Plant Archives Volume 20 No. 2, 2020 pp. 5533-5538 **e-ISSN:2581-6063 (online), ISSN:0972-5210**

PHOTOSYNTHETIC PRODUCTIVITY OF GIANT MISCANTHUS DEPENDING ON ELEMENTS OF GROWING TECHNOLOGY

Liudmyla Pravdyva*, Mykola Grabovskyi, Lesia Kachan, Valerii Khakhula, Yurii Fedoruk and SvitlanaHornovska

BilaTserkva National Agrarian University, Agrobiotechnology faculty,
Department of Technologies in Crop Production and Plant Protection,
pl. 8/1 Soborna, BilaTserkva, Kyivska oblast, 09117, Ukraine.

Abstract

Raw materials for the production of solid biofuels are waste from the woodworking industry (sawdust, woodchips), straw of cereals and legumes, sunflower husk and so on. The production of such raw materials is unstable and seasonal, which adversely affects the efficiency of the biofuel factories. Therefore, special attention is paid to the direction related to the stable provision of raw materials for the production of solid biofuels through the cultivation of new types of high-yielding perennial plants. One such plant is the miscanthus giant (*Miscanthus giganteus*). Due to the high yield of dry biomass (up to 25 t ha^{-1}), high calorific value (5 kW/h/kg or 18 MJ/kg), low natural stem moisture at harvest time (up to 15%), miscanthus is the most effective plant compared to other crops for the production of solid biofuels. The results of studies of photosynthetic miscanthus productivity, depending on the date of planting rhizomes, are highlighted in the article. The maximum leaf surface area of the plant and the net productivity of photosynthesis are observed during the second term of planting rhizomes. The maximum yield of dry biomass of miscanthus plants was obtained by planting rhizomes in the second decade of April and for the third year of vegetation is 15.3 t ha^{-1}.

Key words: miscanthus; leaf surface area; photosynthetic productivity; dry biomass yield.

Introduction

Environmental stresses caused by climate change and unstable irrigation will affect crop productivity and reduce farmland on 2-9% worldwide and on 11-17% across Europe (Zhang and Cai, 2011). The increasing impact of climate change on the production and demand of crop products creates problems for the use of existing agricultural lands. One of the solutions may be to use unsuitable land for growing crops. Perennial crops are second-generation biomass, resistant to environmental stress, contributing to reducing CO_2 emissions, limiting competition with food production (Popp *et al.*, 2014; Goetz M. Richter *et al.*, 2016).

Miscanthus (*Miscanthusgiganteus*) is one of the most promising industrial crops in the world, mainly due to its high resource efficiency and biomass yield. However, the scale of cultivation of this crop in Europe still far from its real potential. The major limiting factors are high initial costs and poor biomass productivity during the harvest period, especially in the first year (Moritz von Cossel *et al.*, 2019).

Miscanthus is considered to be a promising candidate for second generation energy crops (Clifton Brown *et al.*, 2004, 2007; Karp and Shield, 2008; Oliver *et al.*, 2009). As a C4 perennial grass capable of producing high biomass in cool climates, miscanthus is especially suitable for growing in the temperate regions of the world (Beale and Long, 1995; Beale *et al.*, 1996; Naidu *et al.*, 2003; Wang *et al.*, 2008).

A growing body of evidence indicates that second generation energy crops can play an important role in the development of renewable energy and the mitigation of climate change. However, dedicated energy crops have yet to be domesticated in order to fully realize their productive potential under unfavorable soil and climatic conditions (Yan J. *et al.*, 2011).

The European Agricultural Development Policy has provisions aiming at the sustainable development of a maximum of 30% of potentially available biomass that can be used for energy production. Miscanthus as a feedstock for biofuel production has good qualities for burning (Tomi *et al.*, 2011; Daraban *et al.*, 2015).

Due to the appearance many species and varieties of giant miscanthus are used as ornamental plants in landscape design for greening ponds, flower beds, gardens. However, today it is widely used in various sectors of the economy, most of all - in bioenergy. Yes, it can be used directly for burning or for the production of solid biofuels and bioenergy (Jerome J. Maleski David *et al*., 2019; D.J. Krol *et al*., 2019; F. Morandi *et al*., 2019; Szulczewski *et al*., 2018).

The most important task for the effective use of biomass is to develop projects that combine the cultivation of bioenergy crops on marginal lands and use them as raw materials for the production of solid biofuels (Juriši *et al*., 2014).

