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5
6 HARVESTING EFFECTS ON BIOMASS AND NUTRIENT RETENTION IN
7 *PHRAGMITES AUSTRALIS* IN A FREE-WATER SURFACE CONSTRUCTED
8 WETLAND IN WESTERN IRELAND

9
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11
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16
17 ABSTRACT

18
19 The aim of this study was to examine the seasonal variation in biomass, total nitrogen
20 (Tot-N) and total phosphorus (Tot-P) content of *Phragmites australis* in a 3-cell free-
21 water surface (FWS) constructed wetland in western Ireland and to investigate the effects
22 of harvesting on their biomass and nutrient content. One cell of the wetland was divided
23 into two plots: one plot, measuring 80 m², was completely harvested on the 16th June,
24 2005, while the other plot, the control plot, remained uncut throughout the study duration.

25 At approximately monthly intervals over an 8-month study duration, completely
26 randomised 0.64m² areas within each plot were harvested to water level and the shoot
27 biomass and nutrient content were measured. In the control plot, the plant biomass, Tot-N
28 and Tot-P content peaked in August. In the June-cut plot, the shoot biomass, total
29 nitrogen (Tot-N) and total phosphorus (Tot-P) content peaked in September. The mean
30 rate of dry matter production (RPD), defined as the mean daily rate of dry matter
31 production per unit area per day between harvests, attained maximum rates of 12.8g m⁻²d⁻¹
32 ¹ and 4.2g m⁻²d⁻¹ for the control and June-cut plots, respectively, indicating that annual
33 harvesting of emergent vegetation may not have any beneficial effect on biomass
34 production or nutrient content under Irish climatic conditions.

35

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

38

39

1. INTRODUCTION

40

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

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

49

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

58

59 Harvesting of the emergent macrophytes has a pronounced effect on the growth and
60 nutrient uptake rates. Although nutrient uptake and growth rates are higher in young
61 vegetation stands (Batty and Younger, 2004), other factors such as nutrient loading and
62 hydraulic retention time (HRT) may significantly affect the measured rates (Hardej and
63 Ozimek, 2002; Solano *et al.*, 2004). Karunaratne *et al.* (2004) investigated the effects of
64 harvesting *P. australis* in a wetland in Central Japan and found that biomass levels in an
65 uncut section rose to a maximum of 1250g m⁻² in July, whereas June-cut and July-cut
66 sections rose to levels of approximately 400g m⁻² in October and November, respectively.
67 The maximum rate of dry matter production (RDP – the mean rate of dry matter
68 production per unit ground area per day between sampling; gm⁻²d⁻¹) was approximately
69 the same in the uncut and July-cut stands, attaining a rate of 18 and 12g m⁻²d⁻¹,

70 respectively. Kim and Geary (2001) found that there was no statistical difference in Tot-
71 P-uptake between harvested and unharvested *Schoenoplectus mucronatus* shoots in a
72 laboratory study in Australia.

73

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

81

82

2. MATERIALS AND METHODS

83

84

2.1 SITE DESCRIPTION

85

86 The Williamstown FWS tertiary treatment system wetland consists of two cells separated
87 by one retention pond connected in series. The three cells of the wetland are constructed
88 as shallow lagoons enclosed by boulder clay embankments lined with a high-density
89 polyethylene (HDPE) liner (Table 1). An extended-aeration activated sludge system
90 provides secondary treatment for the domestic wastewater from a population equivalent
91 of approximately 330. The combined system is designed to produce an effluent with less

92 than 20mg biochemical oxygen demand (BOD₅) L⁻¹, 30mg suspended solids (SS) L⁻¹ and
93 10mg ammonia-N (NH₄-N) L⁻¹.

