Brown, J.N., 2017. Miscanthus (Elephant grass) exhibits very low nitrogen leaching – Another option for the mitigation toolbox? In: *Science and policy: Nutrient management for the next generation*. (Eds L.D. Currie and M.J. Hedly). http://flrc.massey.ac.nz/publications.html. Occasional Report No. 30. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 9 pages.

MISCANTHUS (ELEPHANT GRASS) – EXHIBITS VERY LOW NITROGEN LEACHING – ANOTHER OPTION FOR THE MITIGATION TOOLBOX?

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Abstract

Miscanthus is a perennial rhizomatous grass of Asian origin that is grown commercially as a biofuel crop in Europe. It has a very high dry matter yield due to its efficient C_4 photosynthetic pathway. Fonterra is interested in Miscanthus as it is suited to substituting or co-firing with coal, providing a sustainable fuel source for industrial heat generation and reducing associated greenhouse gas emissions. Miscanthus could be grown on the large land treatment systems (LTS) surrounding many of its factories where factory wastewater is typically irrigated to pasture to recover the nutrients it contains. A two hectare trial plot of Miscanthus was planted on the Fonterra Darfield LTS in 2011 and suction cup lysimeters installed in 2013. Three seasons of monitoring data have now been collected. The results show that after an initial 'establishment phase' the measured nitrogen leaching is extremely low (< 0.5 kgN/ha/yr). The crops potential as a biofuel crop is discussed, together with potential operational challenges that might need to be overcome. Miscanthus might also be a suitable candidate to support farm riparian plantings as its deep rooted nature (> 1.2 m) may intercept shallow groundwater thereby improving surface water quality. It is palatable to stock thus could act as a partial feed source. When used as shelter belts it provides numerous ecosystem services. If planted with sufficient width, half of each shelter belt could be harvested annually and the resulting biofuel sold to supplement farm incomes.

Introduction

Miscanthus is a perennial rhizomatous grass originating from Asia that may be commercially grown as a biofuel crop. Miscanthus has a very high dry matter yield due to its efficient C_4 photosynthetic pathway. It has become a common biofuel crop in Europe and is being trialled in North America, its' popularity largely due to the fact that it requires little or no inputs of artificial fertilisers or irrigation.

Miscanthus is particularly suited to substituting or co-firing with coal, thereby providing a more sustainable fuel source for industrial heat generation and reducing associated greenhouse gas emissions. Fonterra is interested in Miscanthus as a partial fuel substitute in its factories which utilise coal.

Wastewater from Fonterra factories is often utilised in land treatment systems where pasture is grown either as part of a dairying operation or exported from the farm as cut and carry silage. These land treatment systems generally involve several hundred hectares of irrigated land close to each factory and could be utilised for biofuel production. However, it was not known how a biofuel crop such as Miscanthus would respond to regular irrigation with dairy factory wastewater.

Materials and Methods

Field trials

The 2 ha Miscanthus (*Miscanthus x giganteus)* plot (indicated by the red arrow, Fig. 1) is within the area of centre pivot 6 located towards the southern end of the Fonterra Darfield wastewater irrigation farm. The predominant soils are the Lismore moderately deep stony silt loam which covers approximately half of the farm. The farm is used as a land treatment system for the dairy factory wastewaters, namely Clean-in-Place of the milk dryers and associated industrial plant. The wastewater is treated by dissolved air floatation (removing proteins and fats), prior to temporary storage and then irrigation via centre pivots on to 500 ha of pasture. To meet strict nitrogen leaching limits specified by Environment Canterbury, the farm exports large quantities of grass silage from spring to autumn and runs fattening lambs over winter. Initial Miscanthus planting occurred in 2011. The establishment success was low/medium, thus additional planting was necessary in the following year(s). A small first harvest was obtained in winter of 2014. Harvests occurred again in the winters of 2015 and 2016.

Fig. 1. Location of 2 ha Miscanthus plot on Pivot 6 of Fonterra Darfield Farm.

