Modelling Monto Vetiver Growth and Nutrient Uptake for Effluent Irrigation Schemes

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The Vetiver Network Award Winner

Abstract: The MEDLI model (Model for Effluent Irrigation by Land Irrigation) is used throughout Australia to design and test the sustainability of effluent irrigation schemes. MEDLI models the partitioning of water, nutrients and salt from the waste stream as it passes through pond treatment, is irrigated onto land growing crops or pastures, and percolates to groundwater. It presently has a limited library of crop and pasture species parameter values and due to the enormous potential demonstrated by vetiver for effluent irrigation schemes, this library was extended to include Monto vetiver.

This paper presents the methodology used to determine the growth and nutrient uptake model parameters needed to add Monto vetiver to the dynamic, daily time-step pasture growth model used in MEDLI. The parameters for Monto vetiver were drawn from the literature and determined from a purpose-designed field trial conducted at GELITA APA, Beaudesert, Queensland. The modelling predictions of biomass growth and nutrient uptake using these parameter values were then validated against data collected at an independent field site, at Beenleigh, Queensland.

Monto vetiver demonstrated exceptional growth rates. This can be attributed to radiation use efficiencies comparable with those of other C4 grasses of 18 kg/ha per MJ/m2 and its tolerance to a wide range of conditions that would slow the growth of many species. As a consequence, modelling demonstrated that vetiver exhibits a greater potential to take up nutrients than many other grass species under similar conditions. However, before applying the parameters in other regions or other cultivars of vetiver, it is recommended that model predictions be checked against local knowledge of shoot dry matter yields and nutrient concentrations.

Key words: Monto vetiver grass, wastewater, modelling, shoot growth, nitrogen, phosphorus.
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1 INTRODUCTION

The Vetiver System, which is based on vetiver grass, *Chrysopogon zizanioides* (L.) Roberty, formerly known as *Vetiver zizanioides* L.Nash (Veldkamp, 1999), was first developed by the World Bank for soil and water conservation in India in the mid 1980s. The history of use of vetiver grass has evolved through three phases:

- Soil and water conservation in agricultural lands in the 1980s,
- Bioengineering technique for steep slope stabilisation in the 1990s,
- Environmental protection, particularly in wastewater treatment in the 2000s. (Grimshaw, 2003).

Research has described the many characteristics of vetiver grass suitable for water purification (Anon., 1997, Zheng *et al*. 1997; Truong, 2000, Truong and Hart, 2001), leachate and effluent disposal (Truong and Stone, 1996; Truong and Baker, 1998; Truong, 1999; Truong and

Hart, 2001; Truong 2002; Vietmeyer 2002). Anecdotal evidence of vetiver out-performing other species in utilizing wastewater and removing nitrogen and phosphorus has led to an increased interest among consultants in using vetiver for wastewater reuse schemes in Australia.

However, for vetiver to be accepted for widespread use in Australia, it must not become a weed. Although vetiver grass is very resilient under the most adverse conditions, it can be eliminated easily either by spraying with glyphosate herbicide or uprooting and drying out by hand or farm machinery (Truong, 2000). To comply with the very strict Australian rules on introduced plants, a sterile vetiver cultivar was selected (from a number of existing cultivars in Australia) and exhaustively and rigorously tested for eight years for its sterility under various growing conditions. The Queensland Department of Primary Industries has approved this cultivar for use in soil conservation and it was registered in Australia as Monto vetiver.

In designing effluent irrigation schemes, it is important to be able to size the irrigation area and buffering storage pond volume so that the irrigation area is not overloaded with water or nutrients, which can lead to nitrate leaching, rising water tables and other environmental problems. This requires prediction of the growth rates and nutrient uptake of the plants grown in the irrigation area.

Plant growth models provide a tool for predicting plant growth under various conditions of climate, soil type and water and nutrient management. In this paper, we determine values of the major growth and nutrient uptake model parameters for Monto vetiver. We have drawn on information supplied in the literature, and also the data from a purpose designed pot (Wagner *et al.* 2003) and field trials conducted at Beaudesert, Queensland. We then demonstrate the use of these parameters for growth and nutrient uptake prediction using the daily time-step dynamic pasture module within the MEDLI model (Gardner *et al.*, 1996).

2 LITERATURE REVIEW

2.1 Genetic Characteristics

There are two *C. zizanioides* genotypes being used for soil and water conservation, and land stabilisation purposes:

- The seeded north Indian genotype
- The sterile or very low fertility south Indian genotype.

