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Biomass production and chemical characteristics of four grass species for bioenergy

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Abstract. The aim of the present study was to investigate the potential use of the grasses *Avena sterilis*, *Bromus inermis*, *Hordeum bulbosum* and *Phalaris aquatica* as bioenergy crops. Their dry matter production was measured at two phenological stages (inflorescence and fruiting) and the contents of neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL), macronutrients K, Na, Mg and ash were determined. According to the results, the dry matter production was not affected by the phenological stage, while *Phalaris aquatica* was the most productive followed by *Avena sterilis* and *Bromus inermis*. The higher content in NDF, ADF and ash was detected at the fruiting stage and in K, Na in the inflorescence one, while the content in ADL and Mg was not affected by the phenological stage. *Bromus inermis* had the lower content in NDF, ADF, ADL, Na, Mg and higher in K than the other species, while *Phalaris aquatica* had the lower content in ash. Combined with dry matter production, *Phalaris aquatica* at the fruiting stage had the optimal chemical composition for use as bioenergy crops**.**

Keywords. *Avena sterilis* – *Bromus inermis* – *Hordeum bulbosum* – *Phalaris aquatica* – Biofuel.

La production de biomasse et les caractéristiques chimiques de quatre espèces de graminées pour la bioénergie

Résumé. *Le but de la présente étude était d'examiner l'utilisation potentielle d'*Avena sterilis*,* Bromus inermis*,* Hordeum bulbosum *et* Phalaris aquatica *en tant que cultures bioénergétiques. La production de matière sèche a été mesurée à deux stades phénologiques (floraison et fructification) et les teneurs en fibre au détergent neutre (NDF), fibre au détergent acide (FDA), lignine au détergent acide (ADL), K, Na, Mg et cendres ont été déterminées. Selon les résultats, la production de matière sèche n'a pas été affectée par le stade phénologique, tandis que* Phalaris aquatica *était la plus productive suivie par* Avena sterilis *et* Bromus inermis*. La teneur la plus élevée en NDF, ADF et cendres a été détectée au stade de fructification et en K, Na au stade floraison, tandis que la teneur en ADL et Mg n'a pas été affectée par le stade phénologique.* Bromus inermis *a eu la plus faible teneur en NDF, ADF, ADL, Na, Mg, et teneur plus élevée en K que les autres espèces, tandis que* Phalaris aquatica *avait la plus faible teneur en cendres. En combinaison avec la production de matière sèche,* Phalaris aquatica *et* Avena sterilis *au stade de fructification ont la composition chimique optimale pour une utilisation en tant que cultures de bioénergie.*

Mots-clés. Avena sterilis – Bromus inermis – Hordeum bulbosum – Phalaris aquatica – *Biocarburants.*

I – Introduction

Bioenergy is the chemical energy that is stored in organic material and it can be directly converted into useful energy sources by biological, mechanical or thermo-chemical processes (Bessou *et al*., 2011). It refers to renewable energy from agricultural crops, residues, forest products, aquatic plants, manure and waste that can be used either directly or following conversion processes (e.g., liquefaction or gasification) for heating, electricity, fuel as well as their by-products (Haberl *et al*., 2010).

Among the agricultural crops, grass species and especially the perennials are considered to be the future of the bioenergy industry and are the focus of intense research (Sanderson and

Adler, 2008) because of their beneficial attributes over wood feedstocks for bioenergy applications (Lewandowski *et al*., 2003). These species can be harvested once a year minimizing storage requirements, are easily established, require fewer agricultural inputs than other crops and can be grown on agriculturally marginal lands (McLaughlin *et al*., 2002). The aim of the present study was to investigate the potential use of three perennial grasses, (*Bromus inermis*, *Hordeum bulbosum*, *Phalaris aquatica*) and an annual (*Avena sterilis*), as bioenergy crops.

II – Materials and methods

The experiment was conducted at the farm of the Aristotle University of Thessaloniki, Northern Greece (40°32'N, 22°59'E), at an altitude of 10 m a.s.l. The climate is characterized as Mediterranean semiarid with cold winters. The mean annual precipitation is 443 mm and the mean annual temperature is 15.5 °C.

The grass species *Avena sterilis* (A.st)*, Bromus inermis* (B.in), *Hordeum bulbosum* (H.bu) and *Phalaris aquatica* (P.aq) were used. The experimental plots of 2 m^2 were established October 2012 in completely randomized design with four replicates. The annual A.st after the first establishment was self-seeded. Four reproductive tillers in order the plant material to be more uniform, were randomly collected from each plot at the inflorescence phenological stage (mid May 2013) and at the fruiting one (mid June 2013). The tillers were bulked and the samples were then oven-dried at 60°C for 48 h and subsequently passed through a 1 mm sieve and disrupted by the method of wet oxidation using triple acid mixture H_2SO_4, HNO_3, $HClO_4$ in a ratio of 5:1:1, (Allen *et al*., 1986). Concentration of total Mg, K, and Na was conducted by atomic absorption spectroscopy (Perkin-Elmer AAnalyst 300). Ash content was determined after burning in a muffle furnace at 540 °C for 5 h.

