

4 Switchgrass nutrient composition³

H.W. Elbersen¹, D.G. Christian², N. El Bassam³, G. Sauerbeck³, and E. Alexopoulou⁴

¹ATO (Agrotechnological Research Institute), Wageningen;

²IACR Rothamsted, Harpenden, United Kingdom

³FAL (Federal Anstalt Fuer Landwirtschaft), Braunschweig, Germany.

⁴Center for Renewable Energy Sources, 19th Km Marathonos Ave., 19009, Pikermi, Greece

4.1 Introduction

Switchgrass (*Panicum virgatum* L.) is a perennial C₄ grass native to North America where it occurs naturally from 55° N latitude to deep into Mexico, mostly as a prairie grass. In North America the first varieties were selected in the 1930's for soil conservation and later as a fodder crop. Now it is also used world-wide as an ornamental plant. Since the early 1990s the crop has been developed as a model herbaceous energy crop for ethanol and electricity production in the USA and Canada. Since 1998 switchgrass is being investigated as a novel lignocellulosic C₄ biomass crop for adaptation to European conditions. Proposed uses include bioenergy, ethanol and also pulp production. The plant is best compared to other biomass grasses like *Miscanthus*, *Arundo Donax* and Reed Canary Grass. Switchgrass is propagated by seed which makes it relatively inexpensive to establish.

Nutrient analysis of switchgrass is important in order to help determine the optimum fertiliser requirements. The removal of nutrients by the plant must (in the long term) be equal to the amount of nutrients that are supplied from external sources i.e. fertilisation or deposition.

Nutrient content of a biomass crop is a very important quality trait for thermal conversion (see Chapter 7) and for utilisation as pulp (see Chapter 7). For example the amount of ash and the composition of the ash determines the ash melting behaviour. High K and Na content of the ash will reduce the ash melting point increasing slagging problems in the boiler. High Cl contents will lead to corrosion problems. Therefore nutrient composition determines to quite some extent the thermal conversion options which are available for switchgrass utilisation. When switchgrass is to be utilised for pulp production total ash content and composition are an important factor for reusing chemicals and high ash contents may also increase wear of the machinery.

The main objective of the research presented here was to evaluate nutrient content of switchgrass biomass in relation to growing conditions in Europe.

4.2 Methods and Materials

Site and treatments

Two types of trials were used for sampling for nutrient content. The first, nursery trial, contained some 15 switchgrass varieties in small plots. The other included 5 switchgrass varieties under two or three nitrogen stages (0, 75 and 150 kg N/ha) on larger plots. The experimental conditions and layout of the six experiments which were sampled for nutrient content are presented in Table 1. In the Dutch (NL) experiments *Miscanthus giganteus* was included for comparison.

All samples were taken from material harvest in winter or early spring when plants had senesced. Samples were dried at 105°C and stored until analysis. Nutrient analysis was conducted according to standard laboratory practices for plant analysis.

³ This chapter is to be submitted for publication.

Table 1. Conditions and set-up of the two experiments at four countries.

Experiment	The Netherlands		UK		Germany	Greece
	Productivity	Nursery	Productivity	Nursery	Productivity	Productivity
Site	Wageningen	N.O. Polder	Rothamsted		Braunschweig	Aliartos
Latitude	51°58′	52°38′	51°48′		52°18′	38°22′
T January °C	1,8	1,4	3,1		0,4	7,6
T July °C	16,6	17,4	15,9		17,1	27,4
Prescipation, mm	700	747	688		619	99
Soil texture	Coarse	Fine	Moderately fine over fine		Moderately coarse over coarse	Fine over moderately fine
pH	5,2	7,5	7		6,5	8
Experimental layout	Randomised complete block design in three blocks				Split plot design in three blocks, with variety as main plot and N treatment as a split	Randomised complete block design in three blocks
Treatments	0 and 75 kg N/ha and 5 switchgrass varieties	13 switchgrass varieties	0 and 75 kg N/ha and 5 switchgrass varieties	15 switchgrass varieties	0, 75 and 150 kg N/ha and 5 switchgrass varieties	0, 75 and 150 kg N/ha and 5 switchgrass varieties
Plot size	8 x 6 m	4 x 3.5 m	8 x 5 m	4.5 x 2 m	7.5 x 6.5 m	6.5 x 7.5
Row distance	15 cm		14.2 cm		15 cm	
Seeding date	2-06-98	28-05-98	22-06-98		23-06-98	
Weed control	Chemical, manual, mowing	Chemical, mowing	Chemical		Chemical, manual	

4.3 Results and Discussion

In Chapter 2 and 3 details on development and yield are presented for the experiments which were sampled for nutrients. In Tables 1 and 2 average nutrient content of switchgrass varieties and the *Miscanthus* plots are presented for the experiments on clayey and on a sandy soil. In tables 3 and 4 the individual nutrient content of switchgrass varieties is given.

Effect of soil type

In the Netherlands one experiment was situated on a sandy and the other on a clayey soil. The ash content of switchgrass and *Miscanthus* biomass was 2 to 3 times higher on the clay compared to the sandy soil. The content of other nutrients like P, K and Ca was similar for both soil types. Therefore a higher silica uptake on the clay soil probably explains the difference. This effect was to be expected, as it is known that on a clay soil plants take up more silica.

