2 Switchgrass in NW Europe[1]

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2.1 Introduction

Switchgrass (*Panicum virgatum* L.) is a perennial C_4 grass native to North America where it occurs naturally from 55º N latitude to deep into Mexico, mostly as a prairie grass. In North America it has long been used for soil conservation and as a fodder crop and it is also used world-wide as an ornamental plant. The grass is also found in South America and Africa where it is used as a forage crop. 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 C_4 biomass crop for adaptation to European conditions. It is propagated by seed, which contributes to low cultivation costs.
This chapter will concentrate on the field experiments performed at sites in the UK, Germany and the Netherlands that have similar climatic conditions as defined by the amount of rainfall, temperature, day-length, etc. Therefore the same varieties can be compared between different sites.
The main objective of the research presented here was to evaluate the adaptation of switchgrass varieties to NW European conditions under different soil conditions and nitrogen stages.

2.2 Methods and Materials

Site and treatments

In 1998, two types of trials were established at two sites in The Netherlands and at one site in The UK and Germany each. The first trial aimed to compare a wide range of switchgrass varieties on small plots, no further treatments were applied. The other trial aimed to compare performance of 5 switchgrass varieties under two or three nitrogen stages (0, 75 and 150 kg N/ha) on larger plots. The experimental conditions and experimental layout are presented in Table 1 and the list of varieties used at each site is presented in Table 2.

Measurements

During three growing periods (1998, 1999 and 2000), a series of measurements were carried out to assess establishment and performance of the different varieties.
At regular intervals observations were made to assess the conditions of the plots. Visual observations were made for stand or establishment rating, disease rating, lodging, maturity, blooming, weed cover, etc. Stand ratings were scored from 0 to 6: no emergence (0), few plants visible (1), one row visible (2), several rows visible but with gaps in the row (3), rows clearly defined but may have gaps (4), no gaps (5), or excellent stand (6).

At the end of each growing season the final harvest took place after a killing frost in winter when aboveground biomass had died and was drying down. The fresh and dry matter yields were determined. Nutrient analysis of the biomass is discussed in Chapter 4.

1 This chapter is to be submitted for publication.

Table 1. Conditions and set-up of the experiments in The Netherlands, Uk and Germany.

	------The Netherlands ------		---------- UK ----------		---------- Germany ----------	
Experiment:	Productivity	Nursery	Productivity	Nursery	Productivity	Nursery
Site	Wageningen	N.O. Polder	Rothamsted		Braunschweig	
Latitude	51°58´	52°38´	51°48´		52°18´	
T January °C	1,8	1,4	3,1		0,4	
T July °C	16,6	17,4	15,9		17,1	
Prescipitation, mm	700	747	688		619	
Soil texture	Coarse	Fine	Moderately fine over fine		Moderately coarse over coarse	
pH	5,2	7,5	7		6,5	
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	15 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	3.8 x 3.6
Row distance	15 cm		14.2 cm		15 cm	
Seeding date	2 June	28 May	22 June		23 June	22 June
Weed control	Chemical, manual, mowing	Chemical, mowing	Chemical		Chemical, manual	

Table 2. List of switchgrass varieties used in the six experiments in NW Europe (detailed descriptions of the switchgrass varieties are presented in Chapter 5).

---------- The Netherlands ----------		---------- UK ----------		---------- Germany ----------	
Productivity	Nursery				
Noordoost-Polder	- Wageningen -	---------- Rothamsted ---------		---------- Braunschweig ----------	
Blackwell	Blackwell	Blackwell	Alamo	Blackwell	Blackwell
Carthage	Caddo	Carthage	Blackwell	Carthage	Caddo
Cave-in-Rock	Carthage	Cave-in-Rock	Caddo	Cave-in-Rock	Carthage
Forestburg	Cave-in-Rock	Pangburn	Cave-in-Rock	Forestburg	Cave-in-Rock
Summer	Forestburg	Summer	Forestburg	Summer	Kanlow
	Kanlow		Kanlow		Nebraska-28
	NL 93-1		Nebraska-28		NL 93-1
	NL 93-2		NL 93-1		NL 93-2
	NU 94-2		NL 93-2		NU 94-2
	Pangburn		NU 94-2		Pangburn
	REAP 921		REAP 921		REAP 921
	Shelter		Shelter		Shelter
	Summer		SU 94-1		SU 94-1
			9005439		Sunburst
			9005438		Trailblazer

[1] CIR = Cave-in-Rock. For more details on varieties see Chapter 5 and Annex.