94

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

98

99 2.2 VEGETATION SAMPLING REGIME

100

101 Commencing in April, 2005, the third cell of the wetland was divided into 2 plots: a
102 control plot, measuring 90 m², and a harvested (June-cut) plot, measuring 80 m². In the
103 control plot, completely randomised areas were sampled on the following dates: 2nd
104 April, 18th May, 16th June, 20th July, 25th August, 22nd September and 8th November. In
105 the June-cut plot, an 80m² section was harvested to water level on the 16th June.
106 Subsequent to the harvesting, the June-cut plot was sampled in a manner similar to the
107 control plot.

108

109 On each day of sampling, six completely randomised sections in the remaining
110 unharvested areas of the control and harvested plots were selected, each with a surface
111 area of 0.64m². Within each 0.64m² area, the above-water level shoot height was
112 measured and number of shoots were counted and harvested. All sampling was conducted
113 on above-water level biomass to prevent inundation of the stalks by the surface water and
114 for ease of sampling. This sampling regime has been used by other researchers

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

120

121 Another 70m² plot in the third cell of the wetland was harvested on 25th August, 2005 to
122 investigate the effects of conducting a late harvest on the nutrient uptake and biomass
123 content of the emergent vegetation, but no re-growth occurred following harvesting.

124

125 2.3 WATER QUALITY MEASUREMENTS

126

127 The water level in each cell is controlled by overflow weirs. Throughout the study, the
128 water level in the study cell remained constant at 43cm. Wastewater samples were
129 collected each month at the inlet and outlet of each wetland cell and were tested for the
130 following parameters: chemical oxygen demand (COD) (closed reflux, titrimetric
131 method), Tot-N (persulfate method), NH₄-N (ammonia-selective electrode method),
132 nitrate-N (NO₃-N) (nitrate electrode method), ortho-phosphate (PO₄-P) (ascorbic acid
133 method) and SS (total suspended solids dried at 103-105°C). All water quality parameters
134 were tested in accordance with the Standard Methods (APHA-AWWA-WEF, 1995).

135

136 2.4 STATISTICAL ANALYSIS

137

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

144

145 3. RESULTS AND DISCUSSION

146

147 3.1 WATER QUALITY

148

149 Influent and effluent wastewater characteristics are presented in Table 2. Throughout the
150 study duration, the total organic loading rate on the study cell was approximately 2g
151 CODm⁻²d⁻¹ and the average influent Tot-N was 6±3mg L⁻¹. Nitrification of the
152 wastewater was not complete as the final effluent NH₄-N concentration was 1±2mg L⁻¹.
153 PO₄-P retention within the system was also limited over the study duration as there was
154 no significant difference in influent and effluent PO₄-P concentrations in the wetland.

155

156 3.2 GROWTH DYNAMICS

157

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

161 Tot-P m⁻² from the wetland cell loaded with approximately 0.58g Tot-N m⁻²d⁻¹ and 0.1g
162 Tot-P m⁻²d⁻¹.

163

164 In the control plot, the mean shoot biomass rose from 687±227 g m⁻² in April to a
165 maximum of 1506±215g m⁻² in August. In the control plot, the mean stem density
166 remained constant at 122±23 shoots m⁻² and the total shoot height rose from 1.8±0.3m in
167 April to a maximum of 2.6±0.4m in July (Table 3). The above-water shoot height
168 reduced to 1.9±0.3m in November (Figure 1). Shoot height reductions of this type have
169 been found by other researchers (Hardej and Ozimek, 2002; Karunaratne *et al.*, 2004).
170 Following harvesting in the June-cut plot, the mean shoot biomass reached a maximum
171 value of 286±67g m⁻² in September, indicating that harvesting in June had the effect of
172 delaying the period of peak growth by one month. This trend was evident in the shoot
173 height, Tot-N and Tot-P contents; maximum shoot height and density of 1.6±0.1m and
174 83±23 shoots m⁻², respectively, were also attained during this month. The control plot had
175 a maximum above-water level RPD of 12.8g m⁻²d⁻¹ during July, whereas the June-cut
176 plot achieved a maximum above-water level RPD of 4.2g m⁻²d⁻¹ during September. This
177 result is generally in agreement with the findings of Karunaratne *et al.* (2004) who, in a
178 wetland in Japan, found RPD values of 18 and 20g m⁻² d⁻¹ for control and July-cut plots
179 of *P. australis* when cut at 0.25m-0.3m above ground level. *P. australis* RPD values
180 measured by Hill *et al.* (1997) in a wetland in Alabama, USA were 17.4g m⁻²d⁻¹.