Switchgrass and *Miscanthus*

The average ash content of the switchgrass varieties was higher compared to *Miscanthus* after the second year at both sites (Table 1 and 2). This may be explained by higher leaf to stem ratios for switchgrass, which were probably increased by severe lodging in the third year. Though lodging is a frequent occurrence in switchgrass, the degree was probably unusual in the third year and may not be representative for switchgrass. Lodging in switchgrass is discussed in Chapter 2. Comparison between the average nutrient content of switchgrass and *Miscanthus* shows that average P levels were higher in switchgrass compared to *Miscanthus* this effect was consistent also for individual switchgrass varieties. The average K levels were lower in switchgrass compared to *Miscanthus*. This effect was even larger for early maturing varieties like Forestburg and REAP-921. The average levels of Ca and Mg were consistently higher in switchgrass compared to *Miscanthus*. The average concentration of Na in biomass was consistently lower for

switchgrass compared to *Miscanthus*. This was also the case for the higher Na containing switchgrass varieties like Pangburn. The Cl content of switchgrass was lower for all switchgrass compared to *Miscanthus* even when switchgrass was severely lodged (in year 3). This should contribute to lower corrosion problems in boilers when utilising switchgrass in thermal conversion compared to *Miscanthus* as discussed in Chapter 7.

This is the first comparison of switchgrass and *Miscanthus* in the same experiment. A lower K and Na content combined with the higher Ca and Mg levels in biomass contribute to higher ash-melting temperatures which reduces the chance of slagging in boilers. This explains why higher ash-melting temperatures have been found for switchgrass compared to *Miscanthus* (see Chapter 7 and Christian and Riche, 1999).

Effect of nitrogen

The effect of nitrogen stage on can be observed in Tables 2 and 4 to 7. In the Netherlands, The UK and in Greece no effect of nitrogen on yield could be observed. In Germany higher N stages clearly increased yields, though overall yields were lower than at other sites. Higher nitrogen fertiliser rates increased nitrogen content of the biomass at all the sites, especially when N was increased from 0 to 75 kg N/ha. Other effects were less evident. At the two sites in the Netherlands consistently higher K, Mg and Cl concentrations were found in the switchgrass biomass at the high nitrogen rate (75 kg N/ha) compared to the control. Other effects were generally inconsistent.

Leaf and stem comparisons

In the experiments at Aliartos (GR) and Rothamsted (UK) leaves and stems were analysed for nutrients separately (Table 5 and 7).

The ash content was up to five times higher in leaves compared to stems (Table 5). The N, P, Ca, and Mg concentrations were consistently higher in leaves compared to stems both in Greece and the UK. The K concentrations were consistently lower in leaves compared to stems both in Greece and the UK. This effect may be due to the ease of leaching of the very soluble K compared to immobile nutrients like Ca, Mg and P.

The Na concentration tended to be very high in Greece compared to the other sites. This may be explained by salt accumulation in the soil due to irrigation.

The higher ash and nutrient content of leaves compared to stems illustrates the importance of leaf to stem ratios. This trait is different between varieties (see Table 7) and will decrease as plants mature and loose leaves over winter. Therefore varieties with low leaf to stem ratios that mature early will have comparatively lower ash and nutrient contents which increases biomass quality. Bio-refining of switchgrass into leaf and stem fractions has been proposed in order to increase quality for thermal conversion and pulp production.

Variability between switchgrass varieties

A wide variety of switchgrass varieties was used in the different experiments. These varieties differed in many ways including seed size, seed vigour, establishment success, growth habit, and latitude at which they originated which determines the time to flower and time of maturation. All these and many other attributes contribute to differences in nutrient content of the biomass at harvest in winter.

When plants mature in fall many nutrients are translocated to the underground parts of the plants. This is specifically the case for nutrients that are easily translocated like K and N. Other nutrients like P and Ca are generally less mobile. Another factor is the loss of leaves during the maturation process, which returns nutrients to the soil.

In Figures 1 and 2 the concentration of the most important nutrients of the whole biomass (Figure 1) or leaves and stems (Figure 2) is plotted against the latitude where the switchgrass varieties originated. We see that for N, P, K and Cl there is a consistent negative correlation with latitude of origin. This means that switchgrass varieties originating at northern areas have lower N, P, K and Cl concentrations than varieties originating at southern sites. In the third year the relationship was less pronounced possibly due to lodging of the crop which prevented proper maturation and translocation of nutrients.

In Figure 2 the leaves and stems are regarded separately. Here also N, P, and K and also Mg and Na concentrations are lower in northern compared to southern varieties both in leaves and in stems. For Ca the concentration seems to be higher in leaves of northern varieties.