2.3 Results

A selection of the results of field measurements is presented in Table 3 to 9 for the six experimental sites in The Netherlands, UK and Germany.

Stand ratings

A general visual observation of the stand over three years is presented in Table 3 and 4. We see that in the first year (summer 1998) all varieties had good stand scores except for those that had low emergence due to low seed germination (REAP 921).

At the start of the second year stand scores were lower than in the previous year. In The Netherlands and the UK the lowest scores were recorded for southern varieties like Carthage and Pangburn in the yield trials and for Pangburn, NL 93-1, NL 93-2, Alamo and Kanlow. In Germany stand scores were low for most of the varieties except for northern varieties like Cave-in-Rock, Summer, Shelter, Nebrasca-28, Sunburst. In the Netherlands and especially in the UK most southern varieties like Carthage, Pangburn, Kanlow and even Alamo recuperated later in the season or in the next year to obtain reasonable to good stand ratings. Only NL93-1 failed completely in The Netherlands. In Germany southern varieties like Kanlow, NL93-1, NL93-2, Pangburn, SU 94-1 did not recuperate much and some failed completely. This result should be explained by the colder climatic conditions in Germany compared to The Netherlands and the UK (see Table 1) which resulted in more winter damage for southern varieties leading to almost complete stand loss.

In the first year weeds were a major concern. Chemical and mechanical (mowing above switchgrass height) control was effective. Weeds were also a problem at the start of the second year especially in varieties that emerged late. This aspect of establishment is also discussed in Chapter 6 and 10.

Visual disease ratings were recorded throughout the experiments. Some fungal diseases were observed. For example eyespot was found on stem bases of a few plants during the summer, most prevalent on Blackwell. The disease levels were low, generally less than 1 on a scale from 0 to 6, and should not lead to yield losses.

Table 3. Yield trial. Switchgrass relative stand rating in the first, second and third year after establishment at 3 sites in NW Europe (0 = extremely poor stand, 6 = excellent stand).

Site:	Noordoostpolder (NL)				Rothamsted (UK)				Braunschweig (D)			
Date:	1811-98	11-5-99	22-9-99	4-08-00	23-09-98	22-6-99	5-10-99	13-7-00	21-07-98	22-04-99	21-07-99	24-07-00
Treatment	Rating 1 to 6											
Blackwell	5.1	*3.8*	6.0	6.0	4.3	*4.0*	5.9	5.7	4.7	*3*	3	4
Carthage	5.3	*3.0*	6.0	6.0	4.3	*5.2*	5.8	5.7	5.0	*1.7*	3	4
Cave-in-Rock	5.6	*4.6*	6.0	6.0	4.3	*3.0*	5.7	5.2	6.0	*4.1*	5	5
Forestburg	3.5	*3.3*	5.5	6.0	-	-	-	-	4.0	*3.9*	6	5
Pangburn		-	-		4.3	*1.0*	3.8	4.2	-	--	--	
Summer	4.5	*3.7*	6.0	6.0	4.2	*4.7*	6.0	5.9	4.0	*3.9*	4.5	5
0 N	-	*3.8*	5.8	6.0	-	*3.7*	5.4	5.3	-	-	-	-
75 N	-	*3.6*	6.0	6.0	-	*3.4*	5.5	5.3	-	-	-	-

Table 4. Nursery trial. Switchgrass relative stand rating in the first, second and third year after establishment at 3 sites in NW Europe (0 = extremely poor stand, 6 = excellent stand).