181

182 The Tot-N content of the control plot rose from a minimum value of 5±1g Tot-N m⁻²
183 (7.7±1.8mg g⁻¹ dry weight (DW)) in April to a maximum value of 23±6g Tot-N m⁻²

184 (15.5±2.3mg g⁻¹ DW) in August. This value then decreased to 20±6g Tot-N m⁻²
185 (15.5±1.7mg g⁻¹ DW) and 7±3g Tot-N m⁻² (10.6±2.1mg g⁻¹ DW) in September and
186 November, respectively. These results are comparable to similar studies in the same
187 climatic conditions (Batty and Younger, 2004) but are well below those recorded in
188 warmer climates (Bragato *et al.*, 2006). In a wetland in Northeast Italy, Bragato *et al.*
189 (2006) measured maximum and minimum Tot-N values of 27mg g⁻¹ DW in July and 7.1
190 mg g⁻¹ DW in October, respectively. In the June-cut plot the Tot-N content of the
191 biomass reached a maximum of 6.7±1.6g Tot-N m⁻² (23.4±1.9mg g⁻¹ DW).

192

193 The Tot-P contents of the biomass behaved similarly to the Tot-N content measurements:
194 in the control plot, the Tot-P content rose from a minimum value of 0.48±0.07g Tot-P m⁻²
195 (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
196 g⁻¹ DW) in August before decreasing to 0.7±0.4g Tot-P m⁻² (1.0±0.4mg g⁻¹ DW) during
197 November. Bragato *et al.* (2006) measured maximum Tot-P contents of 0.8mg g⁻¹ DW in
198 July. In the June-cut plot, the Tot-P contents did not achieve the control plot values; the
199 maximum Tot-P value was 0.6±0.1g Tot-P m⁻² (2.2±0.2mg g⁻¹ DW) in September.

200

201

3.3 STATISTICAL ANALYSIS

202

203 Case Profile plots for each response variable – dry weight, Tot-N and Tot-P - are
204 presented in Figures 2, 3 and 4, respectively. On the basis of the graphical evidence, there
205 is a strong suggestion of a higher mean response (for each of the three responses of
206 interest) for the control plots when compared to the June-cut plots. There is a suggestion

207 also that the longitudinal monthly growth pattern is different across the plots where each
208 response tends to decrease from August in the control plots as opposed to in September in
209 the June-cut plots (i.e. a Date/Plot interaction).

210

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

212

213 *Dry Weight*

214

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

219

220 *Tot-N*

221

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

226

227 *Tot-P*

228

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

233

234

4. CONCLUSIONS

235

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

248

249

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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 m ²	Volume m ³	HRT [†] d	HLR [‡] m d ⁻¹
	Length	Width	Depth				
	_____ m _____						
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 m³ d⁻¹.

[‡] Hydraulic loading rate.