Wastewater irrigation hydraulic and nutrient loadings

The Miscanthus receives the same wastewater irrigation regime as the rest of pivot 6. For the 2015/16 season, irrigation followed the milk processing season beginning mid-August 2015 and continuing until the end of May 2016. In total 282,000 m^3 of wastewater was irrigated on the 96.5 ha pivot 6, equating to an annual irrigation depth of 292 mm. The monthly hydraulic and nutrient loadings, are shown in Table 1. For 2015/16 season, the Miscanthus plot received a total of 70 kg N/ha/yr and 28 kg P/ha/yr from the wastewater. No fertiliser was applied. The plot received similar wastewater inputs in earlier seasons.

Table 1. Monthly wastewater hydraulic and nutrient loadings to Miscanthus plot.

Month	Irrigation depth (mm/mth)	N (kgN/ha)	P (kgP/ha)
August	24	8	3
September	29	8	3
October	35	7	3
November	38	7	3
December	37	10	4
January	34	12	5
February	36	7	3
March	27	4	1
April	19	4	2
May	13	3	1
Total	292	70	28

Lysimeter measurements, soil water balance and soil sampling

Two ceramic cup suction lysimeter transects (three lysimeters each transect) are located within the pivot 6 area. They are sampled monthly for soil drainage water and analysed for a variety of chemical constituents, including nitrate-nitrogen. Three lysimeters (600 mm deep) were installed to the Miscanthus plot in mid-2013.

As part of the wastewater irrigation consent monitoring, SoilWork Ltd (2015) calculate a daily soil water balance for all the irrigated land. A monthly drainage volume is calculated which is then multiplied by the measured monthly average lysimeter nitrate-nitrogen to give the nitrogen leaching losses in kg N/ha/mth.

Soil testing is conducted for the pivot 6 lysimeter transects and within the Miscanthus plot.

Results

Lysimeter results

The measured average Miscanthus plot lysimeter nitrate-nitrogen concentrations and calculated pivot 6 drainage depths are shown below (Fig. 2). It can be seen that the plot has clearly exited its establishment phase and since August 2014 nitrate concentrations measured using the suction lysimeters are very low. In fact, from August 2015 in most months nitrate concentrations were below the detection limit (< 0.1 g/m^3). There was a small increase to around 4 g/m^3 in April 2016.

