Published as: Healy, M.G., Newell, J., Rodgers, M. 2007. Harvesting effects on biomass and nutrient retention in Phragmites australis in a free-water surface constructed wetland in western Ireland. Biology and Environment: Proceedings of the Royal Irish Academy 107B(3): 139-145. DOI: 10.3318/BIOE.2007.107.3.139

HARVESTING EFFECTS ON BIOMASS AND NUTRIENT RETENTION IN *PHRAGMITES AUSTRALIS* IN A FREE-WATER SURFACE CONSTRUCTED WETLAND IN WESTERN IRELAND

M.G. Healy[1]*, J. Newell[2] and M. Rodgers[1]

[1*]Corresponding author. Department of Civil Engineering, National University of Ireland, Galway, Ireland.

[2] Department of Mathematics, National University of Ireland, Galway, Ireland.

Tel: +353 91 495364; Fax: +353 91 750507; E-mail: Mark.Healy@nuigalway.ie

ABSTRACT

The aim of this study was to examine the seasonal variation in biomass, total nitrogen (Tot-N) and total phosphorus (Tot-P) content of *Phragmites australis* in a 3-cell free-water surface (FWS) constructed wetland in western Ireland and to investigate the effects of harvesting on their biomass and nutrient content. One cell of the wetland was divided into two plots: one plot, measuring 80 m^2, was completely harvested on the 16th June, 2005, while the other plot, the control plot, remained uncut throughout the study duration.

At approximately monthly intervals over an 8-month study duration, completely randomised $0.64m^2$ areas within each plot were harvested to water level and the shoot biomass and nutrient content were measured. In the control plot, the plant biomass, Tot-N and Tot-P content peaked in August. In the June-cut plot, the shoot biomass, total nitrogen (Tot-N) and total phosphorus (Tot-P) content peaked in September. The mean rate of dry matter production (RPD), defined as the mean daily rate of dry matter production per unit area per day between harvests, attained maximum rates of $12.8g\ m^{-2}d^{-1}$ and $4.2g\ m^{-2}d^{-1}$ for the control and June-cut plots, respectively, indicating that annual harvesting of emergent vegetation may not have any beneficial effect on biomass production or nutrient content under Irish climatic conditions.

Keywords: Free-water surface; constructed wetland; *Phragmites australis*; biomass; nutrient uptake.

1. INTRODUCTION

Constructed wetland technology has been gaining in popularity and is now commonly used for the treatment of municipal wastewater from small communities and agricultural wastewater from farms. In Ireland, much research attention has focused on the quantification of the effectiveness of constructed wetlands for the treatment of secondary or tertiary wastewater (Healy and Cawley, 2002; Dunne *et al.*, 2005). However, studies quantifying the seasonal variation of biomass, total nitrogen (Tot-N) or total phosphorus

(Tot-P) in emergent vegetation or the effect of harvesting on shoot re-growth rates under Irish climatic conditions are rare.

Wetland vegetation has desirable characteristics. They assimilate nutrients into plant biomass and oxygenate the substrate in the vicinity of the plant root. Macrophytes remove pollutants by directly assimilating them into their tissue and providing surfaces and a suitable environment for microorganisms to transform the nutrients and reduce their concentrations (Kaseva, 2004). Although the uptake of nutrients by the macrophyte population only accounts for a small percentage of the total nutrient loading on a wetland (Mantovi *et al.*, 2003; Ciria *et al.*, 2005), they still provide a variety of useful biological functions, such as oxygenation of the rhizosphere (Armstrong *et al.*, 2006).

Harvesting of the emergent macrophytes has a pronounced effect on the growth and nutrient uptake rates. Although nutrient uptake and growth rates are higher in young vegetation stands (Batty and Younger, 2004), other factors such as nutrient loading and hydraulic retention time (HRT) may significantly affect the measured rates (Hardej and Ozimek, 2002; Solano et al., 2004). Karunaratne *et al.* (2004) investigated the effects of harvesting *P. australis* in a wetland in Central Japan and found that biomass levels in an uncut section rose to a maximum of 1250g m^{-2} in July, whereas June-cut and July-cut sections rose to levels of approximately 400g m^{-2} in October and November, respectively. The maximum rate of dry matter production (RDP – the mean rate of dry matter production per unit ground area per day between sampling; $gm^{-2}d^{-1}$) was approximately the same in the uncut and July-cut stands, attaining a rate of 18 and 12g $m^{-2}d^{-1}$, respectively. Kim and Geary (2001) found that there was no statistical difference in Tot-P-uptake between harvested and unharvested *Schoenoplectus mucronatus* shoots in a laboratory study in Australia.

