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THE FEEDING VALUE ASSESSMENT OF FORAGE FROM C-4 GRASS SPECIES IN DIFFERENT PHASES OF VEGETATION. PART I. *ANDROPOGON GERARDII* VITMAN.

ABSTRACT

Experiment was conducted during three years 2003 – 2005. Materials used were three varieties (Bison, Pawnee, Bonilla) of *Andropogon gerardii* Vitman perennial grass species of C-4 photosynthesis. Agro technical part of experiment was conducted in Botanical Garden of PBAI in Bydgoszcz and analytical part – in Department of Animal Nutrition and Feed Management Economy, Faculty of Animal Breeding and Biology of University of Technology and Agriculture in Bydgoszcz. The chemical composition of mentioned varieties was accessed in different phases of plant development. No significant differences between varieties were observed in vegetative phase. Pawnee variety at heading and flowering phases exposed significantly lower water-soluble carbohydrates contents, as compared to other varieties. All tested varieties were of high ensilage quality. High structural carbohydrates contents (NDF, ADF) in dry matter suggested ensiling during early phases of development. Silage quality from *A. gerardi* was good and very good. Silages during oxygenic test were stable, except silage with microbiological and enzymatic addition (AIV), overheated (23°C) after 7 days of incubation. Results suggest possible good forage quality of *Andropogon* biomass.

Key words: aerobic stability, *Andropogon gerardi*, chemical composition, quality, silage stage of vegetation.

INTRODUCTION

During last years the increase in insulation 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 cool season C-3 grass species, mainly due to higher efficiency of utilization of water, nitrogen and other elements (Nalborczyk *et al.* 1996). Some C-4 grass species (as for example *Andropogon gerardi* - big bluestem) are native natural dominants in prairie of North America, and are used as a food for animals (Blasi *et al.* 1991, Coffey *et al.* 2000, Farmer *et al.*

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2001, Hafley *et al.* 1993, Redfearn *et al.* 1995). Big bluestem is best adopted to eastern plains from North Dakota to Texas, but is quite common in Canada, Mexico and United States. It is long lived, perennial species with tufted and solid culms, shortly stoloniferous. It has extensive root system and short or absent rhizomes (Quatrocci, 2006). It is very palatable when harvested for hay and its highest quality is obtainable when harvested before seed heads emerge. It is also suitable to grazing provided it is not overgrazed (Quatrocci, 2006).

In Europe C-4 grass 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 during vegetation.

The aim of above work was to determine the chemical composition and ensilage ability of different varieties of *Andropogon gerardi* Vitman grown in climatic conditions of Poland, during different phases of development as well as quality and oxygenic stability of silage made from mentioned species.

MATERIAL AND METHODS

Three varieties of big bluestem (*Andropogon gerardi* Vitman): Bison, Bonilla (seed from Plant Material Center, Bismarck, USA) and Pawnee (seed from National Seed Storage Laboratory, Fort Collins, USA) were used in above experiment. Plants were planted at spring 1998 on the lessives soil in different quantities: Pawnee – 70 plants, Bonilla – 80 plants and Bison – 95 plants. Each year from 1998 to 2002 plants were allowed to produce seeds and seed heads were collected. No additional treatments (fertilization, watering) were used. During three consecutive years (2003, 2004, 2005) forage was collected at following phases of development:

- — vegetative phase (VS) – at 73 (±5 days) day of vegetation (days starting from 1st April),
- — beginning of earing (BE) – at 100 (±11), 107 (± 7) and 116 (± 5) days of vegetation for Bison, Pawnee and Bonilla, respectively,
- — beginning of flowering (BF) – at 111 (± 5), 123 (± 6) and 142 (± 3) days of vegetation for Bison, Pawnee and Bonilla, respectively.

For each variety, 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 of University of Technology and Agriculture in Bydgoszcz.

After drying, amount of following components was determined according to standard procedures (Collective work, 1991): dry matter (DM), organic substance (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) was calculated. Structural carbohydrates: neutral detergent fiber (NDF) and acid detergent fiber (ADF) were determined according to Goering and van Soest (1979) 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 Nizwokin 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 (VK) was calculated according to Weissbach (1998).

Due to the limited amount of forage, silage was made from mixture of big bluestem varieties in micro-silos (9 l volume per silo) with supplements (Table 1). Supplements were added according to producer recommendations.

