GRASS SPECIES FROM C-4 CARBON FIXATION GROUP: POLISH EXPERIMENT WITH A NOVEL ENERGY AND FORAGE PURPOSES CROP

TRAWY FOTOSYNTEZY C-4: POLSKIE DOŚWIADCZENIE Z ROŚLINAMI ENERGETYCZNYMI I PASZOWYMI

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ABSTRACT

Experiment was conducted during four years 2003-2006. Materials used were three genus grass species of C-4 photosynthesis: Andropogon gerardi Vitman, Panicum virgatum L. and Miscanthus sacchariflorus (Maxim.) Hack. Plants were planted at spring 1998. Agrotechnical part of experiment was conducted in Botanical Garden of Plant Breeding & Acclimatization Institute in Bydgoszcz and analytical part in Department of Animal Nutrition and Feed Management, Faculty of Animal Breeding and Biology of University of Technology and Life Science in Bydgoszcz. Forage from grass C-4 photosynthesis were material of good ensilage suitability. High structural carbohydrates (NDF, ADF) contents in tested forage dry matter suggest ensilage at early phases of plant development. Above results suggest to possibility of usage of forage from grass C-4 carbon fixation group for animal feeding purposes. C-4 grass forage should be recognized as a supplementary source of green matter in periods of insufficient access to traditional silage sources.

Key words: Andropogon gerardi, chemical composition, Miscanthus sacchariflorus, Panicum virgatum, phase of vegetation.

ABSTRACT

Badania przeprowadzono w okresie od 2003-2006 roku. Badaniami objęto 3 gatunki traw fotosyntezy C-4: Andropogon gerardi Vitman, Panicum virgatum L. i Miscanthus sacchariflorus (Maxim.) Hack., wysadzone wiosną 1998 r. Agrotechniczną część badań prowadzono w Ogrodzie Botanicznym IHAR w Bydgoszczy, część analityczną w Katedrze Żywienia Zwierząt i Gospodarki Paszowej Wydziału Hodowli i Biologii Zwierząt Uniwersytetu Technologiczno-Przyrodniczego w Bydgoszczy. Trawy C-4 fotosyntezy były dobrym materiałem kiszonkarskim. Wysoka zawartość węglowodanów strukturalnych wskazuje na konieczność zakiszania tych traw we wczesnych fazach wegetacji. Potrzebę zastosowania tych gatunków w Polsce uzasadnia brak rodzimych wieloletnich, wysokowydajnych gatunków traw, dostosowanych do uprawy na glebach lekkich i słabo uwilgotnionych oraz wzrastające zapotrzebowanie na biomasę do celów energetycznych.

DEATILED ABSTRACT

Analityczną część badań przeprowadzono w Katedrze Żywienia Zwierząt i Gospodarki Paszowej Wydziału Hodowli i Biologii Zwierząt Uniwersytetu Technologiczno-Przyrodniczego w Bydgoszczy. W podsuszonych roślinach określono zawartość podstawowych składników pokarmowych (sucha masa – DM, procedura AOAC 934.01, 2006, białko ogólne – CP metodą Kjeldahla, AOAC 984.13A-D, 2006, tłuszcz surowy – CFA, procedura AOAC 920.39A, 2006, włókno surowe – CFI, procedura AOAC 978.10, 2006). Frakcje neutralno (NDF) i kwaśno detergentową (ADF) włókna surowego i kwaśną ligninę (ADL) określono według metodyki Goeringa i Van Soesta (1970). Węglowodany rozpuszczalne w wodzie (C) oznaczono według PN-R-64784 Pojemność buforową roślin (PB) i wartość współczynnika fermentacji zielonek (FC) określono według Weissbacha (1992 i 1998).

Testowane gatunki traw w fazie wegetatywnej zawierały od 23,2% (Miscanthus sacchariflorus) do 24,5% suchej masy (Andropogon gerardi). W trawach niezależnie od gatunku odnotowano wysoką zawartość frakcji NDF od 64,9% (Miscanthus sacchariflorus) do 65,8% w suchej masie (Andropogon gerardi). W kolejnych fazach wegetacji, niezależnie od gatunku odnotowano, wzrost poziomu węglowodanów strukturalnych do ponad 70% w suchej masie roślin. Wartość współczynnika fermentacji roślin w kolejnych fazach wegetacji wykazywała tendencję wzrostową. Poziom tego parametru w fazie wegetatywnej wynosił od 37,8 (Panicum virgatum) do 41,2 (Miscanthus sacchariflorus). W fazie początku kwitnienia roślin odnotowano wartości od 44,7 (Andropogon gerardi) do ponad 71 (Miscanthus sacchariflorus). Wyniki te wskazują, że testowane gatunki traw C-4 należą do grupy roślin łatwo zakiszających się i stanowić mogą bazę surowcową dla produkcji biogazu.