Over a 2-year study duration, Healy and Cawley (2002) examined the performance of a free-water surface (FWS) constructed wetland treating secondary effluent from a small community in Williamstown in North County Galway, Ireland (PE, 330). As they did not examine the role of emergent vegetation in the treatment of wastewater, the objectives of this study were: (i) to measure biomass, Tot-N and Tot-P profiles of *P. australis* in the constructed wetland over a growing season, and (ii) to assess the effect of harvesting on the their RPD and nutrient contents.

2. MATERIALS AND METHODS

2.1 SITE DESCRIPTION

The Williamstown FWS tertiary treatment system wetland consists of two cells separated by one retention pond connected in series. The three cells of the wetland are constructed as shallow lagoons enclosed by boulder clay embankments lined with a high-density polyethylene (HDPE) liner (Table 1). An extended-aeration activated sludge system provides secondary treatment for the domestic wastewater from a population equivalent of approximately 330. The combined system is designed to produce an effluent with less than 20mg biochemical oxygen demand (BOD_5) L^{-1}, 30mg suspended solids (SS) L^{-1} and 10mg ammonia-N (NH_4-N) L^{-1}.

The wetland was fully operational less than six months after establishment, with maximum macrophyte growth in the summer of 1999 – two years after establishment from seedlings. Standing macrophyte coverage reached 93% in both cells.

2.2 VEGETATION SAMPLING REGIME

Commencing in April, 2005, the third cell of the wetland was divided into 2 plots: a control plot, measuring 90 m^2, and a harvested (June-cut) plot, measuring 80 m^2. In the control plot, completely randomised areas were sampled on the following dates: 2nd April, 18th May, 16th June, 20th July, 25th August, 22nd September and 8th November. In the June-cut plot, an $80m^2$ section was harvested to water level on the 16th June. Subsequent to the harvesting, the June-cut plot was sampled in a manner similar to the control plot.

On each day of sampling, six completely randomised sections in the remaining unharvested areas of the control and harvested plots were selected, each with a surface area of $0.64m^2$. Within each $0.64m^2$ area, the above-water level shoot height was measured and number of shoots were counted and harvested. All sampling was conducted on above-water level biomass to prevent inundation of the stalks by the surface water and for ease of sampling. This sampling regime has been used by other researchers

(Karunaratne *et al.*, 2004). The samples were dried at 75°C to a constant weight and the total shoot dry biomass in each subsection (g biomass m^{-2}) was calculated. Each sample was then ground in a mill and a subsample was tested for Tot-N and Tot-P content. Using these data, the above-water biomass, Tot-N and Tot-P content, and the RDP for each sampling section were obtained.

Another $70m^2$ plot in the third cell of the wetland was harvested on 25th August, 2005 to investigate the effects of conducting a late harvest on the nutrient uptake and biomass content of the emergent vegetation, but no re-growth occurred following harvesting.

2.3 WATER QUALITY MEASUREMENTS

The water level in each cell is controlled by overflow weirs. Throughout the study, the water level in the study cell remained constant at 43cm. Wastewater samples were collected each month at the inlet and outlet of each wetland cell and were tested for the following parameters: chemical oxygen demand (COD) (closed reflux, titrimetric method), Tot-N (persulfate method), NH_4-N (ammonia-selective electrode method), nitrate-N (NO_3-N) (nitrate electrode method), ortho-phosphate (PO_4-P) (ascorbic acid method) and SS (total suspended solids dried at 103-105^oC). All water quality parameters were tested in accordance with the Standard Methods (APHA-AWWA-WEF, 1995).

2.4 STATISTICAL ANALYSIS

A repeated measures mixed effects ANOVA was fitted to investigate whether the date and plot type (control / harvested) had any effect on the longitudinal change in the mean response (i.e. Tot-N, Tot-P, dry weight). Multiple comparisons were performed as appropriate using Tukey 95% simultaneous confidence intervals while the underlying model assumptions were checked using suitable residual plots. All analyses were performed using Minitab 14.