While the seeded genotype is only used in northern India, the southern and sterile genotype is used for essential oil production around the world, and the latter is the genotype that being used for soil and water conservation and land stabilisation purposes. Results of the Vetiver Identification Program using DNA typing, have shown that of the 60 samples submitted from 29 countries outside South Asia, 53 (88%) were a single clone of *C. zizanioides*. These 53 samples tested came from North and South America, Asia, Oceania and Africa. Amongst these 53 cultivars are Monto (Australia) and Sunshine (USA). Recent analysis have confirmed this distinction and shown a clear and replicable separation between the seedy and non-fertile types (Adams and Dafforn, 1999). Hence, much of the extensive research that has been conducted on the sterile vetiver genotype around the world applies to the same clone and, as such, can be used to extract information concerning the parameter values needed for modeling Monto vetiver. The growth, harvest, temperature threshold and nutrient threshold parameter values found in the literature search are listed below.

2.2 Growth Parameters

2.2.1 Maximum root depth

Although vetiver roots are commonly reported to reach 2 m depth, Greenfield (2002) describes vetiver after 8 months of growth showing a rooting depth of 3.6 meters. He also reports how engineers found vetiver roots penetrating a steep fill nearly 4 meters, and in one case in Thailand, roots were found by researches to reach a depth of 6 meters.

2.2.2 *Maximum crop coefficient.*

The parameter relates Class A pan evaporation (PAN) to evapotranspiration (ET) for a crop with 100% cover. It is equal to the ratio ET:PAN. For a lush green pasture, the maximum crop coefficient is usually 0.8-0.9. For trees, the value is about 1.0. Although no data on the maximum crop coefficient for vetiver can be found, it is likely to be about 0.9.

2.2.3 *Biomass growth and Radiation use efficiency.*

Vetiver is a C4 plant and is highly efficient in converting solar radiation to biomass. Biomass production (dry weight) is usually from 20-40 tons/ha/yr, but an irrigated farm in Texas claims to have achieved a yield of 100 tons/ha/yr (Zarotti, 2002). The potential radiation use efficiency (RUE) is a key growth parameter used in describing biomass production in plant growth models and represents the dry matter yield produced for each unit of solar radiation under non-yield limiting conditions of water and nutrient supply. We have found no reports of RUE for vetiver in the literature.

2.2.4 *Minimum yield for full cover*

The percentage of the total land area that is covered with green (transpiring) leaves will depend on the time since vetiver was established and the density at which the vetiver slips were planted. However, before full cover can be established, a certain amount of biomass must be present. This amount is determined from the relationship between % Green cover and Dry Matter Yield. No such relationship has been found in the literature.

2.2.5 *Specific Leaf Area*

For vetiver grown without shading, the specific leaf area was found to about 140 cm^2/g (Yoon, 1991). This increased by 10% for vetiver grown in the shade.

2.2.6 *Shoot to Root ratios*

Yoon (1991) obtained shoot:root ratios of 1.0:0.3 to 1.0:0.4 for vetiver grown on a range of soil types. Recently, vetiver growing in pots of sand (which allowed easier retrieval of the root system) showed shoot:root ratios of 1:1.05 to 1:1.15 (McKenzie, 2002). In another pot trial using sand, Wagner *et al*. (2003), observed shoot:root ratios of 1:1.08. The discrepancy may be due to the difficulty in removing the very fine and extensive vetiver root system from the soil.

2.3 Harvest Parameters

MEDLI assumes that plant material is harvested periodically to export nutrients from the site used for effluent irrigation to prevent the area from becoming overloaded with nitrogen and phosphorus. Hence, a number of harvest parameters are required.

2.3.1 *Harvest trigger yield*

This parameter determines the standing yield that should be present before the plants are mowed or trimmed to remove material. This value will depend on pasture management, but for an effluent irrigation scheme, we assumed that the vetiver sward would be mowed every 9 weeks in summer to curtail flowering and maintain a lush vegetative growth.

2.3.2 *Residual dead cover and residual green cover*

The amount of green cover left determines how quickly the sward will grow after mowing. When mowed, some pastures show considerable amount of dead stubble due to lack of light reaching the base of the sward. Vetiver shows little death of leaves in the center of each clump, if it is periodically topped (National Research Council, 1993). Hence, vetiver may maintain a high percentage of green cover remaining after mowing. The percentage of area that is covered with dead leaf material is the residual dead cover%.

2.3.3 *Residual shoot biomass*

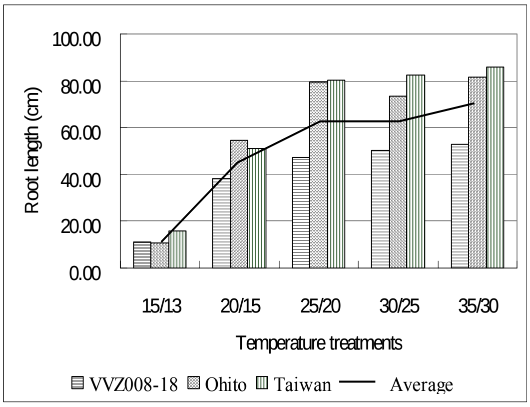
When mowed, a certain amount of biomass remains. The dry weight of this residue needs to be determined for MEDLI modelling.