Miscanthus is a perennial bushy herbaceous plant with C4 type of photosynthesis, capable of develop active leaf growth even at 6°C, which exceeds that of C3 type crops (Dafu Wang *et al*., 2008; Mitchell *et al*., 2014).

According to Pidlisnyuk *et al*., (2014), dates of planting by years may vary depending on the soil condition. The vegetation period of thermophilic crops is limited by the transitions of the average daily air temperature over + 10°C and the period of the most active vegetation – by transitions of the temperature over +15°C.

Other scientists consider that the optimal dates of miscanthus planting occurs when the soil temperature at a depth of 5 cm reaches 10... 12ºC and air – 15ºC, with the physical maturity of the soil. That is, it can be from mid-April to mid-May. Earlier planting is more risky with spring frosts and later – with droughts (Zinchenko, 2008; Frühwirth P. *et al*., 2005).

However, there are studies showing that the optimal planting period is March - April, which is associated with the use of spring moisture in the soil and provides better plant growth and development. This is important because rapid growth and development leads to a greater accumulation of nutrients in the rhizomes and also allows crops to better tolerate drought and frost (Kvak, 2014).

Therefore, in the conditions of the Right-bank Forest Steppe of Ukraine, the optimal dates of miscanthus planting is one of the important investigated factors influencing the formation of photosynthetic plant productivity.

The purpose of the research is to determine the photosynthetic productivity of miscanthus, depending on the dates of planting rhizomes, as raw materials for biofuel production in the conditions of the Forest Steppe of Ukraine.

Materials and Methods

The researches were conducted in 2017-2019 in the conditions of Scientific and Production Center of BilaTerkva National Agrarian University (zone of unstable moistening). The soil of the study area is typical chernozem. Agrochemical characteristics of the soil: humus content is 2.7-3.2%, nitrogen - 90-120 mg/kg, mobile phosphorus - 130-160 mg/kg and exchangeable potassium - 120-130 mg/kg. The climate of the region is moderate continental with average precipitation 538 mm, average annual temperature 8°C, average annual relative humidity about 77%.

The experiment studied different terms of planting rhizomes (in the first decade of April - soil temperature at a depth of 5 cm was 4-6°C; in the second decade of April soil temperature was 7-9°C; the third decade of April - soil temperature - 10-12°C; the first decade of May - the soil temperature 13-15°C).

The experiment was based on the method of systematic repetitions: in each repetition, the variants of the experiment were placed on the plots sequentially. Repetitions of the experiment are four times. Phosphorus-potassium fertilizers (background) were applied during the autumn plowing, nitrogen fertilizers were applied in the spring. Planting of rhizomes weighing 30-60 g was carried out to a depth of 6-10 cm with a row spacing of 70 cm. The area of the plot is 50 m^2, accounting area - 25 m^2.

Field studies were conducted using conventional and special agronomic methods. The dynamics of increment of leaf surface area was determined by the method of "cutting" for field researches. The net productivity of photosynthesis of miscanthus plants was determined by the method of A.A. Nichiporovich. The yield of dry leaf and stem mass was determined by continuous mowing, weighing and counting per unit area.

Results and Discussion

The formation of the photosynthetic apparatus of

Fig. 1: Miscanthus in the experiment.

Table 1: Dynamics of growth of leaf surface area depending on the dates of planting rhizomes, thousand m^2/ha (average for 2017-2019).

Planting time	Date of accounting				
	June	July	August	September	October
I decade of April	0.22	1.30	2.70	4.78	3.15
II decade of April	0.27	1.41	3.26	5.67	3.75
III decade of April	0.19	1.10	2.44	4.28	3.03
I decade of May	0.11	0.49	1.95	3.01	2.21

plants is a complex process. As a result of consistent formation, leaves of different ages are formed on the plant: newly formed, young growing, adult productive leaves and dying old leaves.

In the early stages of plant growth and development, the processes of leaf growth predominate, in the later stages – the processes of dying associated with enhanced nutrient transport from the dying leaves to the storage and reproductive organs.

Miscanthus refers to light-loving crops (Fig. 1). It uses much more solar power than other plants of the cereal family.