3. RESULTS AND DISCUSSION

3.1 WATER QUALITY

Influent and effluent wastewater characteristics are presented in Table 2. Throughout the study duration, the total organic loading rate on the study cell was approximately 2g $CODm^{-2}d^{-1}$ and the average influent Tot-N was 6±3mg L^{-1}. Nitrification of the wastewater was not complete as the final effluent NH_4-N concentration was 1±2mg L^{-1}. PO_4-P retention within the system was also limited over the study duration as there was no significant difference in influent and effluent PO_4-P concentrations in the wetland.

3.2 GROWTH DYNAMICS

Figures 1, 2, 3 and 4 illustrates the seasonal changes in above-water shoot height, biomass, Tot-N and Tot-P, respectively, in the control and June-cut plots of *P. australis*. Harvesting of the emergent vegetation removed approximately 20g Tot-N m^{-2} and 2g

Tot-P m^{-2} from the wetland cell loaded with approximately 0.58g Tot-N $m^{-2}d^{-1}$ and 0.1g Tot-P $m^{-2}d^{-1}$.

In the control plot, the mean shoot biomass rose from 687±227 g m^{-2} in April to a maximum of 1506±215g m^{-2} in August. In the control plot, the mean stem density remained constant at 122±23 shoots m^{-2} and the total shoot height rose from 1.8±0.3m in April to a maximum of 2.6±0.4m in July (Table 3). The above-water shoot height reduced to 1.9±0.3m in November (Figure 1). Shoot height reductions of this type have been found by other researchers (Hardej and Ozimek, 2002; Karunaratne *et al.*, 2004). Following harvesting in the June-cut plot, the mean shoot biomass reached a maximum value of 286±67g m^{-2} in September, indicating that harvesting in June had the effect of delaying the period of peak growth by one month. This trend was evident in the shoot height, Tot-N and Tot-P contents; maximum shoot height and density of 1.6±0.1m and 83±23 shoots m^{-2}, respectively, were also attained during this month. The control plot had a maximum above-water level RPD of 12.8g $m^{-2}d^{-1}$ during July, whereas the June-cut plot achieved a maximum above-water level RPD of 4.2g $m^{-2}d^{-1}$ during September. This result is generally in agreement with the findings of Karunaratne *et al.* (2004) who, in a wetland in Japan, found RPD values of 18 and 20g m^{-2} d^{-1} for control and July-cut plots of *P. australis* when cut at 0.25m-0.3m above ground level. *P. australis* RPD values measured by Hill *et al.* (1997) in a wetland in Alabama, USA were 17.4g $m^{-2}d^{-1}$.

The Tot-N content of the control plot rose from a minimum value of 5±1g Tot-N m^{-2} (7.7±1.8mg g^{-1} dry weight (DW)) in April to a maximum value of 23±6g Tot-N m^{-2}

(15.5±2.3mg g^{-1} DW) in August. This value then decreased to 20±6g Tot-N m^{-2} (15.5±1.7mg g^{-1} DW) and 7±3g Tot-N m^{-2} (10.6±2.1mg g^{-1} DW) in September and November, respectively. These results are comparable to similar studies in the same climatic conditions (Batty and Younger, 2004) but are well below those recorded in warmer climates (Bragato *et al.*, 2006). In a wetland in Northeast Italy, Bragato *et al*. (2006) measured maximum and minimum Tot-N values of 27mg g^{-1} DW in July and 7.1 mg g^{-1} DW in October, respectively. In the June-cut plot the Tot-N content of the biomass reached a maximum of 6.7±1.6g Tot-N m^{-2} (23.4±1.9mg g^{-1} DW).

The Tot-P contents of the biomass behaved similarly to the Tot-N content measurements: in the control plot, the Tot-P content rose from a minimum value of 0.48±0.07g Tot-P m^{-2} (0.7±0.1mg g^{-1} DW) during April to a maximum value of 2.4±0.5g Tot-P m^{-2} (1.6±0.2mg g^{-1} DW) in August before decreasing to 0.7±0.4g Tot-P m^{-2} (1.0±0.4mg g^{-1} DW) during November. Bragato et al. (2006) measured maximum Tot-P contents of 0.8mg g^{-1} DW in July. In the June-cut plot, the Tot-P contents did not achieve the control plot values; the maximum Tot-P value was 0.6±0.1g Tot-P m^{-2} (2.2±0.2mg g^{-1} DW) in September.