2.4 Temperature Thresholds

2.4.1 *Soil temperature thresholds for root growth*

Recent research showed that although very little shoot growth occurred at the soil temperature range of 15^{o}C (day) and 13^{o}C (night), root growth continued at the rate of 126mm/day, indicating that vetiver grass was not dormant at this temperature (Wang pers. comm.). Extrapolation suggested that root dormancy occurred at about 5^{o}C while 25^{o}C was optimal soil temperature for root growth (Fig.1).

Fig 1. The effect of soil temperature on the root growth of vetiver.



<u>*Temperature treatments:*</u> day 15^{o}C /night 13^{o}C

2.4.2 *Minimum air temperature for frost kill*

Although vetiver is a tropical grass, it can survive and thrive under extremely cold conditions. Under frosty weather, its top growth is killed but its underground growing points survived. In Australia, vetiver growth was not affected by severe frost at –11^{o}C and it survived for a short period at –22^{o}C in northern China (Xu pers. comm.). In Georgia (US), vetiver survived in soil temperature of -10^{o}C but not at –15^{o}C (Truong, 2000). Maffei (2002) records vetiver having an absolute minimum temperature of –15^{o}C below which death occurred.

2.4.3 *Minimum daily air temperature for growth*

The grass sprouted when **mean** daily temperature was >12^{o}C (Zhang Xinbao, 1992; Maffei, 2002).

2.4.4 *Minimum and maximum air daily temperatures for optimum growth*

The grass grew rapidly > 25^{o}C (Zhang Xinbao, 1992). Maffei (2002) describes vetiver as growing luxuriantly in areas with temperatures ranging from 21-45^{o}C. Root length, root and shoot dry weight increased with increasing temperature from 15/13 to 35/30^{o}C (day/night) (Wang pers. comm. 2002).

2.4.5 *Maximum daily air temperature for growth.*

Truong (2002) cites Mark Berry’s success in establishing vetiver at an extreme ambient temperature of >54^{o}C on kimberlite, (black waste rock from diamond mining) in South Africa.

2.4.6 Thermal time to full cover (degree days).

Plants grow more slowly under colder conditions and the growth stages are better defined on the basis of thermal time rather than chronological time. The number of degrees that the daily average air temperature is above the base temperature (Minimum daily air temperature for growth, *i.e.* $12^{o}C$), is summed for each day to calculate the number of degree-days that have elapsed during a given period of time. The number of degree-days required for vetiver to reach full cover was not found in the literature.

2.5 Nutrient Thresholds

2.5.1 Minimum N and P shoot concentration for cover/growth development to commence.

Pot trials indicated a minimum shoot N concentration of 0.2% (dry weight) and a minimum shoot P concentration of 0.07% (dry weight) is required for growth (Wagner *et al*., 2003). At concentrations above 2.0% for N and 0.1% for P, growth appeared to be close to maximal.

2.5.2 Maximum N and P shoot concentrations

Shoot concentrations of 2.5% N and 0.16% P have been obtained in a pot experiment (Wagner *et al*., 2003). However, CSIR (1976) observed shoot P concentrations ranging from 0.05 to 0.60%.

2.5.3 Salinity threshold at which yield begins to reduce.

Truong *et al*. (2002) indicated a value of 8 dS/m (saturation extract) before yield reduction occurred.

2.5.4 Yield reduction rate

Truong (1992) and Cook (1993) indicated a value of 5% per dS/m. This means that 50% yield reduction in soil will occur with salinity of about 13-17.5 dS/m, and survival will occur at salinity levels as high as 47.5 dS/m (*i.e.* sea water salinity).

3 EXPERIMENTAL

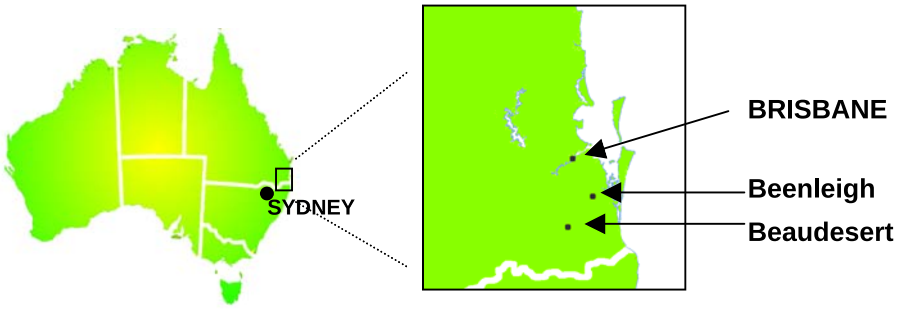
A field trial was also established at GELITA APA, Beaudesert, Queensland (Fig. 2). As with all non-fertile plants, vetiver can only be vegetatively propagated and planted. Planting materials were obtained by subdividing the crown of mature plants into slips or splits. Three replicates of 10 plots (3m x 3m) were planted with Monto vetiver grass slips on 2–5 October 2001. Planting density was 15 plants/m^2. Plots were irrigated with effluent from the gelatine factory as needed, and DAP fertilizer was applied as split applications to allow the plants to grow without limitation in terms of nutrients and water. Spray irrigation of effluent in summer heat resulted in leaf scorch due to the high sulphur content of the effluent (effluent concentrations in mg/L were 544 S, 300 N and 2 P). Flood irrigation of the vetiver solved this problem.