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

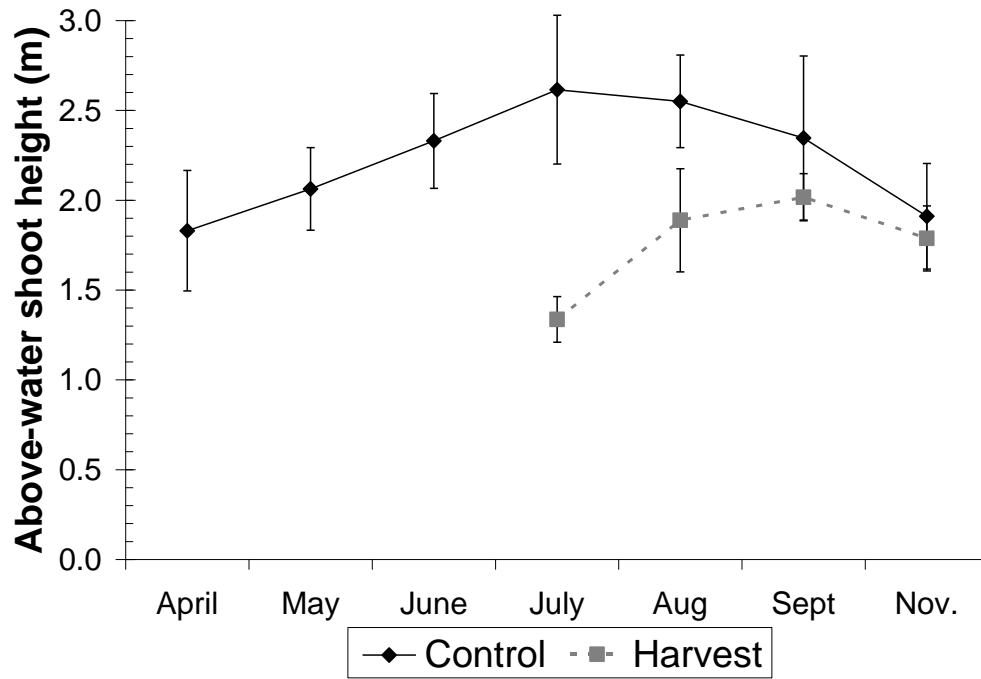
Parameter	Influent (mg L^{-1})			Effluent (mg L^{-1})
	First cell	Retention pond	Third cell	
COD	32 \pm 5	29 \pm 9	24 \pm 9	23 \pm 9
SS	11 \pm 5	7 \pm 8	4 \pm 4	1 \pm 2
Tot-N	10 \pm 5	6 \pm 4	6 \pm 3	5 \pm 4
NO ₃ -N	9 \pm 3	3 \pm 2	6 \pm 4	4 \pm 4
NH ₄ -N	1 \pm 2	2 \pm 1	2 \pm 1	1 \pm 2
PO ₄ -P	2 \pm 1	1 \pm 1	1 \pm 1	1 \pm 2

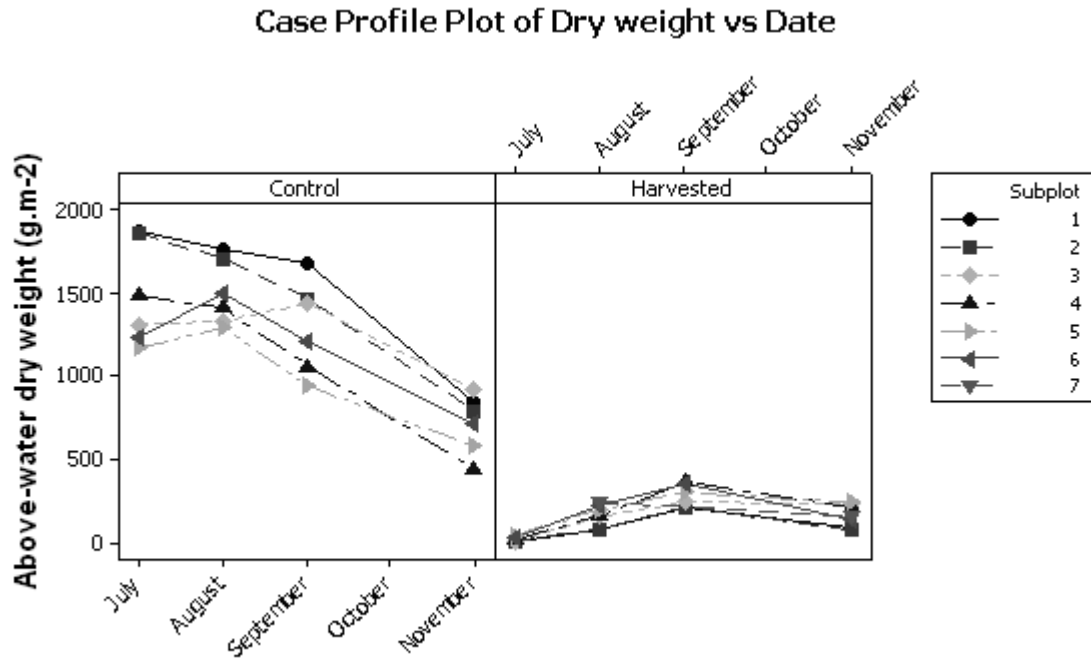
Table 3 - Comparison of the effects of shoot harvesting (\pm standard deviation) on *Phragmites australis* in Williamstown constructed wetland during 2005.