Site:	Wageningen (NL)				Rothamsted (UK)				Braunschweig (D)			
Date:	17-11-98	*6-5-99*	7-10-99	2-08-00	23-09-98	*13-5-99*	5-10-99	13-07-00	29-07-98	22-04-99	27-08-99	8-9-00
Variety ?	Rating 1 to 6											
Alamo	-	-	-	-	4.3	*0.3*	3.7	3.3	-	-	-	-
Blackwell	5.3	*4.8*	6.0	5.3	5.0	*5.3*	6.0	5.0	4.3	*3*	3	3
Caddo	5.7	*4.3*	6.0	5.7	5.0	*5.0*	6.0	5.0	5.3	*1*	1	3
Carthage	5.3	*4.5*	6.0	5.8	-	-	-	-	4.3	*2*	3	4
Cave-in-Rock	5.8	*6.0*	6.0	6.0	5.0	*5.3*	6.0	5.7	5.0	*4*	6	6
Forestburg	4.2	*4.3*	5.4	5.2	4.3	*4.3*	5.7	5.3	-	-	-	-
Kanlow	5.0	*3.0*	5.4	6.0	4.0	*1.3*	4.7	4.3	4.0	*1*	0	1
Nebraska-28	-	-	-	-	4.7	*5.7*	6.0	5.0	6.0	*5*	6	5
NL 93-1	4.3	*1.3*	2.3	1.7	4.0	*0.7*	2.0	3.0	4.0	*1*	0	0
NL 93-2	5.3	*3.5*	4.8	5.3	4.7	*1.3*	4.3	4.3	4.0	*1*	0	1
NU 94-2	5.0	*4.7*	6.0	6.0	4.3	*4.3*	6.0	5.7	4.0	*1*	2	4
Pangburn	4.8	*2.0*	4.1	4.5	-	-	-	-	3.3	*1*	0	1
REAP 921	3.5	*3.7*	6.0	6.0	2.0	*3.7*	4.3	4.7	2.7	*1*	2	3
Shelter	5.7	*5.7*	6.0	6.0	4.3	*5.0*	6.0	5.3	5.3	*4*	4	5
SU 94-1	-	-	-	-	5.3	*5.3*	6.0	5.3	5.7	*1*	1	2
Summer	4.2	*3.8*	5.7	5.8	-	-	-	-	-	-	-	-
Sunburst	-	-	-	-	-	-	-	-	5.0	*5*	6	6
Trailblazer	-	-	-	-	-	-	-	-	6.0	*2*	1	2
9005439	-	-	-	-	4.0	*4.7*	6.0	5.0	-	-	-	-
9005438	-	-	-	-	4.0	*4.7*	6.0	5.0	-	-	-	-

Lodging

Lodging was observed at all sites in NW Europe. In the first year lodging was very mild and was only recorded in The Netherlands (Table 5). In the second year lodging was more pronounced especially in The Netherlands and the UK. There were differences in degree of lodging between varieties. Varieties like Blackwell and Carthage showed more lodging than varieties like Cave-in-Rock or Summer. In the second year (1999) most varieties recovered from lodging by the end of the season. Yield depressions due to lodging were probably minor.

In the third year lodging was very severe both in the Netherlands and the UK as illustrated by the high lodging score presented in Table 5. In 2000 the plants did not recover and there probably was a negative effect on yield, and moisture and nutrient content of the biomass especially in The Netherlands. See discussion below and in Chapter 4. Some varieties lodged later than others, but in the end all showed severe lodging. More robust varieties like Pangburn and Summer showed less lodging but this was still very significant. 2000 appears to have been an exceptional year since in 2001 less lodging was observed. In 2000 other crops grown near to the experimental plots (wheat) showed unusual lodging indicating the conditions were unusually favourable to lodging that year.

Generally there was no difference observed between different nitrogen treatments with respect to lodging. When differences were apparent at the start of lodging these were not consistent between The Netherlands and the UK.