After establishment, when the canopy cover reached 80-90%, the whole experimental area was slashed to 20 cm height (with biomass removed) and the weekly harvest commenced for 9 weeks in autumn, with the Week 1 harvest taken on 7 March 2002. The site was slashed again, and weekly harvests commenced for 10 weeks in winter, with week 1 harvest taken on 19 July 2002. After another slash, summer weekly harvests were commenced for 12 weeks, starting on 12 November 2002.

At each of these harvests, the followings were measured:

• *Crop cover development over time from mowing*. An overhead photograph of the canopy was taken. Due to the 2-3 m height of the vetiver, a digital camera was attached to a boom 3.5m high, inclined to 45^{o} ensuring the camera was in the correct position. The photo was projected on a screen with a grid of 100 dots overlaying it. The number of dots over green cover estimated the green cover percentage. Similarly, the number of dots over bare earth estimated the bare soil cover percentage whilst the remainder (brown leaf material) was dead cover.

Fig 2. Location of Beaudesert and Beenleigh trial sites.



- *Canopy heights*. Mean canopy height was measured with a tape measure.

- *Biomass increase over time*. Due to rigidity and height, a quadrant cannot be used to mark out the sampling area for vetiver. Instead, an area of 1 m^2 (equal to 15 plants) was randomly pegged within each of three plots. New plots were chosen each week so that the biomass yield represented the yield since slashing. Plants in each area (including dead material) were harvested with shears to a height the same as the original slashed height, and placed in labelled bags, oven dried at 60°C until constant weight and weighed to determine shoot dry weight.
- *Residual green cover and residual biomass*. Every third harvest, a quadrant was randomly placed in the harvested plot and the area photographed to allow the green cover percentage of the residue to be determined as described previously. All shoot material down to ground level was then removed, bagged, oven dried and weighed to determine residual shoot dry weight.
- *Plant shoot N & P concentrations* (% dry weight). The oven-dried samples were analysed for total N and total P concentrations of the shoot material using the Dumas combustion method for N and ICP for P.

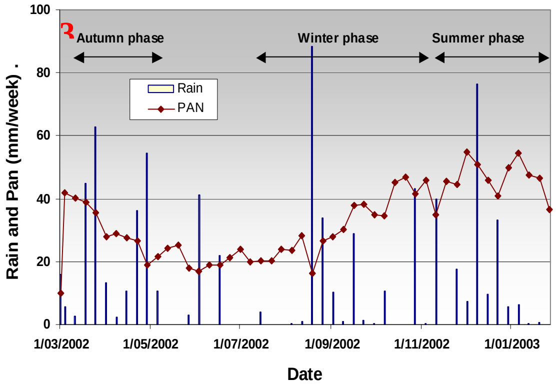
Throughout the period of the field trial, radiation interception by the canopy was measured using four continuously logged radiation sensors, of which one was placed above the canopy and three were placed below the canopy. The incident solar radiation measured at the top of canopy minus the incident solar radiation measured at the base of canopy provided a measure of the total solar radiation interception by the canopy. Daily rainfall, maximum and minimum temperature, Class A pan evaporation and solar radiation were sourced from an on site weather station, and SILO, a database which integrates daily climate data from Bureau of Meteorological stations across Australia (http://www.nrm.qld.gov.au/silo).

Together with the literature review values, the data gathered allowed a number of growth and nutrient uptake parameters to be determined. To provide an **independent** comparison with model predictions, measurements of shoot yield, shoot nitrogen concentration and shoot phosphorus concentration were taken at another site growing vetiver (Teys Abattoir, Beenleigh, Queensland).

4 RESULTS

The climate experienced throughout the three phases of the experimental trial is shown in Figures 3 and 4. The shoot biomass yield (Fig. 5) indicates that after a slow start during the Autumn phase, rapid growth was seen in the last (Summer) phase of the trial. The cause for the slow growth in the Autumn phase is not understood but may have been due to the sward experiencing nutrient deficiency while root systems were establishing. Figure 6 shows canopy heights during the Autumn phase increased disproportionately relative to dry matter production. Hence, estimates of potential radiation use efficiency (RUE) were made using data from the Summer phase only.

Fig 3. Weekly rainfall and Class A pan evaporation for the three phases of the field trial.
Fig 4. Maximum and minimum air temperatures with solar radiation (MJ/m^2) for the three phases of the field trial.