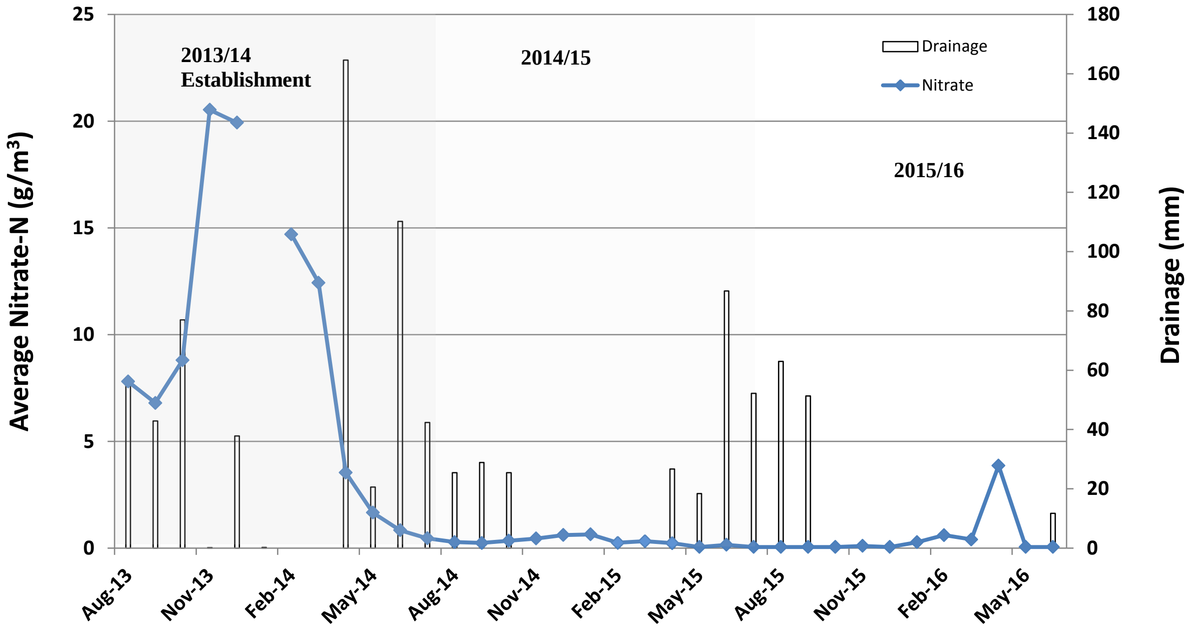

Fig. 2. Monthly Miscanthus lysimeter nitrate concentrations and drainage depths.

Nitrogen leaching

The calculated monthly Miscanthus plot nitrogen leaching results are detailed in Figure 3. From as early as June 2014 the leaching has been very low, after the crop was fully established. From April 2015 onwards, nitrogen leaching has been negligible despite modest drainage figures early in the 2015/16 season. The slightly elevated nitrate concentrations in April 2016 were not associated with leaching as no drainage occurred that month. This nitrate stored in the soil did not seem to leach in May-June 2016 when there was a small amount of drainage but no measured nitrate in the lysimeters.

A comparison of the leaching results from the other two pivot 6 lysimeter transects is shown in Figure 3. While exhibiting similar leaching to the pasture while still establishing, after August 2014 measured nitrogen losses in the Miscanthus plot are an order of magnitude lower than that in the nearby pasture. Annual losses for each lysimeter transect are shown in Table 2. The annualised losses for the pasture areas are low and have decreased over time. Losses from the Miscanthus are minimal.

Table 2. Annual nitrogen leaching results for Pivot 6 lysimeter transects

Transect	Annual Nitrogen Leached (kgN/ha/yr)		
	2013/14	2014/15	2015/16
Pivot 6	9.9	20	7.8
Pivot 6.1	23	14	4.9
Miscanthus	29	0.5	<0.1

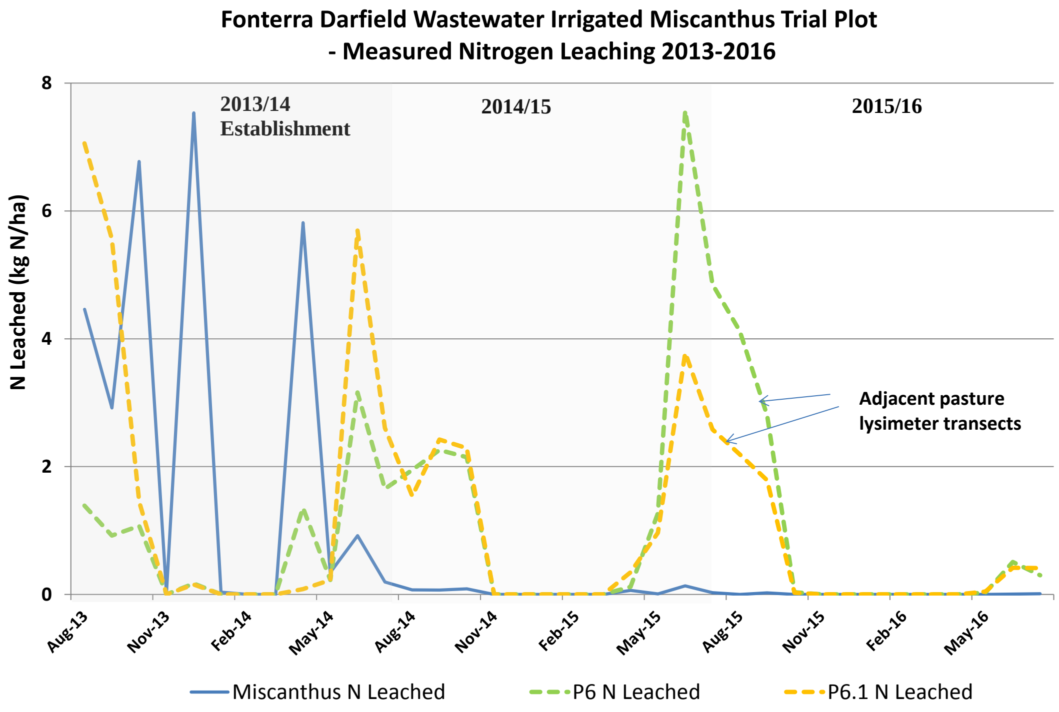

Fig. 3. Comparison to other pivot 6 lysimeter results.