Neutral Detergent Fibre (NDF), Acid Detergent Fibre (ADF) and Acid Detergent Lignin (ADL) were measured using the procedure described by Van Soest *et al.* (1991) with the ANKOM fibre analyzer (ANKOM Technology Corporation, Macedon, NY, USA), using sodium sulphite and α-amylase to the solution for the NDF determination. All analyses were carried out on duplicate samples and results are reported on DM basis.

General linear models procedure (IBM SPSS®21 for Windows) was used for ANOVA. The LSD at the 0.05 probability level was used to detect the differences among means (Steel and Torrie, 1980).

III – Results and discussion

Average dry matter production, ADL, Na and Mg content did not significantly differ between the inflorescence and fruiting stage. The period May to July of the experimental year was relatively dry as the mean precipitation was 15 mm while generally for this period is 30 mm. Especially in May it was only 3 mm. Inversely, NDF and ADF content were significantly lower, while K and ash content significantly higher at the inflorescence phenological stage compared to the fruiting one (Table 1). The average higher content of NDF and ADF at the fruiting stage is the result of plants maturity and is expected especially for grass species (Adler *et al*., 2006; Arzani *et al*., 2004).

P.aq had significantly higher dry matter production and ash content compared to the other species (Table 2). The NDF and ADF content of B.in was significantly lower in comparison to the other species. B.in had the higher K and the lower Na and Mg content compared to the other studied grass species. Significant interaction between phenological stage and species was recorded only for NDF and ADF content (data not shown). According to this, the NDF and ADF content of B.in increased from the inflorescence to the fruiting stage inversely of the main effect.

Table 1. Effect of phenological stage on average dry matter production (DM), ash, NDF, ADF, ADL, K, Na and Mg content (n=16)

Phenological stage	DM ($g*tiller^{-1}$)	Ash (%)	NDF ($g*kg^{-1}$)	ADF ($g*kg^{-1}$)	ADL ($g*kg^{-1}$)	K ($mg*gr^{-1}$)	Na ($mg*gr^{-1}$)	Mg ($mg*gr^{-1}$)
Inflorescence	10 a	7 a	68 b	43 b	7 a	18 a	0.17 a	2.2 a
Fruiting	9 a	6 b	71 a	45 a	7 a	12 b	0.15 a	2.8 a

*Means of each parameter followed by the same letter in the same column are not significantly different (P≥0.05).

Table 2. Dry matter production (DM), ash, NDF, ADF, ADL, K, Na and Mg content of the studied species

Species	DM ($gr*tiller^{-1}$)	Ash (%)	NDF ($g*kg^{-1}$)	ADF ($g*kg^{-1}$)	ADL ($g*kg^{-1}$)	K ($mg*gr^{-1}$)	Na ($mg*gr^{-1}$)	Mg ($mg*gr^{-1}$)
A.st	9 b	8 a	72 a	46 a	7 b	15 b	0.40 a	2.0 b
B.in	7 b	7 b	62 b	37 b	6 b	21 a	0.02 d	1.9 b
H.bu	5 c	5 c	73 a	46 a	9 a	11 b	0.08 c	3.6 a
P.aq	18 a	8 a	72 a	45 a	7 b	14 b	0.20 b	2.6 ab

*Means of each parameter followed by the same letter in the same column are not significantly different (P≥0.05).

High concentration of total fiber (NDF, ADF, ADL) in combination with low concentration of mineral and ash are desirable for bioenergy crops (Trebbi, 1993). All the studied species except B.in had the higher fiber concentration at the fruiting phenological stage. The alkali elements such as potassium (K) and sodium (Na) as well as magnesium (Mg) are decisive factors which determine the behaviour of the biomass under thermal degradation (Fahmi *et al*, 2007). As regards to the above factors, these preliminary results are indicative that B.in could not be used as a bioenergy crop, because of its low concentration in fiber and its high content of K. On the other hand, all the other study species could be potentially bioenergy crops. However, the perennial grass P.au had additionally higher biomass production. These results are in accordance with Sulas *et al.* (2015) that native Mediterranean perennial grasses have a potential for rainfed crops for bioenergy.

IV – Conclusions

The phenological stage affected the chemical characteristics of the grasses but it did not affect their biomass production. At the fruiting stage the plants had higher concentration of total fiber and lower content of K and ash than at the inflorescence one, which are desirable elements for the bionergy crops. *Phalaris aquatica,* among the tested species, showed positive traits for bioenergy as it combined at the fruiting stage high dry matter production and optimal chemical composition for such use. However, these results are preliminary and additional research is needed.

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