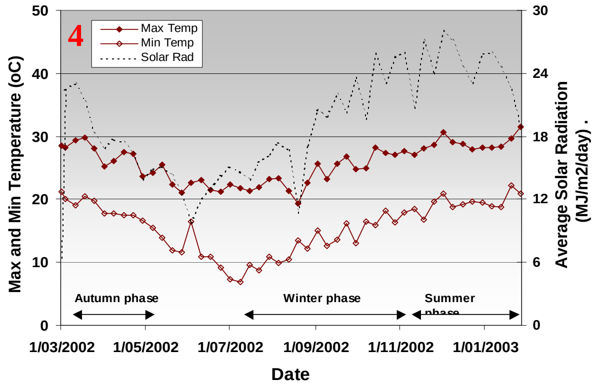
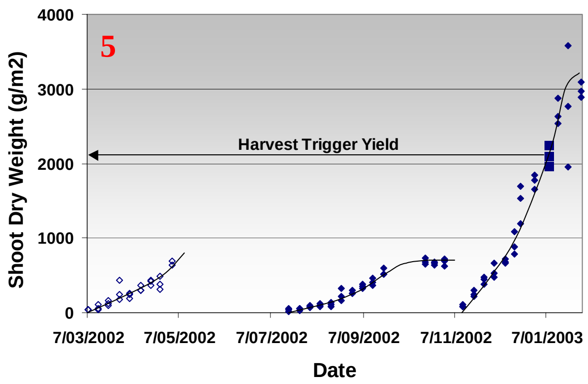
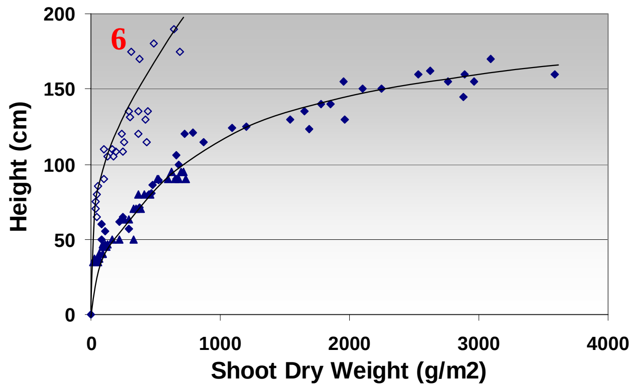


Fig 5. Shoot dry weight yields over time through all three phases of the trial.
Fig 6. Canopy height as a function of shoot dry weight yield, with the Autumn phase data shown using open symbols; the Winter and Summer phase data using solid symbols.





4.1 Radiation Use Efficiency (RUE)

The shoot biomass yield increased over the 12-week harvest period in summer. When cumulative yield (kg/ha) is plotted against the cumulative amount of solar radiation intercepted (MJ/m^2), a linear relationship is found, with the slope representing an RUE of 18 kg/ha per MJ/m^2 (Fig. 7).

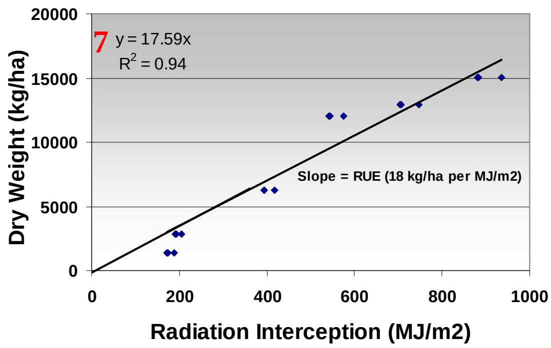
4.2 Residual Shoot Dry Weight

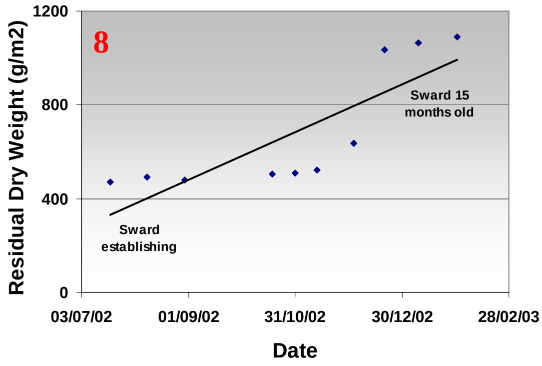
Residual shoot dry weight was found to increase with each harvest, indicating that throughout the trial, vetiver was not yet fully established (Fig. 7). Although not definitive, Figure 8 indicates a residual shoot dry weight of at least 1000 g/m^2 or 10 000 kg/ha for a young vetiver sward, but only 4000 kg/ha for an establishing sward. For a fully established sward, the gaps between clumps (which covered about 50% of the ground area by the end of the trial) would be expected to close and increase the residual shoot dry weight two-fold.