Soil results

Soil samples have been taken within the Miscanthus plot to compare against the bimonthly sampling in the adjacent pivot 6 pasture areas for the monitoring of the wastewater irrigation resource consent. Three sampling transects were conducted within the plot, with 15-20 soil cores (75 mm depth) being amalgamated for each transect sample. The results from the three transects were nearly identical, thus average results are shown below (Table 3).

Table 3. Annual soil monitoring results for Pivot 6 transects

Transect	November 2015 Soil Results					
	pH	Olsen P#	K*	Ca*	Mg*	Na*
Pivot 6	6.8	21	4	13	10	69
Pivot 6.1	6.5	23	4	11	10	69
Miscanthus	6.8	25	8	11	9	86
Guideline level	5.8-6.0	20-30	6-8	-	8-10	-

mg/l * MAF Quicktest units

The soils within the Miscanthus plot generally show similar values to elsewhere on pivot 6. The higher K result may be due to the high rates of grass silage removal from the pasture areas while the Miscanthus was establishing. It will be interesting to see if the difference in sodium levels continues, which may reflect the Miscanthus plot not getting the gypsum applications to mitigate against sodium.

All the pivot 6 soils are within the recommended guideline levels for Olsen P, K and Mg. Soils irrigated with dairy factory wastewater typically have higher pH levels than non-irrigated soils.

Discussion

Miscanthus nutrient cycling

The Miscanthus growth cycle is very different from typical ryegrass/clover pastures or even from common crops. Miscanthus regrows in late spring each year (timing dependant on soil temperature), with the majority of the nutrients required initially being supplied by the soil rhizomes (Cadoux *et al.* 2012). Hence, compared to pasture, nitrate uptake from the soil itself will likely be minor until early summer. The average maximum rooting depth of Miscanthus is around 1.2 m (Finch *et al.* 2009), thus during the active summer growing period it will be capable of removing large amounts of nutrients from the soil to a much greater depth than most other crops. However, unlike typical summer or autumn harvested crops, much of the Miscanthus biomass grown returns to the soil during the late autumn/early winter senescence when the leaves dry and drop off. Prior to leaf drop, the Miscanthus remobilises significant amounts of nutrients from the leaves back into the soil rhizomes. Harvesting of the remaining partially dried stems for biofuel typically occurs in late winter/early spring and removes only half or less of the original nitrogen contained in the biomass at the peak of the crop's growth (Cadoux *et al.* 2012).

Comparison to pivot 6 pasture lysimeter results

Measured nitrogen leaching from the two pivot 6 lysimeter transects has decreased in recent years as the 'Cut and Carry' silage system has become more established. The corresponding decrease in the Miscanthus plot has been even more pronounced, to the point where leaching is almost negligible. A contributing factor may be that Miscanthus has a very different soil water balance than for pasture. The Miscanthus leaching figures are based on the lysimeter measured nitrogen leaching from within the plot itself <u>but</u> the soil water balance is calculated from the pasture areas of pivot 6. Miscanthus has a maximum rooting depth almost ten times that of pasture, which combined with the significant leaf area, indicates that it may have average evapotranspiration values very different from that of pasture (even ignoring the fact of the effect of the cutting of silage on pasture length). Specific measurements within the plot would allow a more accurate water balance for the Miscanthus itself to be calculated.