Table 1

Ensilage supplements used in above experiment

Supplement	Main components of supplement
Without supplement (AI)	–
Chemical supplement (AII)	Formic acid 55% Formate ammonium 24% Propionic acid 5% Other organic acids 2% Water 14%, colouring substance E150d
Microbiological supplement (AIII)	Lactic acid bacteria - min. 10×10^9 CFU per 1 g of substance
Microbiological - enzymatic supplement (AIV)	Micobiological part: lactic acid bacteria - min. 6.7×10^9 CFU/g Enzymatic part: cellulase - min. 43000HEC/g

Forage with supplements was ensiled in 3 replicate per one kind of supplement. Following substances were estimated in forage and silage after 100 days of fermentation in 20°C: dry matter, crude ash, protein, crude fat, crude fiber and its fractions: ADF and NDF. Only for silage following parameters were also estimated: amount of organic acids (lactic, acetic and butyric), pH, amount of ammonia nitrogen ($N\text{-}NH_3$). Quality of silage was determined according to Flieg-Zimmer scale (Collective work, 1991). Oxygenic stability was accessed due to Honig (1985).

Results were analyzed with SAS® statistical package (SAS Institute, 2004 a, b). Tukey's Honestly Significant Differences (HSD) test was used for testing the significance of unplanned pairwise comparisons between means.

Weather conditions

In 2003 and 2004 mean daily air temperature during growing season was higher than normal value, as well as mean for three years (2003 – 2005). Mean temperature in growing season 2003 was 15°C, while in 2004 and 2005 14.2°C and 14.8°C, respectively. Precipitation during experiment was variable. During 2003 high water deficit was noted. Monthly precipitation 28.2 mm higher than normal was noted only in July. Average precipitation during vegetation period in 2004 was also higher than normal. Distribution of rains in this year was not uniform. Only May and August precipitation exceeded normal values. During rest of months precipitation deficit was noted. In 2005 precipitation deficit (12 mm) was noted for all months with exception of May (Table 2).

Table 2

Average monthly temperature and sum of monthly rainfall in 2003-2005

Month	Air average temperature [°C]				Precipitation [mm]			
	2003	2004	2005	1970-1990 (normal)	2003	2004	2005	1970-1990 (normal)
April	6.4	8.3	8.1	6.9	23.3	20.0	39.2	37.0
May	15.3	12.0	13.1	12.4	14.4	64.8	96.1	53.0
June	17.4	15.4	15.5	16.7	36.5	48.3	23.8	66.0
July	19.1	17.2	20.0	17.8	119.2	88.9	72.4	91.0
August	18.4	18.8	16.8	17.0	10.2	100.8	32.3	58.0
September	14.0	13.4	15.5	12.9	19.5	41.9	19.1	48.0
Mean (IV-IX)	15.10	14.18	14.83	13.95	37.18	60.78	47.15	58.83

RESULTS AND DISCUSSION

Chemical composition of forage in different phases of plant development

Vegetative phase. No statistically significant values of any chemical composition parameter tested was noted for forage of big bluestem varieties (Table 3). Dry matter content in forage was similar, and ranged from 22.4% (Bison) to 25.8% (Bonilla). Crude protein contents ranged from 12.3% (Bonilla) to 13.3% (Bison) of dry matter. Crude fat contents were also similar for tested varieties (2.3% of forage dry matter). Nitrogen-free extracts exceeded 45% of forage dry matter and ranged from 45.7% (Pawnee) to 48.9% (Bison). 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 Jing, 2001).

Forage during vegetation phase exposed high neutral detergent fiber contents – from 65.0% (Pawnee) to 67.2% (Bonilla) of dry matter. Acid detergent fiber ranged from 33.5% (Bonilla) to 35.7% (Pawnee) of dry matter. No statistical difference of structural carbohydrates contents between tested varieties was noted. Bonilla and Bison varieties exposed similar contents of water-soluble carbohydrates: 5.8% and 6.0%, respectively, but for Pawnee it was lower – 5.0%. Buffer capacities of Bison and Pawnee forage were similar: 3.9 and 4.0 g, respectively, but lower in Bonilla (3.6 g of lactic acid per 100 g of dry matter).

