage is negligible.

High protein spring pasture made into good quality pasture silage has a crude protein content significantly higher than that of maize silage. Feeding high quality pasture silage will result in an increased excretion of N (Table 4), especially if it is fed in conjunction with leafy pasture that already delivers surplus N when compared to cow requirements.

6.2 Greenfeed crops

Greenfeed crops include brassicas, cereals and a range of summer greenfeed crops (e.g. pennisetum, Japanese millet, and forage sorghum) which are direct grazed by livestock. High stock density can lead to soil physical damage and nutrient losses especially when ground conditions are wet.

An Environment Southland article (Environment Southland, 2009) states: “Breakfeeding stock on a winter crop results in bare, often pugged soil with concentrated amounts of effluent on the soil surface. Rainfall and the resultant overland flow can transport sediment and effluent into drains and waterways.”

A study by McDowell and Houlbrooke (2008) used a trial site in North Otago (Mottled Fragic Pallic soil – Timaru silt loam) with three years’ previous history of sheep and cattle grazing on winter forage crop to measure potential N losses in leachate from shallow lysimeters (15 cm diameter and 24 cm deep). Artificial urine was applied to the site on 16 May and 27 July to simulate the grazing of cattle and sheep. The artificial urine was 6 gN/L for both the sheep and cattle with a change in urine
volume providing the difference of urine N loading of 580 kgN/ha for cattle and 229 kgN/ha for sheep. Cattle urine treatments had nitrate-N losses as high as 250 mg/L (Figure 8).

**Figure 8.** Nitrate-N concentration in lysimeter drainage. Filled symbols signify no DCD application and empty circles signify DCD treatment. Black signifies cattle treatment and grey signifies sheep. A solid line signifies urine patch and a dashed line signifies no urine treatment. Arrows indicate grazing events.

6.3 Palm kernel extract

Palm kernel extract (PKE) is a by-product of the palm oil industry. In the year ending December 2011, approximately 1,783,178 tonnes (NZFMA, 2012) of PKE was imported into New Zealand and the majority was fed to dairy cows.

PKE contains an average of 14% crude protein on a drymatter basis with a range of 12–20% (DairyNZ, 2008). This translates to an average N intake of 22 kg/tDM fed and suggests N excretion rates for cows fed PKE would be similar to those of pasture silage and significantly higher than for cows fed maize silage (Table 4).

PKE also contains an average of 0.65% phosphorus (DairyNZ, 2008) which is more than 2.5 times the amount contained in maize silage (average 0.25%, NRC 2001) and around double the requirement of lactating cows (0.32 – 0.38%, Powell & Satter 2009). Every 1 tDM of PKE fed brings 6.5 kg P onto the milking platform. At current importation rates, this translates to 11,590 t P excreted each year and will contribute to the build-up of soil P levels.

Around 28% of New Zealand dairy farmers who farm from Northland to Canterbury own a meal feeding system (Versus, 2011). Meal feeding systems in the farm dairy provide a low labour method of feeding concentrate feeds (including PKE and PKE blends) with relatively low feed wastage. However, because cows spend little time in the farm dairy, the majority of the additional effluent produced by the cows (which are often better fed and more highly stocked) is excreted in the paddock. This is a concern especially if the supplement generates surplus N and P as is the case for PKE.
• Maize silage is a popular dairy farm supplement that has been proven both on commercial farms and in a number of independent farm system trials and analysis.

• Growing maize silage on farm provides an excellent sink for farm dairy effluent by utilising significant amounts of N, P and K which have dropped below the root zone of shallow rooted pasture species.

• Maize silage has a nitrogen use efficiency approximately three times greater than that of pasture. It also has a water use efficiency twice that of perennial ryegrass on an annual basis and up to three times greater on a summer seasonal basis.

• Maize is a low crude protein feedstuff. Feeding maize silage dilutes dietary protein levels and reduces the excretion of nitrogen especially urinary nitrogen. The Resource Efficient Dairying (RED) trial has demonstrated that feeding maize silage results in greater N and P use efficiency and can substantially reduce nitrogen leaching and the amount of P that is returned to soils.

• Maize silage does not need to be field wilted; instead it can be directly harvested at an ideal harvest drymatter of 30-38%. For these reasons, the effluent production from well-managed maize silage is negligible. This is in contrast to pasture silage which must be wilted and which is commonly harvested at less than 28% drymatter resulting in significant effluent run-off.