INTRODUCTION

During last years the increase in insolation and water deficit in soil were observed. Such changes are of great importance for agriculture (Łabędzki 2004). Some species, as xerotrophic C-4 grass species, are better adopted to changing climate conditions than our native C-3 species, mainly due to higher utilization efficiency of water, nitrogen and other elements (Nalborczyk 1996). C-4 grasses are natural dominants in prairie in North America, and are used as a food for animals (Blasi et al. 1991, Coffey et al. 2000, Farmer et al. 2001, Hafley et al. 1993, Redfearn et al. 1995). In Europe C-4 species were introduced for energetic purposes in Great Britain and Poland (Christian et. al. 1999, Majtkowski and Majtkowska 1998). It is therefore supposed the alternative role of some C-4 grass species for animals feeding in regions of high water deficit in vegetation.

The aim of above work was to determine the chemical composition and ensilage ability of different grasses C-4 photosynthesis in different phases of development.

MATERIAL AND METHODS

During three consecutive years (2003, 2004, 2005) forage was collected at following phases of development:

- vegetative phase (VS) – at 73±5 days (Andropogon gerardi), 74±5 days (Panicum virgatum) and 78±7 (Miscanthus sacchariflorus), day of growing (days counted from 1-st of April),
- beginning of earing (BE) – at 100 (±11), 95 (±8) and 150 (±8) days of growing for Andropogon gerardi, Panicum virgatum and Miscanthus sacchariflorus respectively,
- beginning of flowering (BF) – at 123 (± 6), 123 (± 5) and 167 (± 4) days of growing for Andropogon gerardi, Panicum virgatum and Miscanthus sacchariflorus, respectively.

For each grasses, green forage was collected in 3 replicates from area of 1m^2. Forage was cut by hand collector ca. 3 cm above ground. Further analysis were performed in Laboratory of Department of Animal Nutrition and Feed Management Economy, Faculty of Animal Breeding and Biology, University of Technology and Life Science in Bydgoszcz.

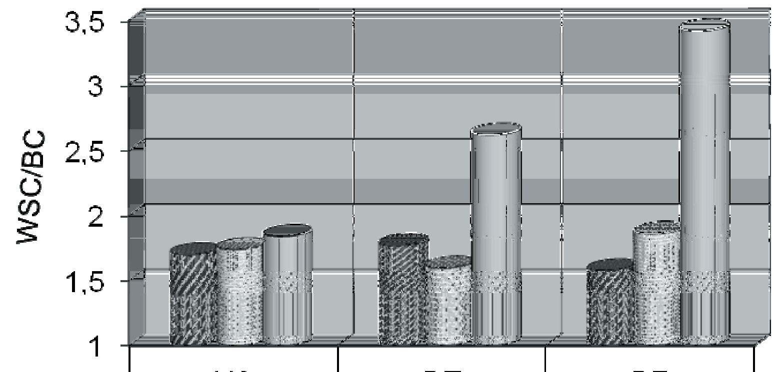
After drying, amount of following components was determined according to standard procedures (AOAC, 1990): dry matter (DM), organic matter (OM) and crude protein (CP) on 2200 Kjeltec auto distillation Foss Tecator, crude fat (CT) on Soxtec HT 1043 Extraction Unit Tecator, crude fiber (CF) on Fibertec System 1010 Heat Extractor Tecator. Amount of nitrogen-free extracts (NFE) were calculated. Structural carbohydrates: neutral detergent fiber (NDF) and acid detergent fiber (ADF) were determined according to Goering and van Soest (1970) on Ankom^{220}-Fiber Analyzer (Ankom technology 8/98). Amount of hemicelluloses (HEM) was calculated: HEM = NDF – ADF. Water soluble carbohydrates (WSC) were determined according to Lane-Eynon with Nizowkin and Jemialinowa modifications (Ładoński and Gospodarek 1986). Buffer capacity of forage (BC) was determined according to Weissbach (1992) and expressed in grams of lactic acid per 100 g of dry matter. Forage fermentation coefficient (FC) was calculated according to Weissbach (1998).