Table 3

Average chemical composition of big bluestem (*Andropogon gerardi* Vitman) in different phases of vegetation

Variety	DM [%]	Contents in dry matter [%]									BC*
		OM	CP	EE	CF	NFE	NDF	ADF	HEM	WSC	
vegetative phase											
Bison	22.41	92.26	13.26	2.33	27.69	48.98	65.31	33.89	31.42	5.99	3.93
Pawnee	25.17	94.29	14.66	2.30	31.65	45.68	64.99	35.71	29.28	4.96	3.96
Bonilla	25.81	93.67	12.31	2.35	32.21	46.80	67.17	33.45	33.72	5.78	3.61
before earing											
Bison	25.56B	94.40B	6.61B	2.03	38.68	47.08	72.17	41.83	30.34	6.55A	3.51
Pawnee	30.29A	94.49B	5.66C	1.61	39.02	48.20	72.13	41.34	30.79	4.13B	3.19
Bonilla	27.19AB	95.06A	7.71A	1.40	37.51	48.44	71.52	39.64	31.88	6.40A	3.60
before flowering											
Bison	29.43	94.68	5.88	1.24	40.21	47.35	73.84	43.96a	29.88	6.45A	3.39
Pawnee	33.97	94.28	5.80	1.64	37.81	49.03	72.47	41.19b	31.28	4.66B	3.52
Bonilla	32.80	94.96	6.27	1.49	37.82	49.38	72.13	40.66b	31.47	5.48A	3.65

* - values expressed in grams of $C_3H_6O_3$ per 100 g DM (dry matter)
Values in the same columns marked with different letters differ significantly a,b,....p<0,05; A,B,...p<0,01
Otherwise, means in columns are not statistically different

Begining of earing.

Significant differences between mean values for tested varieties were noted in four per eleven traits used (Table 3). Forage from Pawnee variety exposed significantly higher ($p<0.01$) dry matter contents than Bison. Tested varieties differ significantly ($p<0.01$) also in crude protein contents in forage dry matter: from 5.7% for Pawnee, 6.6% for Bison and 7.7% for Bonilla.

No differences were noted for nitrogen-free acids in dry matter of tested varieties forage. Dry matter of tested forage consist of 72% of neutral detergent fiber and 41% of acid detergent fiber, with no differences between varieties. Water soluble carbohydrates contents were significantly ($p<0.01$) higher in Bonilla and Bison (6.4% and 6.6%, respectively) than in Pawnee (4.1%). Buffer capacities of Bison and Bonilla forage were similar (3.5g and 3.6g, respectively), while lower in Pawnee forage (3.2 g of lacitic acid per 100 g of dry matter).

Begining of flowering.

Dry matter contents in forage of tested varieties ranged from 29.4% (Bison) to 34.0% (Pawnee). Bison and Pawnee exposed also lower crude protein contents (5.9% and 5.8%, respectively) than Bonilla variety (6.3% of dry matter). Despite of tested variety, big bluestem forage had high neutral detergent fiber contents during this phase of development. It ranged from 72.1% for Bonilla to 73.9% for Bison.

Acid detergent fiber contents in dry matter of Bison forage (44.0%) was significantly higher ($p<0.05$) than for Pawnee and Bonilla (Table 3).

Dry matter contents in forage from C-3 grasses is lower than for C-4 grasses. It ranges from 18.1% (I cut, *Festulolium*) to 28.0% (II cut, *Phleum pratense*) (Podkówka, 2001). As it was mentioned by Podkówka (2001) crude protein contents in *Phleum pratense* forage is variables between cuts and ranges from 11.1% (II cut) to 17.3% (III cut).

Tested big bluestem varieties showed low crude protein contents in dry matter, despite of the plant development phase. High contents of structural carbohydrates (NDF, ADF) in big bluestem varieties were different from native C-3 grass species. Neutral detergent fiber in *Phleum pretense* forage ranges from 50.6% (III cut) to 61.2% (I cut), and acid detergent fiber – from 25.7% (III cut) to 34.1% (II cut) (Podkówka 2001).

Water soluble carbohydrates contents was also low in Big bluestem forage as compared to C-3 grasses. In Podkówka (2001) experiments it ranges from 9.4% (I cut, *Phleum pratense*) to 19.8% (I cut, *Lolium perenne*).

Buffer capacity values of forage from big bluestem varieties were also low, as compared to C-3 grass species where it ranges from 12.6 g (III cut, *Festulolium*) to 72.7 g (II cut, *Phleum pratense*) (Podkówka, 2001).