Nutrient off-take

Nutrient off-take is presented in Tables 1 to 5 and 7. In the Netherlands the N take-off for the most promising switchgrass variety Cave-in-Rock varied between 10 kg/ha in the first year and 111 kg/ha in the third year when the crop lodged severely. In Germany where yields were lower N off-take was between 17 and 56 kg/ha for Cave-in-Rock as the N stage increased from 0 to 150 kg N/ha. At Rothamsted The off-take of Cave-in-Rock amounted to some 60 kgN /ha at which yield were obtained of 15 tonnes /ha. No N response was apparent. Lodging was also reported at the Rothamsted site but was less severe than in The Netherlands.

4.4 Conclusions

The results show that switchgrass biomass has lower K, Na and Cl concentrations compared to *Miscanthus*. The concentrations of N and Ca were higher in switchgrass compared to *Miscanthus*.

At harvest in winter the concentration of N, P, K and Cl was lower in varieties originating at northern regions compared to varieties originating at southern regions.

At yields of some 15 tonnes of dry matter the N off-take of some 60 kg/ha should be expected for currently available well-adapted varieties.

N and also P and K off-take will be increased by lodging.

Table 1. Wageningen (NL) sandy site. Ash and nutrient content of 12 switchgrass varieties and *Miscanthus giganteus* over first 3 years. Samples are mix of 3 plots. The plots were seeded in spring 1998 and harvested on 17 March 1999, 12 January 2000 and 6 March 2001.

	Year	DM yield		Ash	N	P	K	Ca	Mg	Na	Cl	N	P	K
		tonne/ha	g/kg											
Switchgrass	1	0.93	34.9	16.63	1.55	2.10	3.25	1.14	85	-----	15.4	1.4	1.9	
Miscanthus	1	0.19	36.0	9.40	0.85	2.40	1.33	0.90	287	-----	1.7	0.2	0.4	
Switchgrass	2	6.7	21.3	5.01	0.64	2.55	3.80	1.17	107	1.01	33.8	4.3	17.2	
Miscanthus	2	2.9	10.0	2.74	0.35	5.26	0.97	0.64	308	3.55	8.0	1.0	15.4	
Switchgrass	3	12.8	21.5	7.46	0.92	2.54	2.92	1.15	83	0.42	95.4	11.7	32.5	
Miscanthus	3	14.0	12.0	2.39	0.48	2.06	1.34	0.53	139	0.58	33.4	6.7	28.8	

Table 2. Noordoostpolder (NL), clay site. Average ash and nutrient content of 5 switchgrass varieties and *Miscanthus giganteus* under 0 and 75 kg N/ha over first 3 years. The plots were seeded in spring 1998 and harvested on 18 March 1999, 25 January 2000 and 20 February 2001.

Species	N trt	Year	Yield		Ash	N	P	K	Ca	Mg	Na	Cl	N	P	K							
			kg N/ha	Tonne/ha												g/kg ±STD	kg/ha					
Switchgrass	0	1	0.38	97.6	-----	17.67	-----	1.79	-----	2.42	-----	5.75	-----	1.19	-----	0.125	-----	-----	6.7	0.68	0.92	
Miscanthus	0	1	----	154.0	-----	15.90	-----	1.37	-----	2.47	-----	6.03	-----	1.45	-----	0.191	-----	-----				
Switchgrass	0	2	4.76	57.3	8.8	4.04	0.85	0.60	0.12	2.41	1.61	4.26	0.92	0.85	0.13	0.266	0.049	0.72	0.48	19.2	2.87	11.49
Switchgrass	75	2	5.07	52.3	6.9	6.24	1.68	0.69	0.22	3.45	2.07	4.41	0.58	0.98	0.15	0.281	0.064	0.82	0.47	31.6	3.51	17.47
Miscanthus	0	2	0.98	58.7	6.4	4.58	0.69	0.41	0.04	6.50	0.79	1.60	0.21	0.52	0.12	0.738	0.305	3.33	0.44	4.5	0.40	6.37
Miscanthus	75	2	1.18	60.0	6.0	4.85	1.51	0.48	0.09	7.72	0.41	1.57	0.25	0.62	0.14	0.744	0.274	3.97	0.55	5.7	0.57	9.13
Switchgrass	0	3	9.70	75.8	22.8	6.17	2.35	0.83	0.29	2.59	0.91	4.34	1.70	0.84	0.30	0.125	0.058	0.58	0.38	59.9	8.07	25.16
Switchgrass	75	3	8.27	80.6	26.9	8.37	3.23	0.92	0.38	3.15	0.87	5.01	2.10	0.98	0.36	0.130	0.050	0.67	0.39	69.3	7.59	26.02
Miscanthus	0	3	40.62	31.3	3.1	1.53	0.20	0.26	0.08	3.43	0.55	0.73	0.07	0.25	0.01	0.246	0.013	1.33	0.13	62.0	10.39	139.26
Miscanthus	75	3	49.85	31.3	4.2	1.75	0.12	0.14	0.01	3.81	0.82	0.76	0.03	0.33	0.02	0.234	0.018	1.42	0.30	87.1	7.12	189.86

STD = standard deviation

Table 3. Wageningen (NL) sandy site. Ash and nutrient content of switchgrass varieties over first 3 years. Plots were seeded in spring 1998 and harvested on 17 March 1999, 12 January 2000 and 6 March 2001.