Table 5. Yield trial. Switchgrass lodging ratings (0= no lodging, 6= all plants lodged flat) at Noordoostpolder site in The Netherlands and Rothamsted (UK).

		Noordoospolder (NL)					Rothamsted (UK)	
Variety	N Trt	18-03-99*	22-09-99	20-06-00	10-11-00	18-11-01	21-7-00	20-9-00
		Lodging rating (1-6)						
Blackwell	0	3.1	1.3	1.3	5.7	5.3	4.7	4.5
	75		3.3	2.7	5.5	4.8	4.2	4.5
Carthage	0	4.6	0.2	0.2	5.0	5.3	0.0	3.8
	75		1.8	0.2	5.4	5.4	0.0	2.7
CIR	0	1.0	0.0	0.0	5.0	4.0	1.5	4.5
	75		1.5	0.0	4.8	5.0	1.8	4.0
	150		2.2	0.0	5.3	4.4	-	-
Forestburg	0	0.7	0.0	1.2	3.8	3.7	-	-
	75		0.3	2.8	5.3	3.8	-	-
Pangburn	0	-	-	-	-	-	0.0	2.0
	75	-	-	-	-	-	0.0	0.9
Summer	0	0.7	0.0	0.0	4.0	3.3	0.0	4.0
	75		0.5	0.0	4.2	3.5	0.0	3.5
Avg. switchgrass	0	3.3	0.3	0.5	4.7	4.3	1.2	3.7
	75		1.5	1.1	5.1	4.5	1.2	3.1

*In the first growing season no N stage was implemented yet.

Dry matter yield

Dry matter yield of the six experiments is presented in Table 6 and 7. Yields increased from less than 2 tonnes in the first years to up to 12 tonnes per ha in the second year and up to 18 tonnes in the third year. This shows that yield development of switchgrass takes time to develop. Further increases in average yield of most switchgrass varieties are likely. It is known that on clay soils yield takes longer to reach maximum potential. Carthage was among the two best yielding varieties in The Netherlands and The UK (Table 6) but it yielded the worst in Germany. At all sites the lowest yields were recorded for northern varieties that matured very early (Forestburg, 9005438, 9005439) or very late (Alamo, Kanlow, Pangburn, NL93-1). These southern late maturing varieties also had the lowest stand scores because of slow re-growth or stand failure. For further discussion on the relationship between latitude and yield and other attributes see Chapter 5. The highest yields were obtained in the UK (and in The Netherlands and Germany) with the latest maturing varieties that did not suffer from severe stand loss in (the first) winter.

Nitrogen response (Table 7) was not found at The Netherlands and the UK where both the 75 kg N/ha and control treatments had similar yields. There was even a negative trend of N application. In contrast, in the German experiment increased N stage increased yield accordingly. In the third year average DM yield almost doubled from 4.3 to 8 tonnes as N application increased from 0 to 150 kg N/ha.

In the Netherlands *Miscanthus gigantheus* was also included in the experiments. Results show that yield were low compared to most switchgrass varieties but in the third year yields reached up to 14 tonnes at the sandy site in Wageningen and up to 50 tonnes at the Clay site in de Noordoostpolder. It is known that small plot yield estimates will overestimate yields. *Miscanthus* plants were more than 3 meters high in that year. The very high yields are probably not realistic and should not be extrapolated to larger fields. Light interception over the season determines to a large extent the yield of a crop. Especially with a high crop light is intercepted over a larger area than the basic plot size. This should account for the very high yield estimates. The same will apply to a lesser extent to the switchrass yield estimates as light from a larger area is intercepted than the sole plot.

Table 6. Nursery trial. Switchgrass dry matter yield (DM) at harvest after in winter after the first, second and third year.