• Greenfeed crops (such as brassicas and cereals) which are direct grazed by highly stocked animals can damage soil structure and are often associated with high nutrient (especially N) losses particularly when ground conditions are wet. Maize silage fed on a feed pad which doubles as a stand-off pad with the facility to capture and store effluent can be used to reduce pasture pugging and nutrient leaching.

• Palm kernel extract (PKE) brings additional nitrogen and phosphorus onto New Zealand dairy farms. Concentrates such as PKE and PKE blends are often fed through meal feeding systems in the farm dairy. Because cows spend little time in the farm dairy, in-shed feeding systems do not enable farmers to capture the majority of the additional effluent produced by the cows.

For these reasons (and the others outlined in this report), we believe maize silage offers a win-win solution for farmers and environment councils by increasing farm production and profitability in an environmentally sustainable manner. Environment councils can achieve a number of their nutrient leaching and water use efficiency objectives by promoting the use of maize silage, especially if it is grown on-farm.
Paul and Chris MacKenzie  
Waharoa, Eastern Waikato

Profitable and environmentally friendly

A highly productive system is reaping financial and environment rewards for Paul and Chris MacKenzie. The MacKenzie’s farm 83 hectares at Waharoa in the Eastern Waikato. In the 2010-11 season, their 356 cow split-calving Friesian and Friesian cross herd produced 227,000 kgMS (637 kgMS/cow and 2,734 kgMS/ha). This year they have lifted cow numbers and are on track to produce 250,000 kgMS (3,012 kgMS/ha).

Excellent facilities, including two Herd Homes®, a mixer wagon and well-designed and planned feed bunkers, are central to the success of the operation. While production is impressive the system itself is relatively simple to run. Contract milker Nic Coppard (21) manages the day-to-day operations, assisted by farm worker David Candy (20). This leaves Paul and Chris free to pursue off-farm interests.

“A lot of high input systems appear to be labour intensive and I didn’t want that”, says Paul. “Our aim was to build a simple system that did not require a lot of time to manage.”

Cows are dried off 50 days prior to their expected calving date. They spend 30 days on a dry cow diet comprising of 3-4 kgDM pasture plus 8-10 kgDM supplements including maize silage, straw and a range of by-products. Three weeks prior to calving they are moved onto a transition diet.

Two-thirds of the herd, including all of the heifers, calve between 20 February and 1 May. The balance of the herd consists of carryover cows and spring calvers which start calving on 1 September.

Once cows have calved, intakes are lifted to 21-22 kgDM/cow/day. Typically pasture intake is around 6 kgDM with the other 15 kgDM being a mix of supplements including maize silage, straw, palm kernel extract and by-products. Each morning Batt latches open the paddock gate at 3am allowing the cows to wander back to the Herd Home® where they consume their supplement allowance prior to the 5am milking. Once cows are milked they return to the paddock. This process is repeated prior to the afternoon milking.

Last season the MacKenzie’s grew 15 ha of Pioneer® brand maize silage and this season they have planted 25 ha (30%) of the farm in maize. Pioneer® brand 36M28 is the hybrid of choice because it produces good yields, stands up to wind and can be planted at the end of September and harvested around 20 February.

“We can get 24 tDM/ha of low cost maize silage that is good quality and safe to feed”, says Nic. “It fits in well with our pasture renewal programme and allows us to increase the total amount of feed we harvest from every hectare.”

Dairy effluent from under the Herd Homes is applied to the paddocks prior to maize planting.
“Growing maize allows us to use our effluent in an environmentally-friendly manner”, says Paul.

“Dairy effluent is ideal for growing maize and we are growing crops with no or very little additional fertiliser.”

Last year’s analysis of the farm system using Overseer shows the farm leached just 28kg N/ha. This is the level of nitrogen loss currently being achieved by low-stocked organic systems. It is also delivering excellent profit per hectare.

“It’s a flexible system that is based on margins”, says Paul. “Each time we buy in feed we get the chance to check whether the numbers stack up.”

Watching healthy, well-conditioned cows produce high milk yields is satisfying for everyone involved.

“We are producing more than 600 kgMS per cow using the same animals that used to produce 350 kgMS in an all-grass system”, says Paul. “I enjoy farming like this and I’d be reluctant to go back.” So what does the future hold for this farm which in many ways is already ahead of itself?

“I wouldn’t rule out further intensification if it was sustainable”, says Paul. “It’s a cheaper option than buying more land.”


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