Variety	Year	Yield tonne/ha	Ash	g/kg							kg/ha		
				N	P	K	Ca	Mg	Na	Cl	N	P	K
Blackwell	1	1.26	34.0	17.41	1.64	2.19	3.42	1.33	0.084	---	22.0	2.1	2.8
Caddo	1	1.23	30.0	17.38	1.72	2.58	3.02	1.17	0.090	---	21.4	2.1	3.2
Carthage	1	0.82	28.0	18.05	1.66	1.58	2.76	1.06	0.058	---	14.8	1.4	1.3
CIR	1	1.24	34.0	15.20	1.36	1.78	2.80	1.18	0.081	---	18.9	1.7	2.2
Forestburg	1	0.47	66.0	14.52	1.14	2.05	3.68	1.04	0.107	---	6.9	0.5	1.0
Kanlow	1	1.13	30.0	18.79	1.85	2.00	3.32	1.43	0.065	---	21.3	2.1	2.3
NU 94-2	1	1.10	34.0	15.94	1.42	1.63	2.91	1.10	0.087	---	17.5	1.6	1.8
Pangburn	1	0.86	36.0	18.92	2.00	2.13	3.59	1.22	0.073	---	16.3	1.7	1.8
Reap 921	1	0.26	28.0	15.24	1.37	1.86	2.93	1.02	0.090	---	4.0	0.4	0.5
Shelter	1	0.95	34.0	14.95	1.29	1.59	4.07	0.96	0.068	---	14.2	1.2	1.5
Summer	1	0.85	30.0	16.50	1.61	3.68	3.26	1.08	0.130	---	14.1	1.4	3.1
Blackwell	2	8.21	26.0	4.66	0.66	2.34	3.94	1.30	0.110	0.83	38.3	5.4	19.2
Caddo	2	8.08	26.0	4.80	0.61	2.09	3.90	1.12	0.104	0.88	38.8	4.9	16.9
Carthage	2	6.53	26.0	5.86	0.75	3.31	3.38	1.25	0.113	0.83	38.3	4.9	21.6
CIR	2	9.23	22.0	4.56	0.58	2.46	4.27	1.30	0.103	1.10	42.1	5.3	22.7
Forestburg	2	6.07	16.0	4.26	0.61	1.36	3.86	0.88	0.080	0.41	25.8	3.7	8.2
Kanlow	2	6.08	20.0	6.33	0.88	5.45	2.52	1.37	0.091	2.27	38.5	5.3	33.2
NU 94-2	2	8.22	14.0	4.20	0.48	2.49	3.82	1.10	0.185	1.11	34.5	3.9	20.5
Pangburn	2	4.28	26.0	7.20	0.77	5.35	2.89	1.23	0.169	2.77	30.9	3.3	22.9
Reap 921	2	4.45	18.0	3.81	0.53	0.86	3.76	0.96	0.068	0.21	17.0	2.4	3.8
Shelter	2	6.82	22.0	5.11	0.56	1.28	4.84	1.25	0.077	0.41	34.9	3.8	8.7
Summer	2	6.24	18.0	4.31	0.58	1.03	4.64	1.11	0.076	0.27	26.9	3.6	6.4
Blackwell	3	10.05	26.0	9.11	1.13	2.70	3.07	1.19	0.083	0.49	91.6	11.4	27.2
Caddo	3	10.16	20.0	9.31	1.13	2.92	3.05	1.38	0.094	0.38	94.6	11.5	29.6
Carthage	3	16.02	20.0	7.39	0.99	2.72	2.61	1.12	0.074	0.52	118.3	15.8	43.6
CIR	3	13.80	12.0	8.05	0.86	2.76	2.91	1.10	0.089	0.46	111.1	11.9	38.1
Forestburg	3	8.63	22.0	7.37	0.83	1.40	2.96	0.87	0.065	0.23	63.6	7.2	12.1
Kanlow	3	17.54	22.0	6.54	1.01	4.37	2.17	1.44	0.090	0.76	114.8	17.8	76.6
NU 94-2	3	15.19	24.0	8.21	0.91	2.24	3.25	1.30	0.095	0.41	124.7	13.9	34.0
Pangburn	3	12.57	28.0	6.83	1.00	4.07	2.52	1.21	0.109	0.74	85.9	12.6	51.2
Reap 921	3	11.47	18.0	5.85	0.63	1.29	2.35	0.90	0.069	0.16	67.0	7.2	14.8
Shelter	3	12.81	22.0	6.19	0.76	1.45	4.26	1.10	0.068	0.20	79.2	9.7	18.5
Summer	3	12.44	22.0	7.22	0.81	2.03	2.95	1.09	0.078	0.24	89.8	10.0	25.2

Table 4. Noordoostpolder (NL), clay site. Ash and nutrient content and Nutrient offtake per ha of switchgrass varieties over first 3 years under 0, 75 or 150 kg N /ha per year. The plots were seeded in spring 1998 and harvested on 18 March 1999, 25 January 2000 and 20 February 2001.