Site:	-------- Wageningen (NL) -------			------- Rothamsted (UK) --------			---------Braunschweig (D) ------		
Date:	17-03-99	12-01-00	6-03-01	26-01-99	20-12-99	16-01-01	19-01-99	22-11-99	19-01-01
Variety ?	---------- tonne/ha ----------								
Alamo	-	-	-	0.4	6.6	16.7	-	-	-
Blackwell	1.3	8.2	10.1	0.5	10.2	12.1	1.5	4.1	11,2
Caddo	1.2	8.1	10.2	0.8	10.1	12.1	2.2	2.6	7,8
Carthage	0.8	6.5	16.0	-	-	-	1.1	4.0	10,5
Cave-in-Rock	1.2	9.2	13.8	0.5	10.3	15.3	1.8	6.4	14,5
Forestburg	0.5	6.1	8.6	0.1	5.7	11.6	-	-	-
Kanlow	1.1	6.1	17.5	0.6	8.4	18.5	0.9	0.5	2,0
Nebraska-28	-	-	-	0.1	6.9	11.1	1.6	7.4	13,2
NL 93-1	0.8	2.0	7.3	1.0	4.6	9.0	0.7	0.1	0,3
NL 93-2	1.2	5.6	19.6	0.9	7.6	18.9	1.1	0.4	2,1
NU 94-2	1.1	8.2	15.2	0.2	9.1	15.1	1.3	3.8	12,2
Pangburn	0.9	4.3	12.6	-	-	-	0.7	0.5	2.0
REAP 921	0.3	4.5	11.5	----	5.9	12.0	0.6	2.7	8,8
Shelter	1.0	6.8	12.8	0.1	7.7	12.9	1.2	4.6	10,2
SU 94-1	-	-	-	1.5	12.4	14.2	1.9	1.7	5,3
Summer	0.9	6.2	12.4	-	-	-	-	-	-
Sunburst	-	-	-	-	-	-	1.3	7.2	13,8
Trailblazer	-	-	-	-	-	-	2.4	2.1	7,7
9005439	-	-	-	0.8	5.8	10.3	-	-	-
9005438	-	-	-	0.1	5.8	10.7	-	-	-
Miscanthus	--	2.9	14.0	-	-	-	-	-	-

Table 7. Yield trial. Switchgrass dry matter yield (DM) at harvest in winter after the first, second and third year.

Site:	----- Noordoostpolder (NL) -----			------- Rothamsted (UK) --------			-------- Braunschweig (D) -------		
Date:	18-03-99	25-01-00	20-02-01	26-01-99	17-01-00	13-02-01	19-01-99	15-11-99	19-01-01
Treatment	---------- tonne/ha ----------								
Blackwell	0.5	5.3	8.8	0.9	9.2	13.6	1.6	2.1	6.4
Carthage	0.2	5.5	10.7	1.3	9.9	13.9	1.0	2.0	5.9
Cave-in-Rock	0.6	5.4	9.3	1.2	8.7	14.6	1.5	3.0	6.9
Forestburg	0.2	3.6	6.1	-	-	-	0.6	2.8	6.2
Pangburn	-	-	-	1.0	7.6	11.3	-	-	-
Summer	0.3	4.6	10.0	0.9	9.1	13.0	0.5	2.3	6.4
0 N	-	4.8	9.7	-	9.2	14.5	-	2.0	4.3
75 N	-	5.1	8.3	-	8.5	12.0	-	2.4	6.8
150 N	-	-	-	-	-	-	-	3.0	8.0
Miscanthus 0 N	-	1.0	40.6	-	-	-	-	-	-
Miscanthus 75 N	-	1.2	49.8	-	-	-	-	-	-

Moisture content

Moisture content is important for a biomass crop since it determines a.o. the cost of transport and possibilities of storage. The crop dries down in fall and winter until low enough moisture content is reached which makes longer storage times possible. If the crop fails to dry down sufficiently before re-growth of the plants in spring biomass cannot be stored, at moisture content above 20% biomass can only be stored for a short period, and will have to be dried or used immediately. Drying of biomass is expensive**.**

In Table 8 and 9 moisture contents of the biomass are presented at harvest in winter or early spring. In the first year later harvesting in the Netherlands resulted in very dry biomass compared to earlier harvesting in The UK and Germany. In the UK the highest moisture contents were consistently recorded for Alamo, NL93-1, Kanlow and Pangburn. These are robust southern varieties that matured later than the other varieties resulting in a lower rate of dry-down during fall and winter and higher moisture content at harvest. For the Netherlands the higher moisture content of late maturing varieties was not as clear which is probably due to lodging which prevented all varieties to dry down. In Germany the same effect as in The UK could be observed though the moisture content measurements from very poor stands should be considered less reliable.