4.3 Minimum Standing Yield for Full Cover

For each harvest, the shoot dry weight yield was plotted against the green cover percentage. Figure 9 shows that the lowest yield for achieving 100% green cover was 200 g/m^2 or 2000 kg/ha. The Standing Yield is the shoot yield present in the field, and equals the harvestable yield plus the residual shoot dry weight. Hence, the minimum standing yield for full cover for the sward was 6000 (2000 + 4000) kg/ha (Autumn) and 12000 (2000 + 10000) kg/ha (Summer).

Fig. 7: The potential radiation use efficiency shown by vetiver during the Summer phase.
Fig. 8: The change of residual shoot dry weight with age of vetiver sward.





4.4 Harvest trigger yield

The Standing yield 9 weeks after slashing in Summer represents the harvest trigger yield. Figure 4 (in which the 9-week yield data are shown as “×”) indicates that harvestable is about 2000 g/m^2 or 20 000 kg/ha. The harvestable yield plus the residual dry weight in summer calculates a total harvest trigger yield of 30 000 kg/ha.

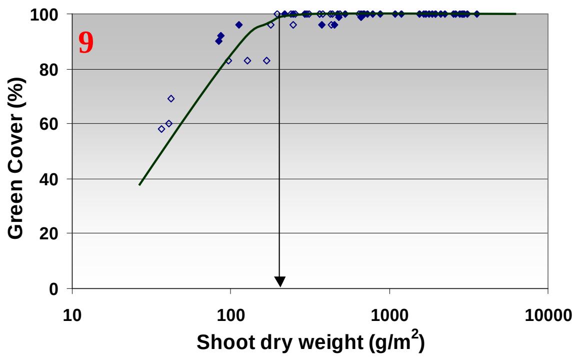
4.5 Residual Green and Dead Cover

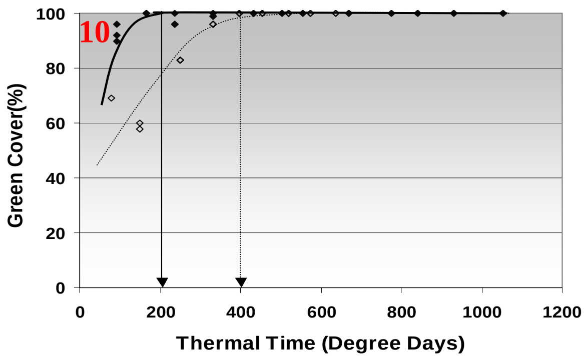
During establishment, immediately following the first slashing (2/3/2002), the residue showed about 35% green cover and 60% dead cover. By the end of the experiment in January 2003, the residue after harvesting showed about 50% green cover and 50% dead cover.

4.6 Thermal time to reach full cover

Using a base temperature of 12^{o}C (the minimum daily average air temperature for growth), the thermal time to reach 100% Green Cover can be determined by plotting thermal time against Green Cover %. Figure 10 shows that during the Autumn phase, vetiver required about 400 degree days to reach full cover, while during the Summer phase, only 200 degree days were required.

Fig 9. Determination of the minimum yield for full cover. Note the use of the log scale.
Fig 10. The thermal time to reach full cover.
For both Figures, the Autumn phase data is shown by the use of open symbols.





5 GROWTH AND NUTRIENT UPTAKE MODELLING

The modeling framework used for this work was MEDLI (Model for Effluent Irrigation by Land Irrigation), a Windows based computer program developed by Queensland Department of Natural Resources and Mines, Queensland Department of Primary Industries, and the CRC for

Waste Management and Pollution Control, Australia (Gardner *et al.,* 1996). MEDLI is used throughout Australia for designing and predicting the sustainability of effluent irrigation schemes.

The MEDLI dynamic pasture growth model is fully described in the MEDLI manual (Gardner and Davis (1998), and consists of a plant growth module, a plant transpiration and soil evaporation module and a plant nutrient uptake module. In developing the vetiver model, we assumed that the vetiver growth and nutrient uptake can be described adequately as follows:

- Biomass is increased each day according to solar radiation intercepted by the green cover after adjustment for any water, temperature or nitrogen stress.
- Green cover increases according to thermal time, and eventually reaches 100% cover.
- Roots grow downward (until they reach their maximum rooting depth) according to thermal time, accessing water and nutrients within the rooted zone only.
- The pasture grows until the biomass yield reaches a predefined value, at which point it is harvested by mowing. The pasture is then allowed to reestablish biomass as described above.

Table 1 shows two sets of parameters, one set for the Autumn (establishing) phase and the other for the Summer phase. This indicates that growth of vetiver including establishment cannot be adequately captured by MEDLI using one set of parameters. However, the modelling of the pasture establishment phase is not critical when designing long-term effluent irrigation schemes using permanent pastures and so we chose to use the Summer phase parameters from Table 1 for our MEDLI modelling, discarding the first year of predictions since MEDLI will underpredict the establishment phase of vetiver using the Summer phase parameters.

Table 1. Model growth and nutrient uptake parameters determined for Monto vetiver grass.