Variety	N trt	Year	Yield	Ash		N		P		K		Ca		Mg		Na		Cl		N	P	K			
	kg N/ha		Tonne/ha	----- g/kg ±STD -----																			----- kg/ha -----		
Blackwell	0	1	0.48	102.0	---	17.82	---	1.79	---	2.08	---	6.32	---	1.18	---	0.102	---	---	---	8.5	0.86	1.00			
Carthage	0	1	0.21	104.0	---	19.52	---	2.05	---	2.48	---	6.25	---	1.26	---	0.099	---	---	---	4.1	0.43	0.52			
CIR	0	1	0.64	86.0	---	17.24	---	1.68	---	2.03	---	5.65	---	1.23	---	0.101	---	---	---	11.0	1.07	1.30			
Forestburg	0	1	0.16	104.0	---	17.11	---	1.61	---	3.05	---	5.17	---	1.21	---	0.201	---	---	---	2.7	0.25	0.47			
Summer	0	1	0.30	92.0	---	16.68	---	1.81	---	2.43	---	5.36	---	1.08	---	0.122	---	---	---	5.0	0.54	0.73			
Blackwell	0	2	5.09	59.3	5.0	3.88	0.17	0.61	0.04	2.48	0.32	3.67	0.68	0.87	0.02	0.252	0.034	0.82	0.11	19.7	3.12	12.63			
Blackwell	75	2	5.60	56.7	5.0	6.67	1.52	0.77	0.12	3.38	0.32	4.15	0.26	1.03	0.11	0.244	0.021	0.90	0.08	37.3	4.32	18.92			
Carthage	0	2	5.56	52.0	8.0	5.42	0.71	0.77	0.15	5.03	0.53	3.18	0.80	0.96	0.21	0.307	0.057	1.49	0.11	30.1	4.30	27.98			
Carthage	75	2	5.45	54.0	4.0	7.71	0.58	0.99	0.07	6.19	1.09	3.55	0.26	1.14	0.08	0.233	0.038	1.47	0.17	42.0	5.38	33.73			
CIR	0	2	5.29	54.7	4.2	3.70	0.42	0.49	0.06	2.77	0.54	4.24	0.48	0.86	0.02	0.213	0.014	0.74	0.13	19.6	2.61	14.66			
CIR	75	2	5.66	57.3	6.1	7.62	1.21	0.73	0.16	4.87	1.18	4.72	0.33	0.98	0.08	0.324	0.082	1.07	0.11	43.1	4.14	27.54			
CIR	150	2	5.34	53.3	2.3	8.76	0.87	0.78	0.10	5.49	0.85	3.90	0.18	1.02	0.07	0.294	0.096	1.11	0.03	46.7	4.16	29.27			
Forestburg	0	2	3.44	68.7	11.5	3.92	0.60	0.60	0.05	0.93	0.17	5.17	0.25	0.78	0.13	0.264	0.044	0.27	0.04	13.5	2.05	3.19			
Forestburg	75	2	3.75	48.0	8.7	4.34	0.62	0.44	0.01	1.20	0.40	4.84	0.30	0.79	0.15	0.355	0.037	0.37	0.01	16.3	1.67	4.50			
Summer	0	2	4.41	52.0	2.0	3.27	0.04	0.54	0.04	0.86	0.15	5.06	0.07	0.77	0.13	0.295	0.044	0.26	0.02	14.4	2.39	3.81			
Summer	75	2	4.88	45.3	3.1	4.84	0.76	0.53	0.10	1.59	0.45	4.78	0.39	0.95	0.13	0.248	0.029	0.28	0.09	23.6	2.59	7.77			
Blackwell	0	3	10.03	94.0	4.0	6.97	0.24	0.95	0.02	1.96	0.14	4.65	0.27	0.98	0.08	0.110	0.030	0.38	0.05	70.0	9.57	19.63			
Blackwell	75	3	7.54	110.0	12.2	10.13	0.49	1.11	0.10	3.27	0.69	6.20	1.23	1.30	0.28	0.120	0.012	0.64	0.20	76.4	8.38	24.64			
Carthage	0	3	11.39	81.3	16.8	8.31	0.49	1.10	0.07	3.42	0.10	4.79	0.45	1.17	0.17	0.109	0.002	0.57	0.07	94.6	12.55	38.92			
Carthage	75	3	10.10	88.7	16.2	9.36	0.47	1.14	0.03	3.28	0.44	5.13	0.82	1.22	0.03	0.114	0.010	0.52	0.10	94.5	11.55	33.14			
CIR	0	3	10.08	77.3	4.6	6.83	0.47	0.91	0.05	3.33	0.77	5.04	0.30	0.89	0.06	0.104	0.002	0.60	0.21	68.8	9.13	33.52			
CIR	75	3	8.58	92.7	8.1	10.86	0.98	1.14	0.12	3.95	0.42	6.08	0.91	1.13	0.18	0.112	0.010	0.63	0.15	93.2	9.77	33.87			
CIR	150	3	9.14	85.3	5.0	10.97	0.87	1.11	0.14	3.14	0.55	5.90	0.15	1.09	0.06	0.114	0.011	0.55	0.13	100.3	10.17	28.70			
Forestburg	0	3	7.14	91.3	6.4	6.79	1.77	0.86	0.18	1.59	0.33	5.34	0.15	0.86	0.03	0.096	0.006	0.31	0.08	48.5	6.14	11.38			
Forestburg	75	3	5.04	86.7	15.3	8.30	1.56	0.89	0.14	1.88	0.43	5.66	0.51	0.86	0.11	0.097	0.010	0.39	0.08	41.8	4.50	9.45			
Summer	0	3	9.88	79.3	13.0	6.62	1.17	0.91	0.14	1.83	0.42	5.50	0.16	0.92	0.06	0.083	0.008	0.26	0.04	65.4	8.99	18.09			
Summer	75	3	10.10	74.0	7.2	9.84	0.35	1.08	0.11	2.69	0.64	6.25	0.59	1.08	0.13	0.102	0.013	0.41	0.15	99.4	10.87	27.21			