Table 8. Nursery trial. Switchgrass moisture content at harvest in winter after the first, second and third year.

Site:	------- Wageningen (NL) --------			---------othamsted (UK) ---------			------- Braunschweig (D) --------		
Date:	17-03-99	12-01-00	6-03-01	26-01-99	20-12-99	16-01-01	19-01-99	22-11-99	19-01-01
Variety ?	---------- Moisture % ----------								
Alamo	-	-	-	63	59	43	-	-	-
Blackwell	12	23	32	50	32	26	25	49	-
Caddo	8	20	21	46	33	26	25	46	-
Carthage	7	16	32	-	-	-	27	45	-
Cave-in-Rock	7	17	27	54	37	22	25	45	-
Forestburg	9	20	20	40	26	21	-	-	-
Kanlow	8	24	31	69	46	38	27	56	-
Nebraska-28	-	-	-	37	29	31	25	41	-
NL 93-1	18	21	32	57	51	40	28	49	-
NL 93-2	8	26	33	68	50	30	27	62	-
NU 94-2	7	18	25	54	39	24	29	53	-
Pangburn	8	24	28	-	-	-	30	56	-
REAP 921	19	18	29	---	29	22	29	47	-
Shelter	8	22	25	41	27	23	27	50	-
SU 94-1	-	-	-	47	38	24	23	56	-
Summer	15	19	25	-	-	-	-	-	-
Sunburst	-	-	-	-	-	-	24	48	-
Trailblazer	-	-	-	-	-	-	24	51	-
9005439	-	-	-	35	25	24	-	-	-
9005438	-	-	-	46	29	22	-	-	-
Miscanthus	----	26	33	-	-	-	-	-	-

Table 9. Yield trial. Switchgrass biomass moisture content at harvest in winter after the first, second and third year at three sites in NW Europe.

Site:	------Noordoostpolder (NL) ----			------- Rothamsted (UK) --------			------- Braunschweig (D) --------		
Date:	18-03-99	25-01-00	20-02-01	26-01-99	26-01-00	-01-01	19-01-99	15-11-99	19-01-01
Treatment	---------- Moisture % ----------								
Blackwell	12	24	65	54	31	26	37	44	24
Carthage	12	27	67	56	35	26	44	44	25
Cave-in-Rock	12	29	68	54	32	27	38	44	24
Forestburg	15	20	62	-	-	-	30	35	22
Pangburn	-	-	-	67	40	30	-	-	-
Summer	13	21	60	48	26	20	24	32	22
0 N	-	23	63	-	32	26	-	39	23
75 N	-	25	65	-	33	25	-	40	23
150 N	-	-		-	-	-	-	41	23
Miscanthus 0 N	-	35	27	-	-	-	-	-	-
Miscanthus 75 N	-	44	26	-	-	-	-	-	-

2.4 Conclusions

Yields of up to 18 tonnes dry matter per ha were recorded for winter harvested switchgrass.

The highest yields were obtained in The UK with the latest maturing varieties that did not suffer from severe stand loss in (the first) winter. The same was the case for The Netherlands and Germany.

For switchgrass yield development to reach maximum potential probably takes more than 3 years.

Nitrogen response was absent at 2 out of 3 experimental sites.

In the first year weed was the most important concern. In following years lodging was the most important concern. Lodging of switchgrass was recorded to different degrees at all sites in NW Europe. Varieties differ in the degree of susceptibility to lodging if the conditions are relatively mild.