Miscanthus requires intense sunlight during the growing season to form the optimum leaf area and accumulate sufficient organic matter. Under insufficient light, plants are getting long and yellow and their photosynthesis intensity and number of assimilants are significantly reduced (Kvak, 2014). One of the main conditions for the high productivity of miscanthus is the intensity of absorption and use of solar radiation by leaves. To enhance the photosynthetic activity of miscanthus plants, it is important to keep the plants warm and moist.

The results of studies have shown that during the growing season up to 18-20 leaves can be formed in miscanthus plants. At different dates of planting rhizomes, the area of the leaf surface of the plants changed during the growing season (Table 1).

On average, during the years of research, the maximum leaf surface area (5.67 thousand m^2/ha) of miscanthus plants was formed in September for planting rhizomes in the second decade of April. At an earlier and later date, the area of leaf surface area was smaller and accordingly amounted to 4.78 thousand m^2/ha, 4.28 and 3.01 thousand m^2/ha.

It should be noted that in all variants of the experiment there is an increase in leaf surface from June to September, where the area of leaf surface reaches a maximum. After this their drying and dying occurs, which leads to a decrease in this indicator.

The most important process in plant life is the process of photosynthesis. As it goes, the growth and development of the plants and their final productivity depends. By changing the dates of planting, you can adjust the photosynthetic potential of plants and the amount of used photosynthetically active radiation. The size and spatial structure of the leaves depends on the amount of light energy absorbed by the plantations, the intensity of organic matter production and the total transpiration. Therefore, the productivity of photosynthesis in plants is determined by two main indicators – the total area of leaves (assimilating surface) and the intensity of photosynthetic processes per unit area of leaves.

Analyzing the net productivity of photosynthesis of miscanthus plants, we observe that its intensity during the growing season initially increased and then decreased (Table 2). Since the planting rhizomes in the II decade of April, net productivity of miscanthus was the highest in the experiment at all stages of plant growth and development.

In June, for all sowing periods, the net productivity of photosynthesis was the lowest and was in the range of 0.40… 1.12 g/m^2 per day, in July respectively 2.90… 4.23 g/m^2 per day, in August - 4.13 … 5.81 g/m^2 per day. In September, the maximum values 5.23… 6.81 g/m^2 per day were obtained. However, in October the net productivity of photosynthesis declines and fluctuates from 4.01 to 5.78 g/m^2 per day, depending on the dates of planting rhizomes.

This is due to the fact that at the beginning of the growing season miscanthus plants have a poorly developed assimilation apparatus, so photosynthetic productivity is low. However, in September it reaches its maximum and in October it is reduced by the dying of the lower leaves.

Table 2: Net productivity of photosynthesis of miscanthus plants, depending on the dates of planting rhizomes, g/m^2 per day (average for 2017–2019).

Planting time	Date of accounting				
	June	June	June	June	June
I decade of April	1.07	3.10	4.53	6.15	5.48
II decade of April	1.12	4.23	5.81	6.81	5.78
III decade of April	0.93	2.94	4.40	5.98	4.43
I decade of May	0.40	2.90	4.13	5.23	4.01

It should be noted that the increase in the net productivity of photosynthesis in miscanthus was facilitated by earlier dates of planting rhizomes. In September, for the first and second planting period, net productivity was 6.15 and 6.81 g/m^2 per day, respectively, for the third and fourth planting periods, 4.43 and 4.01 g/m^2, respectively, due to the increase in the growing season. At late planting times, the plants reduced the length of the growing season, developed a smaller leaf apparatus and quickly transitioned to the reproductive phase.

Early rhizomes' planting allows plants to make better use of light, moisture, which creates favorable soil and climatic conditions in the first half of the growing season. As a result, the productivity and quality of raw materials are increased.

The maximum yield of dry biomass of miscanthus plants is observed for planting rhizomes in the second decade of April and is 1.6 t ha^{-1} in the first year of vegetation, 9.5 t ha^{-1} in the second vegetation year and 15.3 t ha^{-1} in the third year (Fig. 2).

For planting rhizomes in the first decade of April, the yield was slightly lower and amounted to 1.4 t ha^{-1} in the first year, 8.9 t ha^{-1} in the second and 14.1 t ha^{-1} in the third year of vegetation.

The dry mass yield for planting rhizomes of miscanthus in the third decade of April and the first decade of May was lower than the yield, obtained during the optimal planting period (second decade of April).

In line with the increase in biomass yields, the output of biofuels and energy per unit area increased (Fig. 3).