std = standard deviation

Table 5. Braunschweig, Germany. Nutrient content and off-take per ha of switchgrass varieties under 3 nitrogen stages over the three first growing seasons. Plants were harvested after a killing frost in late winter.

Variety	N trt	Year	Yield	N	P	K	Ca	Mg	N	P	K
			tonne/ha	g/kg					kg/ha		
Blackwell	0	1	1.6	17.67	2.47	4.83	14.07		28.8	4.0	7.9
Carthage	0	1	1.5	13.87	1.99	4.46	8.66	1.58	20.8	3.0	6.7
CIR	0	1	1.0	15.70	2.20	3.87	8.37		16.1	2.3	4.0
Forestburg	0	1	0.6	14.30	1.87	5.30	9.20		7.8	1.0	2.9
Summer	0	1	0.5	17.60	1.97	4.50	12.77		9.5	1.1	2.4
									0.0	0.0	0.0
CIR	0	2	2.5	6.90	1.36	4.40	14.33	0.78	17.0	3.3	10.8
CIR	75	2	2.8	7.10	1.41	4.48	13.61	0.84	19.8	3.9	12.5
CIR	150	2	3.8	7.10	1.19	4.57	13.18	1.08	27.3	4.6	17.5
									0.0	0.0	0.0
Blackwell	0	3	5.0	5.20	0.80	2.20	7.13		25.9	4.0	11.0
Blackwell	75	3	6.3	5.80	0.70	2.20	8.00		36.4	4.4	13.8
Blackwell	150	3	8.1	6.00	0.60	2.40	7.60		48.4	4.8	19.4
Carthage	0	3	4.8	7.40	0.70	2.08	7.92	0.54	35.4	3.4	10.0
Carthage	75	3	7.3	8.10	0.66	1.74	7.70	0.60	59.1	4.8	12.7
Carthage	150	3	8.5	6.40	0.57	2.16	7.92	0.72	54.4	4.8	18.4
CIR	0	3	3.2	5.40	0.60	2.20	7.70		17.4	1.9	7.1
CIR	75	3	6.7	6.10	0.50	2.40	7.60		40.7	3.3	16.0
CIR	150	3	7.8	7.10	0.60	2.30	7.20		55.5	4.7	18.0
Forestburg	0	3	4.2	5.30	0.70	1.80	8.50		22.5	3.0	7.6
Forestburg	75	3	6.4	6.00	0.70	1.50	8.40		38.5	4.5	9.6
Forestburg	150	3	8.0	6.10	0.80	1.50	9.70		48.5	6.4	11.9
Summer	0	3	4.5	5.50	0.70	1.70	7.60		24.6	3.1	7.6
Summer	75	3	7.2	5.70	0.70	1.50	8.40		41.0	5.0	10.8
Summer	150	3	7.6	6.30	0.80	1.30	9.60		47.8	6.1	9.9
Average	0	3	4.3	5.76	0.70	2.00	7.77		25.2	3.1	8.7
Average	75	3	6.8	6.34	0.65	1.87	8.02		43.2	4.4	12.6
Average	150	3	8.0	6.38	0.67	1.93	8.40		50.9	5.4	15.5

Table 6. Aliartos, Greece. Ash and nutrient content of leaves and stems of switchgrass varieties Alamo and Cave in Rock over the second and third growing season. Harvested after over-wintering on 31 January 2000 and 13 January 2001.