After vegetative season (November 2006) green matter yield (kg·m^{-2}) was evaluated.

RESULTS AND DISCUSIONS

In vegetative phase dry matter contents in forage were similar, and ranged from 23,2% (Miscanthus) to 24,5 (Andropogon) (table 1). Crude protein contents ranged from 12,0% (Miscanthus) to 13,9% (Panicum) of dry matter. Crude fat contents were not different for tested grasses (2,3-2,7% of forage dry matter). N-free extracts exceeded 46% of forage dry matter and ranged from 44,0% (Panicum) to 48,8% (Miscanthus). The contents of structural carbohydrates depend both on genetic constitution of plant and environmental factors such as: temperature during growing season, level of insolation and soil moisture (Moore and Jung 2001). Forage during vegetation phase exposed high neutral detergent fiber contents – from 64,9% (Miscanthus) to 65,8% (Andropogon) of dry matter. Acid detergent fiber ranged from 32,1% (Miscanthus) to 34,3% (Andropogon) of dry matter. No statistical difference of structural carbohydrates contents between tested varieties was noted. In begining of earing forage from

C-4 grases was dry matter contents than in vegetative stage (table 2). Crude protein contents ranged from 6,0% (Miscanthus) to 7,9% (Panicum) and crude fat from 1,4 (Miscanthus) to 1,7 (Andropogon) of dry matter. N-free extracts exceeded 48% of forage dry matter and ranged from 46,5% (Panicum) to 50,2% (Miscanthus). In beginning of flowering further plant development yielded in increase of dry matter from 31,0% (Panicum) to 44,0% (Miscanthus). Forage contents from 5,9% (Miscanthus) to 6,3% (Panicum) of crude protein. N-free extracts exceeded 49,6% of forage dry matter and ranged from 48,6% (Andropogon) to 52,4% (Miscanthus). Dry matter contents in forage from C-3 grasses is lower than for C-4 grasses. It ranges from 18,1% (1[st] cut, Festulolium) to 28,0% (2[nd] cut, Phleum pratense) (Podkówka 2001). As it was mentioned by Podkówka (2001) crude protein contents in Phleum pratense forage varies between cuts and ranges from 11,1% (2[nd] cut) to 17,3% (3[rd] cut). Tested C-4 grasses had low crude protein contents in dry matter, despite of the plant development phase. High contents of structural carbohydrates (NDF, ADF) in C-4 grasses is quite different from native C-3 grass species. Neutral detergent fiber in Phleum pratense forage ranges from 50,6% (3[rd] cut) to 61,2% (1[st] cut), and acid detergent fiber – from 25,7% (3[rd] cut) to 34,1% (2[nd] cut) (Podkówka 2001). Water soluble carbohydrates (WSC)/ buffering capacity (BC) quotient was different in phases of vegetation (fig.1). For Andropogon WSC/BC increased from 1,7 during vegetative phase and beginning of earing to 1,8 during flowering. Different relations were found



	VS	BE	BF
Andropogon	1,7	1,77	1,58
Panicum	1,74	1,6	1,86
Miscanthus	1,84	2,62	3,42

VS – vegetative phase, faza wegetatywna, BE – beginning of earing, początek kłoszenia, BF – beginning of flowering, początek kwitnienia, WSC - water soluble carbohydrate, węglowodany rozpuszczalne w wodzie,