3.3 STATISTICAL ANALYSIS

Case Profile plots for each response variable – dry weight, Tot-N and Tot-P - are presented in Figures 2, 3 and 4, respectively. On the basis of the graphical evidence, there is a strong suggestion of a higher mean response (for each of the three responses of interest) for the control plots when compared to the June-cut plots. There is a suggestion also that the longitudinal monthly growth pattern is different across the plots where each response tends to decrease from August in the control plots as opposed to in September in the June-cut plots (i.e. a Date/Plot interaction).

The formal results based on the (separate) ANOVA models are as follows:

Dry Weight

There was evidence of a significantly lower mean Tot-N for the June-cut plots when compared to the control plots ($p<0.001$) and of a significant Plot/Date interaction ($p<0.001$) (Fig. 2). The estimated difference in mean dry weight in the control plots compared to June-cut plots in September ranged from 694.3 to 1336 g m^{-2}.

Tot-N

There was evidence of a significantly lower mean Tot-N for the June-cut plots when compared to the control plots ($p<0.001$) and of a significant Plot/Date interaction ($p<0.001$) (Fig. 3). The estimated difference in mean Tot-N in the control plots compared to June-cut plots in September ranged from 7.76 to 19.33 mg g^{-1}.

Tot-P

There was evidence of a significantly lower mean Tot-P for the June-cut plots when compared to the control plots ($p<0.001$) and of a significant Plot/Date interaction ($p<0.001$) (Fig. 4). The estimated difference in mean Tot-P in the control plots compared to June-cut plots in September ranged from 0.63 to 1.65 mg g^{-1}.

4. CONCLUSIONS

This 8-month study of the growth and nutrient retention dynamics of *P. australis* in a FWS constructed wetland showed that the above-water shoot biomass in the control plot varied throughout the growing season and reached a maximum value of 1506±215g m^{-2} during August. Maximum RPD rates occurred in the control plot during July and maximum Tot-N and Tot-P contents were measured in August. The effects of a June harvesting of the above-water biomass were investigated but neither biomass, Tot-N and Tot-P content, nor the RPD attain the values of the control plot. A repeated measures ANOVA, using a significance level of alpha = 0.05 indicated that the dry matter, Tot-N and Tot-P content of the control plot was greater than the June-cut plot. The maximum RPD of the June-cut plot was 4.2g m^{-2} d^{-1}, indicating that harvesting of *P. australis* is not recommended in June as a method to permanently remove nutrients from wetlands under Irish climatic conditions.

ACKNOWLEDGEMENTS

This project was funded by the Irish EPA under the Small Scale Study scheme. The first author would like to express his appreciation to the late Dr. John Mulqueen, NUI, Galway. The help of Mr. Brian Finan, Gardening and Grounds Supervisor, NUI Galway is also acknowledged.

<u>REFERENCES</u>

APHA-AWWA-WEF. 2005. *Standard methods for the examination of water and wastewater.* 21st edition. American Public Health Association. Washington, USA.

Armstrong, J., Jones, R.E. and Armstrong, W. 2006. Rhizone phyllosphere oxygenation in *Phragmites* and other species in relation to redox potential, convective gas flow, submergence and aeration pathways. The New Phytologist **172**, 719-731.

Batty, L.C. and Younger, P.L. 2004. Growth of Phragmites australis (Cav.) Trin ex. Steudel in mine water treatment wetlands: effects of metal and nutrient uptake. Environmental Pollution **132**, 85-93.

Bragato, C., Brix, H. and Malagoli, M. 2006. Accumulation of nutrients and heavy metals in *Phragmites australis* (Cav.) Trin. Ex Steudel and *Bolboschoenus maritimus* (L.) Palla in a constructed wetland of the Venice lagoon watershed. Environmental Pollution **144**, 967-975.

Ciria, M.P., Solano, M.L. and Soriano, P. 2005. Role of macrophyte *Typha latifolia* in a constructed wetland for wastewater treatment and assessment of its potential as a biomass fuel. Biosystems Engineering **92**, 535-544.

Dunne, E.J., Culleton, N., O'Donovan, G., Harrington, R. and Olsen, A.E., 2005. An integrated constructed wetland to treat contaminants and nutrients from dairy farmyard dirty water. Ecological Engineering **24**, 221-234.