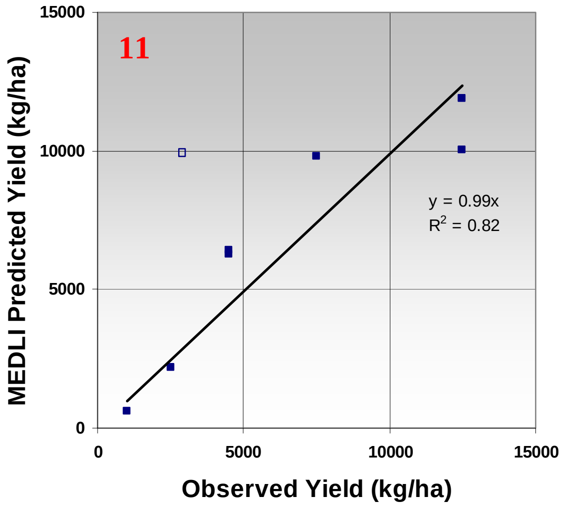
	Parameters	**Autumn Phase Values**	**Later Phase Values**
Growth	Maximum crop coefficient	0.9	0.9
	Maximum root depth (m)	4.0	4.0
	Potential Radiation Use Efficiency (MJ/m^2 per kg/ha)	18	18
	Minimum yield for full cover (kg/ha)	6000	12000
Harvest	Harvest trigger yield (kg/ha)	24000	30000
	Residual green cover for established sward (%)	35	50
	Residual dead cover (established) (%)	60	50
	Residual shoot biomass (kg/ha)	4000	10000
Temperature Thresholds	Minimum daily temperature for growth (^{o}C)	12	12
	Minimum daily temperature for optimum growth (^{o}C)	25	25
	Maximum daily temperature for optimum growth (^{o}C)	45	45
	Maximum daily temperature for growth (^{o}C)	60	60
	Thermal time to full cover (degree days)	200	200
Nitrogen	Minimum N shoot concentration for cover/growth development to commence (%)	0.2	0.2
	Minimum N shoot concentration for optimal cover/growth (%) before model calibration	2.0*	2.0*
	Maximum shoot N (%)	2.5	2.5
Phosphorus	Maximum shoot P (%)	0.6	0.6
Salinity	Salinity threshold at which yield begins to reduce (dS/m)	8	8
	Yield reduction rate (% per dS/m)	5	5

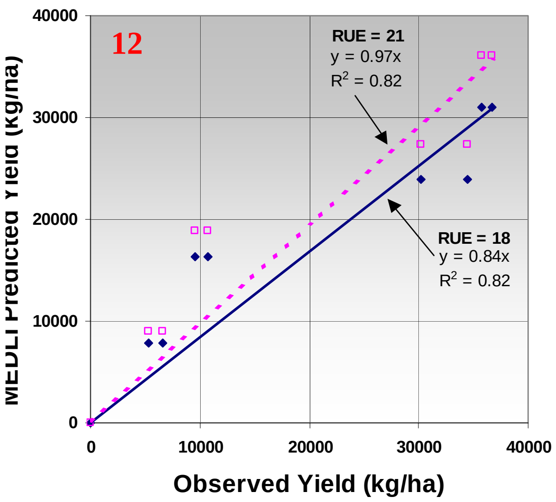
* These values were later changed to 1.5, after model calibration.

Using Table 1 parameter values (Summer phase), MEDLI was run starting in 2001 to establish the sward, and then examining the monthly yields over the trial period (3/2002 – 1/2003). Without calibration, MEDLI underpredicted the yields due to nitrogen deficiency. But when the minimum shoot N concentration for optimal cover/growth was reduced from 2.0 to 1.5%, a good match was observed between the observed and predicted yields (Fig. 11) for all months except March 2002, where MEDLI overpredicted vetiver growth early in the trial. The average shoot nitrogen and phosphorus concentrations predicted by MEDLI were also comparable with the observed values (Table 2), using the measured soil concentrations of 106 mgN/kg and 52 mgP/kg, and effluent concentrations of 300 mgN/L and 2 mgP/L at the Beaudesert trial site. The predicted yield for 12 months was 80 000 kg/ha shoot dry weight.

Using Table 1 parameter values for vetiver, a value of 1.5% for minimum shoot N concentration for optimal cover/growth, and appropriate soils and climate data, MEDLI was also run for an established vetiver grass pasture at Beenleigh. The Beenleigh vetiver data represents an independent data set; *i.e.* a data set that was not used in the development and calibration of the vetiver model. This data set was used to validate the vetiver model. Figure 12 shows a reasonable match between the observed and predicted monthly shoot dry weight yields, with MEDLI underpredicting yields by 16%. Using soil concentrations of 2500 mgN/kg and 700 mgP/kg and effluent concentrations of 160 mgN/L and 31 mgP/L at the Beenleigh site, a good match was again obtained between predicted and observed shoot nitrogen and phosphorus concentrations. The predicted yield for 12 months was 87 000 kg/ha shoot dry weight.