The output of biofuels in the first year of vegetation was very low and depending on the dates of planting rhizomes of miscanthus was 1.1-1.76 t ha^{-1}. In the second year of the growing season, the estimated output of solid fuel was slightly higher and ranged from 8.69 t ha^{-1} in the late term to 10.45 t ha^{-1} in the second planting period. The highest output of biofuels was observed in the third year of vegetation throughout the experiment, but in the second term it was maximum equal to 16.83 t ha^{-1}.

The highest energy output 286.11 GJ ha^{-1} from the biomass of the third year of vegetation was obtained during the second period (II decade of April) of planting rhizomes (Fig. 4). For planting rhizomes in the first and third decades of April, as well as in the first decade of May, the energy output decreased accordanly to 263.67 and 258.06GJ ha^{-1}, as well as to 237.49 GJ ha^{-1}.

Although final yield of crops depends on the amount of photosynthesis achieved during the growing season, studies which have focused on rates of single leaf photosynthesis have not been successful in the identification of more productive genotypes of crop plants to be used in the field (Lawlor, 1995).

Leaves must expand to intercept radiation for photosynthesis and it is possible that the rate of leaf growth is more important as a selective characteristic than photosynthesis when trying to evaluate the potential production of different genotypes. Indeed, it has been suggested that, in temperate climates, temperature is likely to limit leaf growth of field crops to a

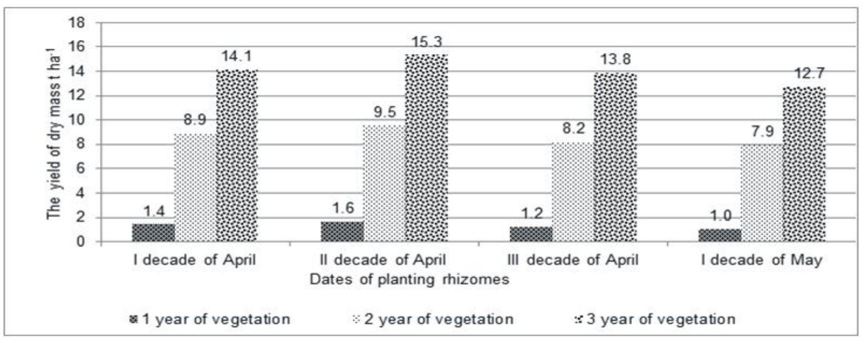

Fig. 2: The yield of dry mass miscanthus depending on the dates of planting rhizomes, t ha^{-1} (average for 2017-2019).

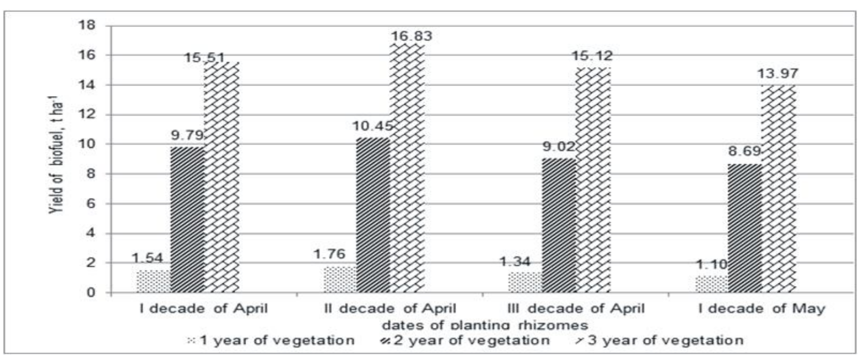

Fig. 3: The output of solid biofuels, depending on the dates of planting rhizomes, t ha^{-1} (average for 2017-2019).

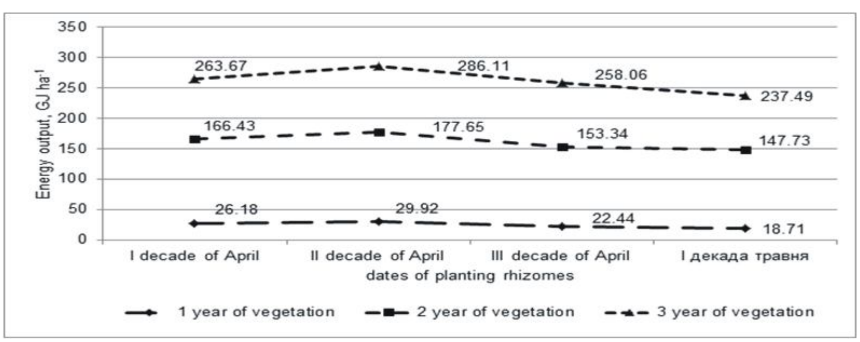

Fig. 4: Energy output depending on the dates of planting rhizomes, GJ ha^{-1} (average for 2017-2019).

greater extent than it limits photosynthesis (Monteith and Elston, 1972).