Sampling Date	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)	
	Control	June-cut	Control	June-cut	Control	June-cut	Control	June-cut	Control	June-cut	Control	June-cut
2 April	102 \pm 17	-	1.80 \pm 0.30	-	687 \pm 227	-	-	-	5 \pm 1	-	0.48 \pm 0.07	-
18 May	101 \pm 11	-	2.00 \pm 0.20	-	662 \pm 91	-	-0.50	-	13 \pm 2	-	1.95 \pm 0.43	-
16 June	133 \pm 27	-	2.30 \pm 0.30	-	1056 \pm 261	-	6.90	-	18 \pm 2	-	2.19 \pm 0.07	-
20 July	141 \pm 21	26 \pm 10	2.60 \pm 0.40	1.30 \pm 0.10	1491 \pm 312	28 \pm 15	12.80	0.80	20 \pm 5	0.8 \pm 0.50	2.30 \pm 0.40	0.10 \pm 0
25 Aug.	143 \pm 7	56 \pm 16	2.50 \pm 0.30	1.90 \pm 0.30	1506 \pm 215	170 \pm 64	0.40	4.00	23 \pm 6	4.1 \pm 1.00	2.40 \pm 0.50	0.40 \pm 0.20
22 Sept.	115 \pm 23	83 \pm 23	2.30 \pm 0.50	2.00 \pm 0.10	1301 \pm 279	286 \pm 67	-7.30	4.20	20 \pm 6	6.7 \pm 1.60	1.80 \pm 0.30	0.60 \pm 0.10
8 Nov.	109 \pm 17	59 \pm 17	1.90 \pm 0.30	1.80 \pm 0.20	717 \pm 196	171 \pm 66	-12.30	-2.50	7 \pm 3	3 \pm 1.20	0.70 \pm 0.40	0.20 \pm 0.10