Water soluble carbohydrates to buffer capacity quotient was different in development phases of big bluestem varieties (Fig. 1). For Bonilla, decrease of WSC/BC during growing season was observed, while for other varieties only slight increase before earing phase was noted. Above values were close to C-3 forage (Janicki, Piłat 1998). Similar values for *Lolium perenne, Phleum pratense* and *Festulolium* were also obtained by Podkówka (2001).

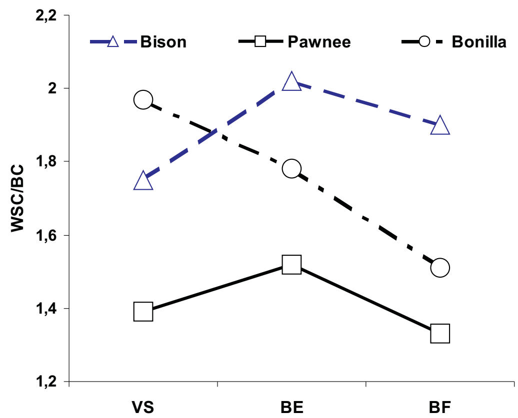

Fig. 1. Changes in water soluble carbohydrates to buffer capacity quotient (WSC/BC) in different phases of vegetation of tested big bluestem (*Andropogon gerardi* Vitman) varieties

Forage fermentation coefficient for Bison and Pawnee increased with plant growth and development (Fig. 2). For Bonilla variety lower values of mentioned coefficient were noted at earing phase. In flowering phase values of above coefficient were similar for tested varieties. Forage fermentation coefficient above 35 means that forage from C-4 grass species as big bluestem will ensile quite easy (Weissbach 1998).

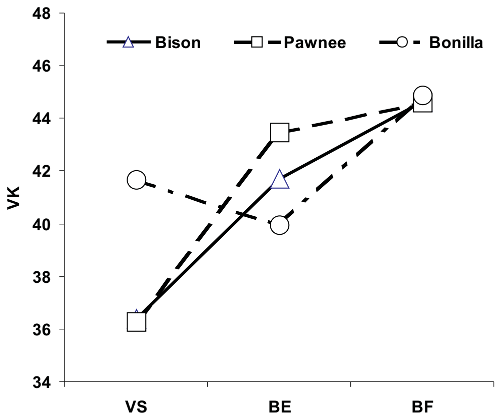

Fig. 2. Changes in fermentation coefficient (VK) in different phases of vegetation of tested of Big bluestem (*Andropogon gerardi* Vitman) varieties

Chemical composition, quality and oxygenic stability of silage

Dry matter contents in silage and forage were similar (Table 4). Level of crude protein in silage was lower than in forage and was not affected by silage supplements. Crude fiber, NDF and ADF contents were higher in silage than in forage. Share of nitrogen-free extracts in forage dry matter was higher than in silage. Silage with microbiological – enzymatic supplement (AIV) as compared to silage without supplements (AI) contained significantly lower contents of: crude protein, NDF and ADF (p<0.05) and nitrogen-free extracts (p<0.01).

Table 4

Chemical composition of silages

Supplement	DM [%]	Contents in dry matter [%]							
		OM	CP	EE	CF	NDF	ADF	HEM	NFE
Green forage									
-	24.48	91.33	14.96	1.7	28.47	62.43	34.99	27.44	46.2
Silages									
AI	25.85	87.91	13.63	3.07	33.30 a	71.79 a	39.89 a	31.90 a	37.91 B
AII	23.97	88.76	13.5	3.19	28.60 b	68.67 b	38.49 b	30.18 b	43.47 AB
AIII	23.28	88.80	12.96	3.15	32.07 a	70.82 ab	40.01 a	30.81 ab	40.62 AB
AIV	23.71	88.71	13.98	2.76	27.94 b	69.30 b	38.14 b	31.16 ab	44.03 A

Values in the same columns marked with different letters differ significantly a, b, ab - p<0.05; A, B, AB - p<0.01. Otherwise, means in columns are not statistically different

Higher level of nitrogen-free extracts in silage with microbiological – enzymatic supplement is probably the effect of decomposition of a part of crude fiber to simple sugars. Similar results were obtained by Voight *et al.* (1991).