Hardej, M. and Ozimek, T. 2002. The effect of sewage sludge flooding on growth and morphometric parameters of *Phragmites australis* (Cav.) Trin. Ex Steudel. Ecological Engineering **18**, 343-350.

Healy, M. and Cawley, A.M. 2002. The nutrient processing capacity of a constructed wetland in western Ireland. Journal of Environmental Quality **17**, 1739-1747.

Hill, D.T., Payne, V.W.E., Rogers, J.W., Kown, S.R. 1997. Ammonia effects on the biomass production of five constructed wetland plant species. Bioresource Technology **62**, 109-113.

Karunaratne, S., Asaeda, T. and Yutani, K. 2004. Shoot regrowth and age-specific rhizome storage dynamics of *Phragmites australis* subjected to summer harvesting. Ecological Engineering **22**, 99-111.

Kaseva, M.E. 2004. Performance of a sub-surface flow constructed wetland in polishing pre-treated wastewater – a tropical case study. Water Research **38**, 681-687.

Kim, S-Y. and Geary, P.M. 2001. The impact of biomass harvesting on phosphorus uptake by wetland plants. Water Science and Technology **44** (11-12), 61-67.

Mantovi, P., Marmiroli, M., Maestri, E., Tagliavini, S., Piccinini, S. and Marmiroli, N. 2003. Application of a horizontal subsurface flow constructed wetland on treatment of dairy parlor wastewater. Bioresource Technology **88**, 85-94.

Solano, M.L., Soriano, P. and Ciria, M.P. 2004. Constructed wetlands as a sustainable solution for wastewater treatment in small villages. Biosystems Engineering **87**, 109-118.

CAPTIONS FOR FIGURES

Fig. 1 - Comparison of the seasonal variation in above-water shoot height in uncut and June-cut plots in Williamstown constructed wetland, Ireland.

Fig. 2 - Comparison of the seasonal variation in above-water biomass in uncut and June-cut plots in Williamstown constructed wetland, Ireland.

Fig. 3 - Comparison of the seasonal variation in above-water Tot-N in uncut and June-cut plots in Williamstown constructed wetland, Ireland.

Fig. 4 - Comparison of the seasonal variation in above-water Tot-P in uncut and June-cut plots in Williamstown constructed wetland, Ireland.

Table 1 - Details of combined wetland configuration.

Cell	Cell dimensions			Area	Volume	HRT[†]	HLR[‡]
	Length	Width	Depth				
	m			m^2	m^3	d	$m\ d^{-1}$
First cell	28	10	0.3	280	84	1.5	0.20
Retention pond	39	8	0.8	312	250	4.4	0.18
Third cell	47	9-12	0.4	564	225	4.1	0.10

† Approximate hydraulic residence time, based on a mean flow of 55 $m^3\ d^{-1}$.

‡ Hydraulic loading rate.

Table 2 - Mean influent and effluent concentrations (± standard deviation) in Williamstown constructed wetland (n=7).