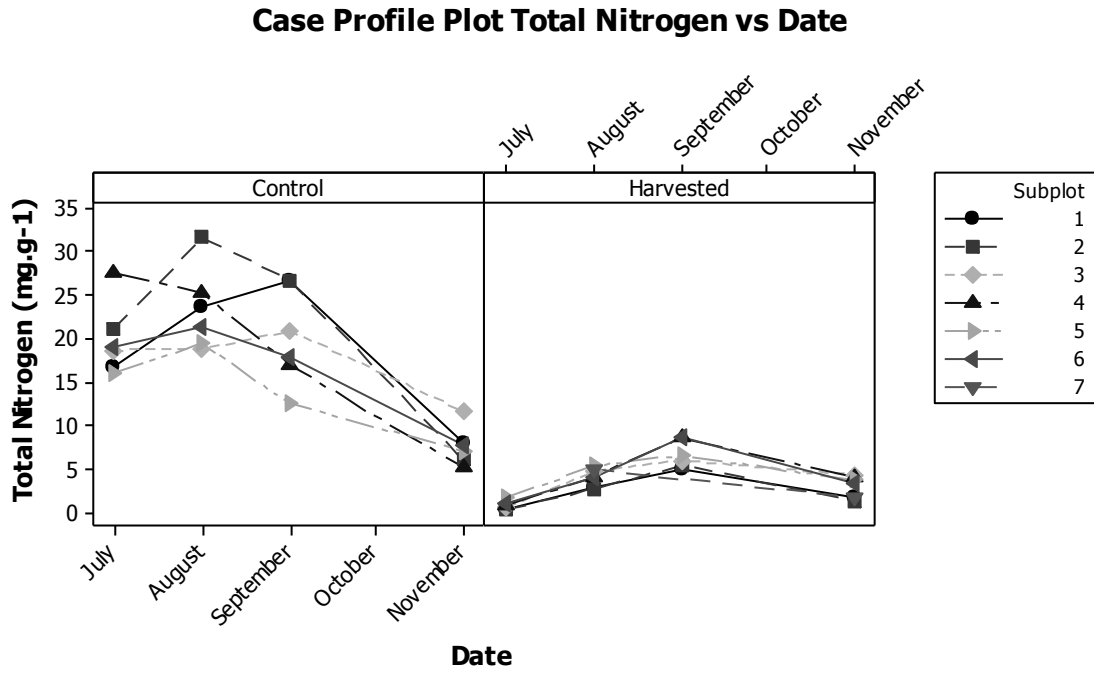
[†] RPD= rate of dry matter production above-water level per unit area per day between harvests.

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

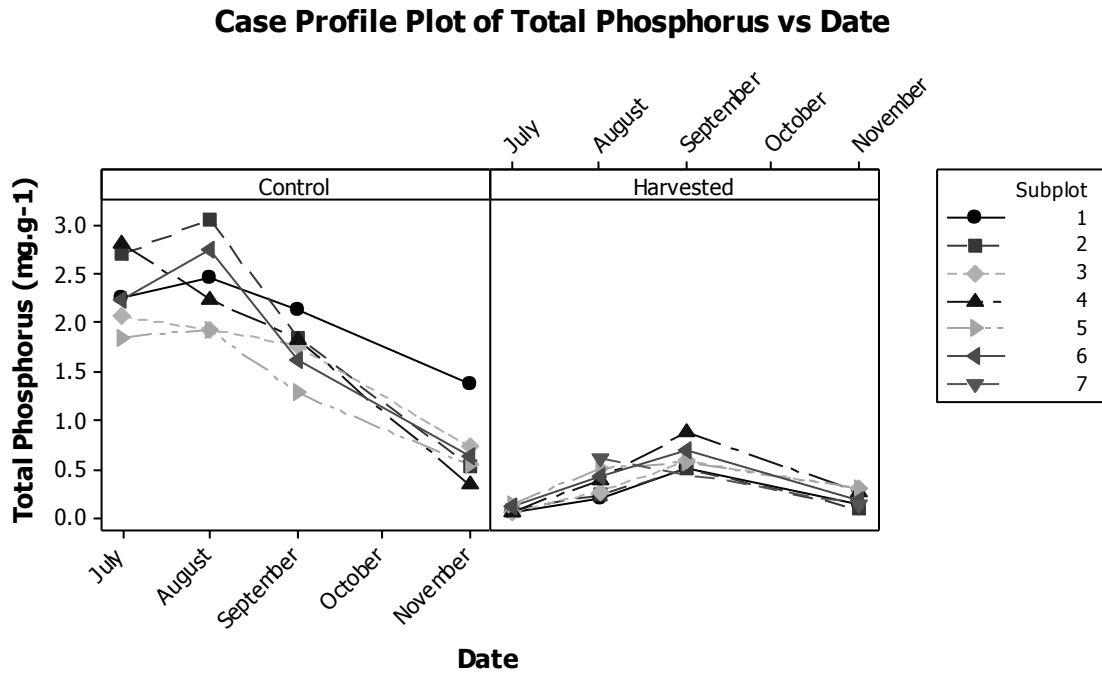




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