Table 5

Quality of silages

Supplement	pH	N-NH_3	Acid contents [%]			Flieg-Zimmer evaluation	
			Lactic	Acetic	Butyric	Scores	Quality
AI	4.47^{ab}	0.0324	1.61	0.59	0.01	91	Very good
AII	4.34^{b}	0.0357	1.24	0.69	0.00	77	Good
AIII	4.69^{a}	0.0255	1.38	0.91	0.00	72	Good
AIV	4.65^{a}	0.0279	1.25	0.73	0.02	74	Good

Values in the same columns marked with different letters differ significantly a.b.....$p<0.05$. Otherwise, means in columns are not statistically different

Acidity (pH) of silage with chemical supplement (AII) was significantly lower ($p<0.05$) than silage with microbiological supplement (AIII) (Table 5). Amount of ammonia nitrogen (N-NH_3) in silage with AIII was lower than in silages with other supplements, however no significant difference was noted for this parameter. Mikołajczak and Grabowicz (1998) discovered that addition of microbiological and enzymatic supplements increased share of lactic acid and decreased proteolysis in silage. In above experiments the higher value of lactic acid (1.6% of fresh matter) was observed in silage without supplements, while the lowest value (1.2%) in silage with chemical supplement. Acetic acid contents ranged from 0.6% (silage without supplements) to 0.9% (silage with microbiological supplement). Traces of butyric acid were noted only in silage without supplements and in silage with microbiological – enzymatic supplement.

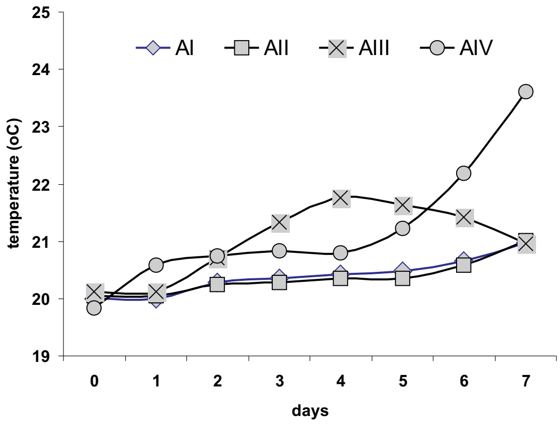

Fig. 3. Average age temperatures of silages during incubations period (ambient temperature 20°C ± 1°C).

Supplements used in above experiments had no statistically significant effect on fermentation profile. Quality of silage estimated on the basis of

Flieg-Zimmer scale was very good (silage without supplements) to good (silages with other supplements).

Silages from big bluestem were stable during oxygenic test period. Addition of microbiological and enzymatic supplement resulted in overheating (temperature above 23°C) at the last part of oxygenic phase (after 7 days of incubation) (Fig. 3). Temperature rise at the end of oxygenic phase was probably the effect of oxygenic conversion of lactic acid made by fungi, moulds and *Bacillus* bacteria. Conversion products were: carbon dioxide, acetic acid and ethanol with emission of heat (Lindgern *et al.* 1985, Kung Jr. 2001).

CONCLUSIONS

Forage from big bluestem (*Andropogon gerardi* Vitman) varieties was material of good ensilage suitability, similar to native C-3 forage grass species.

High structural carbohydrates (NDF, ADF) contents in tested forage dry matter suggest ensilage at early phases of plant development.

Silages at the oxygenic test period were stable, despite of silage with microbiological – enzymatic supplement, overheated (temperature above 23^0C) after 7 days of incubation.

Above results suggest the possibility of usage of forage from big bluestem 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.

REFERENCES

Blasi D.A., Ward J.K., Klopfenstein T.J., Britton R.A. 1991. Escape protein for beef cows: III. Performance of lactation beef cows grazing smooth brome or big bluestem. Journal of Animal Science 69: 2294-2302.

Christian D.G., Riche A.B., Yates N.E. 1999. Evaluation of some herbaceous grasses as biomass crops in southern England. Materiały konferencyjne 'Alternative crops for sustainable agriculture', 13-15 June, Turku: 58-69.

Coffey K.P., Nagaraja T.G., Towne E.G., Brazle F.K., Moyer J.L. 2000. Digestibility of praire hay diets supplemented with different levels of magnesium-mica by beef heifers. Journal of Animal Science 78: 718-725.

Collective work. 1991. Ćwiczenia z żywienia zwierząt i paszoznawstwa. AR Kraków, ss. 240.