Differences with other New Zealand landuses

The measured nitrogen leaching from the Miscanthus is extremely low in comparison to other New Zealand landuses. The figure used in the Overseer nutrient management model for native or exotic forestry is 2 kgN/ha/yr. Figures for low intensity sheep and beef are 9-15 kg N/ha/yr (Lilburne *et al.* 2010). DairyNZ nutrient management indices for Canterbury report nitrogen leaching of 10-85 kg N/ha/yr with a mode of 35 kg N/ha/yr for dairy farms (http://www.dairynz.co.nz/media/629818/Canterbury-RNMI.pdf). Cropping systems may leach 26-80 kg N/ha/yr (Beare *et al.* 2010).

Comparison to overseas Miscanthus studies

A limited number of international studies have analysed nitrogen leaching losses from Miscanthus plots. Several of these report significantly higher nitrogen leaching during the first 1-3 years after planting. This has been attributed to excess nitrogen being mineralised from the previous pasture or crop residues. Additionally, lower growth rates during establishment, and frost induced die-off reducing establishment success, limit Miscanthus nitrogen requirements thereby resulting in higher leaching losses. Leaching rates as high as 85-228 kg N/ha/yr have been reported but median values are around 10-30 kg N/ha/yr (Cadoux *et al.* 2012; Lesur *et al.* 2013; Smith *et al.* 2013). During its establishment phase, the Darfield 2013/14 result of 29 kg N/ha/yr is almost identical to that measured by Behnke *et al.* (2012) for Illinois Miscanthus (also fertilised, 120 kg N/ha/yr).

International studies indicate that after the establishment phase, nitrogen leaching rates can be < 5 kg N/ha/yr in unfertilised plots (Lesur *et al.* 2013; McIsaac *et al.* 2010; Smith *et al.* 2013), but are reported around 20-30 kg N/ha/yr when artificial fertiliser is applied at 120 kg N/ha/yr in a single spring application (Behnke *et al.* 2012). The Darfield results are of a similar order of magnitude to the 0.8 kgN/ha/yr reported by Smith *et al.* (2013) for an unfertilised Miscanthus crop in Illinois four years after planting. Given the Darfield plot received a nitrogen loading of around 140 kgN/ha/yr in the 2014/15 season and 70 kgN/ha/yr for the 2015/16 season, the recent results indicate exceptional performance.

Potential for crop height leading to irrigation difficulties (?)

The centre pivot irrigator ‘dropper’ heights can range 0.5-2 m above the soil surface. Once fully established, the Miscanthus should grow from ground level to 3-4 m each season. Even at a dropper height of 2 m, wastewater irrigation would have to stop once the crop neared this height, otherwise the wastewater irrigation uniformity might be severely compromised. Additionally, if permanently set at 2 m, the increased distance above the ground might result in increased spray drift when the crop height is low. Potential solutions to the 3-4 m height of mature Miscanthus crops could involve:

Centre pivot irrigators at 4 m. This would require a major re-design and complete pivot rebuild. Pumps, lines etc. might also need revision due to extra hydraulic head. If the dropper distance was not matched to crop height i.e. always irrigating at 4 m, spray drift could be an issue. Problems of irrigators being pushed over in extreme winds would also be increased.

Harvest Miscanthus crop mid-season at 1.5 m height. This option would allow the use of centre pivots of a standard design but it would have significant effects on the yield, quality and end use of the crop produced. Harvesting Miscanthus in early autumn, prior to senescence and leaf drop, provides the highest biomass yield (Cadoux *et al.* 2012, Yates *et al.* 2015). However, harvesting just the stems in late winter produces a partially dried product that has superior fuel qualities (Finch *et al.* 2009, Lewandowski *et al.* 2003). Thus there is a trade-off between quantity and quality.

Once Miscanthus is fully established (3-5 years) and capable of growing to 3-4 m, harvesting it at 1.5-2 m i.e., prior to it reaching the irrigator droppers, would mean cutting the crop several months before peak biomass occurring. The material removed would have a much lower volume of stems and would likely have very different properties as a potential biofuel. Additionally, time of harvest also affects mineral content of the biomass, which in turn affects the amount and quality of ash produced once combusted (Lewandowski *et al.* 2003). Early harvesting would also impact on internal Miscanthus nutrient cycling (Yates *et al.* 2015), however this could be beneficial under a wastewater irrigation situation where external nitrogen is applied via the wastewater.