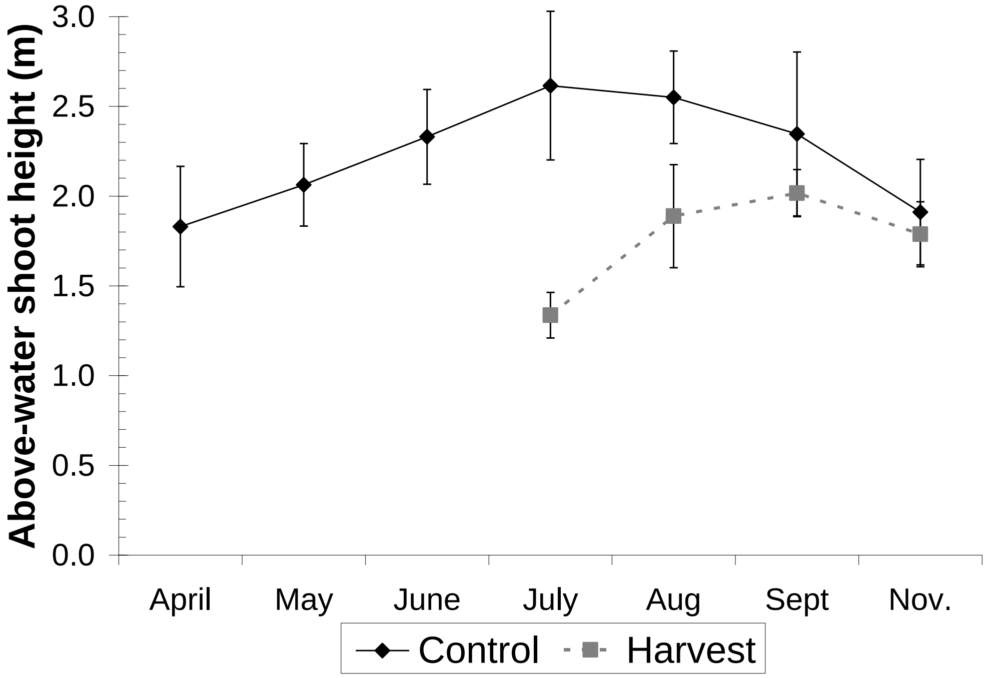
	Influent ($mg\ L^{-1}$)			
Parameter	First cell	Retention pond	Third cell	Effluent ($mg\ L^{-1}$)
COD	32±5	29±9	24±9	23±9
SS	11±5	7±8	4±4	1±2
Tot-N	10±5	6±4	6±3	5±4
NO_3-N	9±3	3±2	6±4	4±4
NH_4-N	1±2	2±1	2±1	1±2
PO_4-P	2±1	1±1	1±1	1±2

Table 3 - Comparison of the effects of shoot harvesting (± standard deviation) on *Phragmites australis* in Williamstown constructed wetland during 2005.

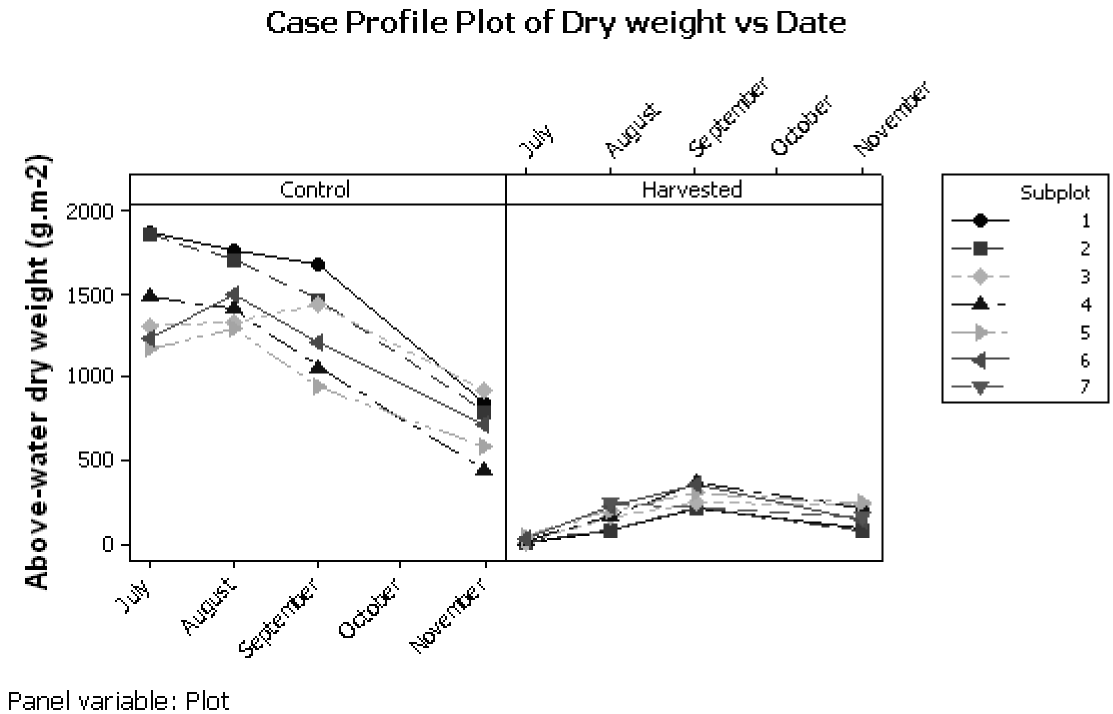
Sampling	Stem density (no. shoots m^{-2})		Total shoot height (m)		Dry weight (g m^{-2})		RPD† (g m^{-2} d^{-1})		Shoot Tot-N content (g Tot-N m^{-2})		Shoot Tot-P content (g Tot-P m^{-2})	
Date	Control	June-cut	Control	June-cut	Control	June-cut	Control	June-cut	Control	June-cut	Control	June-cut
2 April	102±17	-	1.80±0.30	-	687±227	-	-	-	5±1	-	0.48±0.07	-
18 May	101±11	-	2.00±0.20	-	662±91	-	-0.50	-	13±2	-	1.95±0.43	-
16 June	133±27	-	2.30±0.30	-	1056±261	-	6.90	-	18±2	-	2.19±0.07	-
20 July	141±21	26±10	2.60±0.40	1.30±0.10	1491±312	28±15	12.80	0.80	20±5	0.8±0.50	2.30±0.40	0.10±0
25 Aug.	143±7	56±16	2.50±0.30	1.90±0.30	1506±215	170±64	0.40	4.00	23±6	4.1±1.00	2.40±0.50	0.40±0.20
22 Sept.	115±23	83±23	2.30±0.50	2.00±0.10	1301±279	286±67	-7.30	4.20	20±6	6.7±1.60	1.80±0.30	0.60±0.10
8 Nov.	109±17	59±17	1.90±0.30	1.80±0.20	717±196	171±66	-12.30	-2.50	7±3	3±1.20	0.70±0.40	0.20±0.10