Fig 11. Comparison of predicted and observed shoot yields for the Beaudesert trial after calibration. Exclusion of the March value (open symbol outlier) resulted in a good match.
Fig 12. Comparison of predicted and observed shoot yields for the Beenleigh site. The effect of increasing the RUE to 21 kg/ha per MJ/m^2 is also shown, using open symbols.





6 DISCUSSION AND CONCLUSIONS

Vetiver demonstrates the high growth rates of a C4 grass, as indicated by a RUE of 18 kg/ha per MJ/m^2. This value is comparable with similar data for other C4 grasses such as maize (*Zea mays L.*) with a value of 16 kg/ha per MJ/m^2 (Muchow et al. 1990), and sugarcane (*Saccharum officinarum*) with a value of 18 kg/ha per MJ/m^2 (Inman-Bamber 1974) and much higher than the RUE of C3 grasses such as coastal couch grass (*Cynodon dactylon*) of 5.3 kg/ha per MJ/m^2 (Burton *et al.*, 1988). This high growth rate, combined with its tolerance of a wide range of conditions such as high salinity and waterlogging, suggests that vetiver would be an ideal plant for utilising high strength rural industry effluent, provided it is periodically harvested. The harvesting not only encourages lush vegetative growth in vetiver, but also exports nutrients from the effluent irrigation site in the harvested material. The deeply penetrating roots of vetiver also have the potential for reclaiming land with excess levels of nutrients at depth. Total nitrogen and phosphorus removal was 1020 kgN/ha and 85 kgP/ha over 10 months (Apr 2002 to Jan 2003) at Beaudesert and 740 kg N/ha and 110 kgP/ha over 3 months at the nutrient-rich site at Beenleigh.

Conservatively using the Beaudesert data, removal rates were 1200 kg/ha/yr of N and 100 kg/ha/yr of P. This compares favourably with removal rates (kg/ha/yr) of 430 N and 70 P for Green Panic (*Panicum maximum*), 500 N and 90 P for Kikuyu grass (*Pennisteum clandestinum*), 600 N and 90 P for Rhodes grass (*Chloris gayana*), 360 N and 70 P for Jumbo sorghum (*Sorghum bicolor* var. Jumbo) and 620 N and 110 P for Jumbo sorghum and ryegrass (*Lolium italicum*) rotation shown at an irrigated pasture trial under high fertilizer rates (1000 kg N/ha/yr and 200 kgP/ha/yr) at Gatton, 100 km NW of Beaudesert (Gardner pers. comm. 1995).

The moderate shoot concentrations of 2 %N and 0.3%P observed in vetiver shoots at Beaudesert indicate that the high rates of nutrient removal were primarily due to the high growth rate ofvetiver, rather than a capacity to store unusually high concentrations of nutrients in the shoot tissues.

Table 2. Average predicted and observed shoot nutrient concentrations over the trial period.

	Beaudesert Trial Site		Beenleigh Site	
Shoot Concentrations (%)	**Predicted**	**Observed**	**Predicted**	**Observed**
Nitrogen	1.6	1.7	1.9	2.1
Phosphorus	0.17	0.14	0.33	0.31

Models can provide a helpful tool in designing schemes where prediction of possible outcomes is required. We have demonstrated how parameter values for a simple plant growth and nutrient uptake model have been derived for vetiver and then used to predict vetiver growth and nutrient uptake at Beenleigh. Such information is invaluable for sizing the irrigation area required such that the inputs of nutrients and water do not exceed their export, hence allowing sustainable effluent irrigation schemes to be designed.

However, this work is far from complete as many of the parameter values have been derived from a young (15 month old) vetiver sward and parameters such as the residual biomass and residual green cover may be greater for a fully established sward, leading to faster recovery of the sward after mowing. Different management strategies, such as different mowing height and mowing frequency would need suitable harvest parameters to be determined. Also, the relatively slow vetiver growth at the start of the trial, and the lower shoot nitrogen and phosphorus concentrations exhibited by the vetiver at Beaudesert compared with Beenleigh could indicate that we may not have achieved maximal growth rates. Hence, the RUE parameter may be underestimated. Indeed, a RUE of 21 kg/ha per MJ/m^2 is suggested by the Beenleigh data (Fig. 12). This would give a predicted yield of 101000 kg/ha over a 12-month period. Indeed, this is similar to the yield of 100 tons/ha/yr claimed for an irrigated farm in Texas (Zarotti, 2002)!

Nevertheless, the parameters in Table 1 represent an excellent starting point. Before applying the parameters in other regions or other cultivars of vetiver, it is recommended that model predictions be checked against local knowledge of shoot dry matter yields and nutrient concentrations. As more information on growth parameters is obtained through experimentation, these parameters estimates can be refined. Improved predictions will lead to better design of effluent irrigation schemes involving vetiver.

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A Brief Introduction to the First Author

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