None of the existing studies have examined a **dual harvest regime**, where an initial ‘green’ crop is cut in summer, the plants allowed to regrow to produce canes which are then harvested in winter after senescence and leaf drop. Such a management regime could result in two different products. An early green crop that could be used as a biofuel after appropriate processing or potentially a stock food after being put through a silage fermentation process. The second crop would be the usual Miscanthus canes biofuel crop, albeit at a reduced yield compared to the typical single annual harvesting regime. Annual nutrient deficits would likely be greater, thus making it fit well for a wastewater irrigation land treatment system.

Other potential applications for Miscanthus

Miscanthus might also be a suitable candidate to support farm riparian plantings as its deep rooted nature (> 1.2 m) may intercept shallow groundwater thereby improving surface water quality. It is palatable to stock thus could act as a partial feed source. Initial trials of cutting a green crop for silage have yielded promising results (Peter Brown, Miscanthus NZ, personal communication).

A trial of Miscanthus as a shelter belt, also in Canterbury, has shown that in addition to shelter it provides numerous ecosystem services such as improved pasture growth in the lee and habitat for beneficial insects (Littlejohn *et al.* 2015). If planted with sufficient width, half of each shelter belt could be harvested annually and the resulting biofuel sold to supplement farm incomes.

Miscanthus may provide additional options for land treatment systems for treated municipal wastewater. Land treatment for municipal wastewater is often preferred to surface waters discharges by policy makers, iwi and the public, but challenges exist to its widespread adoption. These include large land requirements, capital costs, wet weather irrigation and increasingly strict nutrient loss regulations. An additional barrier for treated municipal wastewaters is the present requirement for compliance with ‘Title 22, Regulations Related to Recycled Water’ (CDPH 2014) should the treated municipal wastewater be irrigated on to pasture for animals producing milk for human consumption. Title 22’s strict compliance requirements therefore likely limit irrigation of treated municipal wastewater to dry stock farms, which may not be in close proximity to the treatment plant. A biofuel crop such as Miscanthus could be irrigated with such wastewaters and provide an alternate economic return to the landowners. In addition, the probable decrease in nitrogen leaching losses could potentially be used for nitrogen off-setting or trading where Regional Plans allow this.

Conclusions

Miscanthus is a high yielding, perennial rhizomatous grass grown as a biofuel crop that usually requires no irrigation or fertiliser inputs. Miscanthus is particularly suited to substituting or co-firing with coal for industrial process heat generation. The 2 ha trial plot of *Miscanthus x giganteus* established in 2011 on pivot 6 of the Fonterra Darfield wastewater land treatment system was designed to determine its success when grown in Canterbury and under a wastewater irrigation scenario. Initial establishment success was low, mirroring other reports in temperate latitudes. Modest replanting was required, but 2014 saw the first small harvest from the plot in late winter. Soil lysimeters have measured the nitrogen leaching under the Miscanthus since 2013. As the Miscanthus has matured, the measured nitrogen leaching has dropped dramatically. 2015/16 measurements showed that leaching was almost non-existent and significantly lower than the adjacent pivot 6 pasture areas.

The Miscanthus growth cycle and nutrient cycling regime is very different from any other crop grown in New Zealand. Miscanthus regrows late spring each year from the soil rhizomes which supply most of the nutrients. Maximum biomass is reached mid-autumn, but senescence and leaf drop recycle two thirds of the nutrients back to the rhizomes and soil surface. The 3-4 m height of the mature crop might require re-design of existing irrigation systems. An alternative may be a **dual harvest regime**, where an initial green crop is cut in early summer and after regrowth, a further crop of canes for biofuel harvested in late winter. Miscanthus could provide an alternative crop for treated municipal wastewater land treatment systems that would provide an economic return and significantly lower nitrogen leaching losses.

Acknowledgements: Lysimeter sampling by site staff, water balance results from SoilWorks Ltd and assistance from Miscanthus NZ is gratefully acknowledged.

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