† RPD= rate of dry matter production above-water level per unit area per day between harvests.

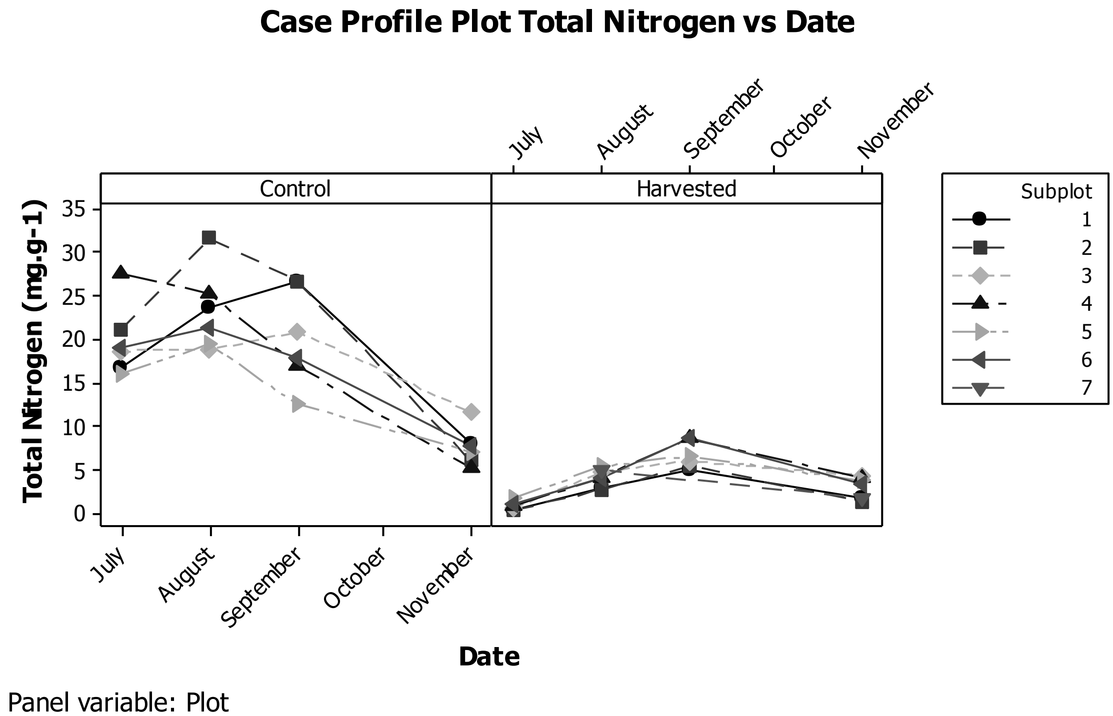
Healy, M.G. et al. Fig 1.



Healy, M.G. et al. Fig 2.



Healy, M.G. et al. Fig 3.



Healy, M.G. et al. Fig 4.