Variety	N trt	Leaves							Stems							
		Ash	N	P	K	Ca	Mg	Na	Ash	N	P	K	Ca	Mg	Na	
<i>31 January 2000</i>		----- g/kg -----														
Alamo	0	83.5	2.71	0.39	3.40	13.38	2.38	1.89	18.4	0.89	0.28	4.39	4.25	0.88	2.22	
Alamo	75	82.5	3.52	0.34	3.89	15.38	2.50	1.72	24.7	1.40	0.23	3.99	3.38	1.00	2.38	
Alamo	150	92.3	5.58	0.68	4.43	9.63	5.88	2.55	19.4	1.54	0.30	5.02	2.88	0.75	2.22	
Cave in Rock	0	99.5	2.24	0.35	2.57	13.50	1.63	1.56	22.3	0.84	0.18	2.67	4.75	0.50	1.39	
Cave in Rock	75	106.4	2.88	0.55	2.86	18.88	2.25	1.89	18.4	0.84	0.17	3.35	3.50	0.50	1.39	
Cave in Rock	150	97.9	4.06	0.43	3.11	15.75	2.00	1.72	22.4	0.85	0.32	4.39	3.63	0.63	1.72	
<i>13 January 2001</i>																
Alamo	0	77.7	2.89	0.45	2.96	12.00	1.50	1.89	18.3	1.14	0.30	4.88	4.25	1.00	2.22	
Alamo	75	84.2	3.66	0.39	2.23	8.75	1.63	1.39	18.9	1.15	0.19	3.99	3.63	1.00	1.89	
Alamo	150	77.2	4.31	0.48	3.70	13.38	2.13	2.05	18.8	1.74	0.27	3.94	3.88	1.13	2.05	
Cave in Rock	0	77.4	3.17	0.43	2.57	13.38	1.50	2.05	15.1	1.05	0.23	3.40	3.75	0.75	1.39	
Cave in Rock	75	81.2	4.19	0.58	3.65	13.50	2.00	2.05	16.1	1.10	0.27	4.29	4.00	0.88	1.89	
Cave in Rock	150	87.4	4.33	0.38	3.16	13.88	1.50	1.72	18.5	1.33	0.17	3.50	5.00	0.88	1.72	

Table 7. Rothamsted (UK). Nutrient content and nutrient off-take of switchgrass varieties after the third growing season for a small plot experiment (Nursery trial) and for a larger plot field experiment (Yield trial) with implementation of a nitrogen stage (0 and 75 kg N/ha). The nursery trial was harvested in winter on 16-01-2001 and the yield trial was harvested 13-02-2001.

Treatment	L/S*	DM	Leaf						Stem					Total off-take				
			N	P	K	Ca	Mg	Na	N	P	K	Ca	Mg	Na	N	P	K	
Nursery trial	ratio	Tonne/ha	g/kg													kg/tonne		
Alamo	0.35	16.7	11.73	1.30	3.76	8.22	2.58	0.32	5.17	0.74	8.84	1.06	1.03	0.28	114.9	14.8	125.8	
Blackwell	0.33	12.1	7.71	0.72	1.32	11.99	1.38	0.30	3.04	0.42	2.38	1.73	0.60	0.16	50.9	6.0	25.6	
Caddo	0.23	12.1	7.74	0.76	1.17	10.85	1.12	0.29	2.96	0.41	2.44	1.59	0.54	0.19	46.9	5.8	26.6	
Cave in rock	0.30	15.3	7.09	0.62	1.22	8.89	1.01	0.22	3.33	0.42	3.82	1.19	0.33	0.16	64.2	7.1	49.3	
Forestburg	0.23	11.6	7.26	0.59	0.89	13.70	1.00	0.32	2.17	0.20	1.21	1.32	0.43	0.17	36.4	3.2	13.4	
Kanlow	0.32	18.5	8.40	0.80	2.89	7.99	2.06	0.32	4.53	0.59	6.22	1.59	1.07	0.17	100.9	11.9	100.2	
Nebraska 28	0.33	11.1	6.28	0.68	0.87	10.84	0.80	0.19	2.60	0.42	2.03	1.62	0.47	0.10	39.1	5.4	19.4	
NL 93-1	0.25	9.0	12.42	1.02	3.13	9.50	1.94	0.50	5.05	0.56	6.48	1.65	0.88	0.18	58.7	5.9	52.3	
NL 93-2	0.32	18.9	9.74	0.78	2.47	9.41	1.99	0.48	5.35	0.57	5.70	2.01	1.07	0.29	121.0	11.7	93.1	
NU 94-2	0.37	15.1	8.64	0.85	1.51	10.15	1.29	0.17	3.70	0.45	3.55	1.78	0.56	0.10	76.0	8.4	45.3	
Reap 921	0.19	12.0	6.94	0.53	0.92	11.17	0.89	0.28	2.86	0.27	2.22	1.24	0.36	0.15	42.2	3.7	24.2	
Shelter	0.33	12.9	7.21	0.49	0.76	13.76	0.91	0.19	2.50	0.20	1.24	1.77	0.31	0.10	47.4	3.5	14.4	
Su 94-1	0.27	14.2	10.42	1.29	1.76	9.66	1.34	0.23	3.57	0.57	3.14	1.84	0.70	0.13	71.2	10.2	40.4	
9005439	0.18	10.3	7.03	0.56	0.95	14.60	0.77	0.28	2.41	0.24	1.07	1.89	0.37	0.20	31.9	3.0	10.8	
9005438	0.18	10.7	6.47	0.65	0.76	15.27	0.78	0.26	2.02	0.32	1.30	1.44	0.36	0.11	28.8	3.9	13.1	
Yield Trial																		
Cave in rock 0N	0.21	14.9	6.81	0.55	0.78	8.37	1.21	0.07	3.51	0.34	1.74	0.99	0.46	0.07	60.9	5.6	23.4	
Cave in rock 75N	0.18	12.8	6.77	0.36	0.64	6.50	0.92	0.05	3.74	0.26	2.68	0.66	0.34	0.06	53.7	3.5	30.4	
Carthage 0N	0.16	17.2	9.09	0.79	0.92	5.88	1.04	0.07	4.79	0.58	2.15	1.26	0.71	0.09	92.6	10.4	34.1	
Carthage 75 N	0.23	12.0	9.69	0.88	0.98	6.61	1.28	0.05	4.85	0.48	2.14	1.14	0.67	0.07	69.0	6.6	23.1	

* L/S = Leaf to stem ratio.