Farmer C.G., Cochran R.C., Simms D.D., Klevesahl E.A., Wickersham T.A., Johnson D.E. 2001. The effects of several supplementation frequencies on forage use and the performance of beef cattle consuming dormant tallgras praire forage. Journal of Animal Science 79: 2276-2285.

Goering H.K., Van Soest P.J. 1970. Forage fiber analyses, apparatus reagents procedures and some applications. Agriculture Handbook No.379. Agricultural Research Service, United States Department of Agriculture.

Hafley J.L., Anderson B.E., Klopfenstein T.J. 1993. Supplementation of growing cattle grazing warm-season grass with proteins of various ruminal degradabilities. Journal of Animal Science 71: 522-529.

Honig H. 1985. Determination of aerobic deterioration - System Völkenrode. Institut für Grünland und Futterpflanzenforschung der Bundesforschunganstalt für Landwirtschaft, Braunschweig-Völkenrode: 2, 3.

Janicki B., Piłat J. 1998. Wpływ różnych dodatków do zakiszania na wartość pH kiszonek sporządzonych z traw i motylkowatych oraz kukurydzy o zróżnicowanej zawartości suchej masy. Zeszyty Problemowe Postępów Nauk Rolniczych 462: 403-408.

Kung Jr. L. 2001. Aditivos microbianos e quimicos para silagem-Efeitos na fermentação e resposta animal. In:Anais do2° Worshop sobre Milho para silagem.Piracicaba, SP, Brazil: 53-74.

Lindgren S., Jonsson K., Petterson S., Kasperson A. 1985. Microbial dynamics during aerobic deterioration of silage. Journal of Science and Food Agriculture 36: 765-774.

Łabędzki L. 2004. Problematyka susz w Polsce. Woda – Środowisko – Obszary Wiejskie 4(1): 47-66.
Ładoński W., Gospodarek T. 1986. Podstawowe metody analityczne produktów żywnościowych. PWN, Warszawa: 166-182.
Majtkowski W., Majtkowska G. 1998. Introdukcja pozaeuropejskich gatunków traw na tereny parkowe i zdegradowane. Biuletyn Ogrodów Botanicznych 7: 117-122.
Mikołajczak J., Grabowicz M. 1998. Aktualne zagadnienia stosowania dodatków do zakiszania pasz. Zeszyty Problemowe Postepów Nauk Rolniczych 462: 285-296.
Moore K.J., Jing H.J.G. 2001. Lignin and fiber digestion. Journal of Range Management 54(4): 420-430.
Nalborczyk E. *et al.*. 1996. Nowe rośliny uprawne na cele spożywcze, przemysłowe i jako odnawialne źródła energii. SGGW Warszawa: 1 - 176.
Podkówka L. 2001. Wartość pokarmowa oraz ocena przydatnosci do zakiszania zielonek z *Phleum pratense, Lolium perenne* i *Festulolium*. Rozprawa doktorska, ATR Bydgoszcz, ss. 88.
Quatrocci U. 2006. CRC world dictionary of grasses. Common names, scientific names, eponymes, synonyms and etymology. Vol. 1, 118 – 119.
Redfearn D.D., Moser L.E., Waller S.S., Klopfenstein T.J. 1995. Ruminal degradation of switchgrass, big bluestem and bromegrass leaf proteins. Journal of Animal Science 73: 598-605.
SAS Institute Inc. 2004 a. SAS 9.1 Companion for Windows. Cary, NC, USA, SAS Publishing, SAS Institute Inc.
SAS Institute Inc. 2004 b. SAS/STAT 9.1 User's Guide. Cary, NC, USA, SAS Publishing, SAS Institute Inc.
Voigt J., Nagel S., Robowski K.D., Krawielitzki R., Schultz G. 1991. Der Einfluss des Zusatzes von Cellulase bei der Silierung von Grünfutter auf Nährstoffumsatz und Kauverhalten bei der Wiederkäuern. Arch.Tierz. 34(6): 457-468.
Weissbach F. 1992. Bestimung der Pufferkapzität. Institut für Grünland und Futterpflanzenforschung FAL, Braunschweig, ss. 3.
Weissbach F. 1998. Über der Einfluss von verschiedenen kräutern in aufwuchs extensiv genutzter wiesen auf den gärungsverlauf bei der bereitung von grassilagen. Zeszyty Problemowe Postępów Nauk Rolniczych 462: 297-313.