BC - buffering capacity, pojemność buforowa

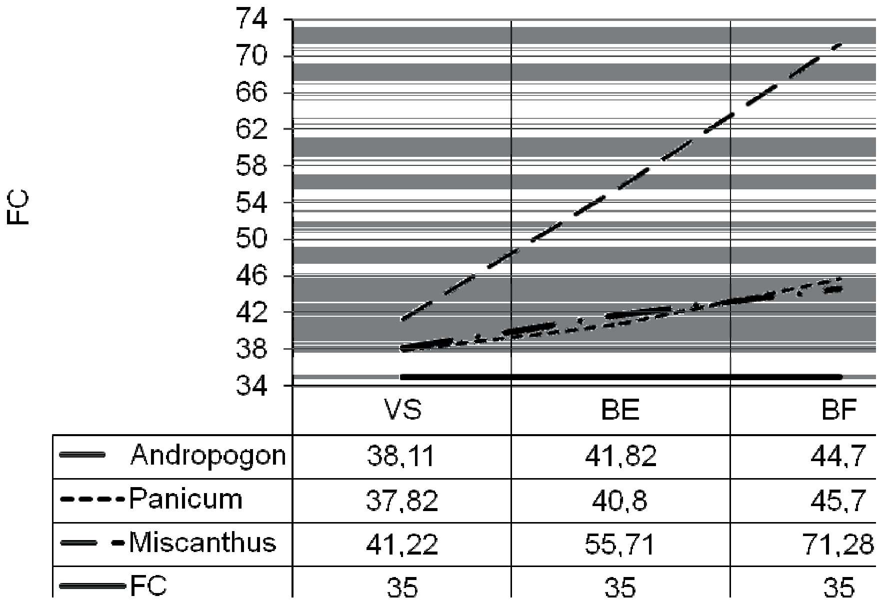
Figure 1. Changes in water soluble carbohydrates to buffer capacity quotient (WSC/BC) in different phases of growing of tested grasses.

Rys. 1. Zmiany stosunku węglowodanów rozpuszczalnych w wodzie do pojemności buforowej w różnych fazach rozwojowych badanych gatunków traw

Table 1. Chemical composition of tested grasses in vegetative phase
Tabela 1. Skład chemiczny badanych traw w fazie wegetatywnej

Species Gatunek	DM (%)	Content in dry matter (%) Zawartość w % suchej masy							
		OM	CP	CFA	CFI	NFE	NDF	ADF	HEM
Andropogon	24,46	93,51	13,41	2,33	30,52	47,25	65,82	34,35	31,47
gerardi	3,65	0,99	2,10	0,29	4,30	3,06	2,60	2,71	3,36
SD									
Panicum virgatum	23,88	92,79	13,90	2,73	32,14	44,02	65,57	33,49	32,08
SD	2,62	0,98	1,92	1,02	2,39	2,30	2,12	2,13	2,11
Miscanthus sacchariflorus	23,19	93,01	11,99	2,33	29,89	48,80	64,89	32,11	32,78
SD	9,57	0,25	1,01	0,41	1,37	0,84	2,22	1,36	2,70

SD – standard deviation odchylenie standardowe, DM - dry matter sucha masa, OM - organic matter substancja organiczna, CP - crude protein białko surowe, CFA - crude fat tłuszcz surowy, CFI - crude fibre włókno surowe, NFE - N-free extract bezazotowe związki wyciągowe, NDF - neutral detergent fraction neutralno detergentowa frakcja włókna surowego, ADF - acid detergent fraction kwaśno detergentowa frakcja włókna surowego, HEM – hemicellulose hemiceluloza



VS – vegetative phase, faza wegetatywna, BE – beginning of earing, początek kłoszenia,
BF – beginning of flowering, początek kwitnienia,
FC - fermentation coefficient, współczynnik fermentacji

Figure 2. Changes in fermentation coeffcient (FC) in different phases of growing of tested grasses
Rys. 2. Zmiany współczynnika fermentacji w zależności od fazy rozwojowej badanych traw

for Panicum, where WSC/BC decreased from 1,7 during vegetative phase, through 1,6 during beginning of earing to 1,9 during flowering. Water soluble carbohydrates to buffer capacity quotient (WSC/BC) for Miscanthus forage was different in different phases (fig. 1). Miscanthus WSC/BC increased from 1,8 during vegetative phase to 3,4 during flowering. WSC/BC quotients for switch grass varieties were higher than estimated by Janicki and Piłat (1998) for C-3 forage grasses, where values ranged from 1,0 to 1,4. Lower values of WSC/BC were also given by Podkówka (2001) for Festulolium forage collected at first (1,8) and third cut (0,9). For other forage grass species WSC/BC ranged from 1,9 to 1,2 (Lolium perenne, from first and third cut, respectively) and from 1,1 to 1,4 (Phleum pratense, also from first and third cut, respectively) (Podkówka 2001). Forage fermentation coefficient (FC) for C-4 grasses varieties decreased with plant growth and development (fig. 2). It was from

Table 2. Chemical composition of tested grasses in beginning of earing
Tabela 2. Skład chemiczny badanych traw w fazie początku kłoszenia