Figure 1. Relationship between the latitude of origin of 5 switchgrass varieties (Forestburg, 44° N; Summer, 41° N; Cave in Rock 38° N; Blackwell 37° N; Carthage 35° N) and the nutrient content of the harvested biomass over the second (1999) and third (2000) growing season on a clay (Noordoostpolder) and a sandy (Wageningen) site in The Netherlands.

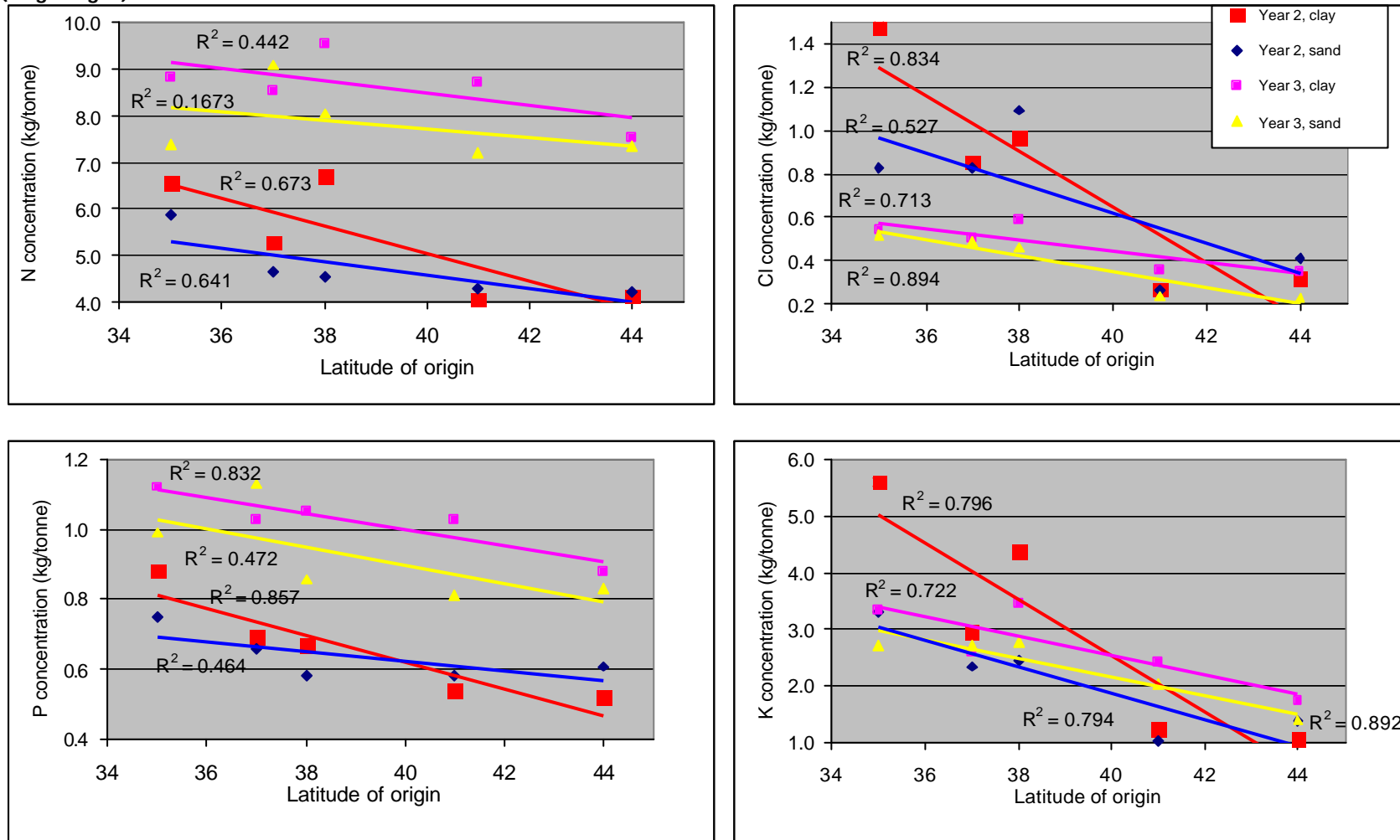


Figure 2. Rothamsted (UK). Relationship between the latitude of origin of 9 switchgrass varieties (Alamo, 28° N; Blackwell 37° N; Caddo, 35° N; Cave in Rock 38° N; Forestburg, 44° N; Kanlow 35° N, Nebraska28, 42° N; Reap- 921 41° N; Shelter, 40° N) and the nutrient content of leaves and stems harvested in winter after the third growing season at Rothamsted (UK).