Species Gatunek	DM (%)	Content in dry matter (%) Zawartość w % suchej masy							
		OM	CP	CFA	CFI	NFE	NDF	ADF	HEM
Andropogon gerardi	27,68	94,65	6,66	1,68	38,40	47,91	71,94	40,94	31,00
SD	3,22	0,35	0,72	0,63	2,27	2,53	1,95	2,12	2,64
Panicum virgatum	28,02	94,11	7,95	1,63	38,03	46,50	72,92	40,00	32,92
SD	2,32	0,66	0,70	0,41	2,32	2,86	1,88	1,88	1,86
Miscanthus sacchariflorus	34,78	95,83	5,98	1,41	38,29	50,15	71,42	41,99	29,43
SD	1,83	0,59	0,68	0,25	1,65	0,60	1,39	3,17	3,35

SD – standard deviation odchylenie standardowe, DM - dry matter sucha masa, OM - organic matter substancja organiczna, CP - crude protein białko surowe, CFA - crude fat tłuszcz surowy, CFI - crude fibre włókno surowe, NFE - N-free extract bezazotowe związki wyciągowe, NDF - neutral detergent fraction neutralno detergentowa frakcja włókna surowego, ADF - acid detergent fraction kwaśno detergentowa frakcja włókna surowego, HEM – hemicellulose hemiceluloza

Table 3. Chemical compositon of tested grasses in beginning of flowering
Tabela 3. Skład chemiczny badanych traw w fazie początku kwitnienia

Species Gatunek	DM (%)	Content in dry matter (%) Zawartość w % suchej masy							
		OM	CP	CFA	CFI	NFE	NDF	ADF	HEM
Andropogon gerardi	32,07	94,64	5,98	1,46	38,61	48,59	72,81	41,94	30,87
SD	2,15	0,65	0,82	0,24	2,36	2,19	2,48	2,31	1,89
Panicum virgatum	31,01	94,38	6,35	1,40	38,76	47,87	74,24	42,46	31,78
SD	2,01	0,47	0,60	0,30	2,02	2,35	1,66	1,74	1,83
Miscanthus sacchariflorus	43,96	95,61	5,93	1,48	35,81	52,39	71,01	40,32	30,69
SD	4,06	0,49	1,07	0,27	1,97	2,21	1,71	2,40	1,65

SD – standard deviation odchylenie standardowe, DM - dry matter sucha masa, OM - organic matter substancja organiczna, CP - crude protein białko surowe, CFA - crude fat tłuszcz surowy, CFI - crude fibre włókno surowe, NFE - N-free extract bezazotowe związki wyciągowe, NDF - neutral detergent fraction neutralno detergentowa frakcja włókna surowego, ADF - acid detergent fraction kwaśno detergentowa frakcja włókna surowego, HEM – hemicellulose hemiceluloza

Table 4. Results of evaluation of tested grass species in the end of 2006 vegetative season
Tabela 4. Plon świeżej i suchej masy badanych gatunków traw w końcu sezonu wegetacyjnego 2006 r.

Species Gatunek	Fresh weight Świeża masa [$kg \cdot m^{-2}$]	Moisture of a.d.[1] Wilgotność [%]	Yield in a.d.[1] Plon s.m. [$kg \cdot m^{-2}$]
Andropogon gerardi	1,72	28,1	1,24
Panicum virgatum	1,84	23,3	1,42
Miscanthus sacchariflorus	2,58	45,2	1,41

[1] – aerial dry matter powietrznie sucha masa

37,8 (Panicum virgatum - vegetative phase) to 71,3 (beginning of flowering) for Miscanthus sacchariflorus. As it has been proved by Weissbach (1998) FC of value higher than 35 ensure correct fermentation. Observation on the development of C-4 grass species resulted in the conclusion that there are good conditions of them in Poland. Four–year old experimental plots of the mentioned species yielded between 12,4-14,1 t a.d.m./ha (table 4). There is no tall, perennial grass species in the Polish flora that will be suitable for cultivation on light soil as a source of renewable for forage and energy purposes.

CONCLUSIONS

1. Forage from Andropogon gerardi, Miscanthus sacchariflorus and Panicum virgatum were material of good ensilage suitability.
2. High structural carbohydrates (NDF, ADF) contents in tested forage dry matter suggest ensilage at early phases of plant development.

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