Zub *et al*. (2012) in their studies indicate that more developed plants (6 or 7-leaf stage) were less frost tolerant than those at the 3 or 5-leaf stage. The leaf-stage of the plant is linked to apex height and this appeared to play a role in frost tolerance. Moreover, the differences in frost tolerance were negatively correlated (r = -0.94) with the mean leaf surface area of clones at the time of frost exposure.Therefore, the study of the elements of growing technology is promising and needs further research.

Conclusions

Thus, it has been established that the dates of planting rhizomes of miscanthus influences the formation of the assimilation surface of the leaves, the net productivity of photosynthesis and the yield of dry biomass.

The highest rates of photosynthetic activity of the miscanthus leaf apparatus were obtained by planting rhizomes in the second decade of April. The maximum leaf surface area 5.67 thousand m^2/ha of plants was formed in September. It was determined that miscanthus plants formed the highest net productivity of photosynthesis - 6.81 g/m^2 per day during the same planting period.

The maximum yield of dry biomass of miscanthus plants is observed for planting rhizomes in the second decade of April and for the third year of vegetation is 15.3 tha^{-1}. Accordingly, the estimated output of solid biofuels (16.83 tha^{-1}) and energy (286.11 GJ ha^{-1}) were the highest. Therefore, this period of miscanthus planting is optimal and recommended in the zone of the Forest Steppe of Ukraine.

References

Beale, C.V., D.A. Bint and S.P. Long (1996). Leaf photosynthesis in the C4 grass Miscanthusgiganteus, growing in the cool temperate climate of southern England. *Journal of Experimental Botany,* **47:** 267-273.

Beale, C.V. and S.P. Long (1995). Can perennial C4 grasses attain high efficiencies of radiant energy conversion in cool climates? *Plant, Cell and Environment*, **18:** 641-650.

Clifton-Brown, J.C, P.F. Stampfl and M.B. Jones (2004). Miscanthus biomass production for energy in Europe and its potential contribution to decreasing fossil fuel carbon emissions. *Global Change Biology,* **10:** 509-518.

Clifton-Brown, J.C., J. Breuer and M.B. Jones (2007). Carbon mitigation by the energy crop Miscanthus. *Global Change Biology,* **13:** 2296-2307.

Daraban,A.E. (Oros), Jurcoane, Ş., I. Voicea and G. Voicu (2015). *MiscanthusGiganteus* Biomass for Sustainable Energy in Small Scale Heating Systems. *Agriculture and Agricultural Science Procedia,* **6:** 538-544.

Frühwirth, P., P. Liebhard and A. Graf (2005). Miscanthus sinensis Giganteus. Produktion, Inhaltsstoffe und Verwertung, *Oberösterreich*, **232**.

Goetz, M.R., A. Francesco, A. Barker, D. Costomiris and A. Qi (2016). Assessing on-farm productivity of Miscanthus crops by combining soil mapping, yield modelling and remote sensing. *Biomass and Bioenergy,* **85:** 252-261.

Jurişi, V., N. Bilandžija and T. Krika *et al.* (2014). Fuel Properties Comparison of Allochthonous Miscanthusxgiganteus and *Autochthonous Arundodonax* L., a Study Casein Croatia. *Agriculturae Conspectus Scientificus,* **79(1):** 7-11.

Karp, A. and I. Shield (2008). Bioenergy from plants and the sustainable yield challenge. *New Phytologist,* **179:** 15-32.

Krol, D.J., M.B. Jones, M. Williams, Ó. Ní. Choncubhair, G.J. Lanigan (2019). The effect of land use change from grassland to bioenergy crops Miscanthus and reed canary grass on nitrous oxide emissions. *Biomass and Bioenergy,* **120:** 396-403.

Kvak, V.M. (2014). Optimization of the elements of the technology of growing of the miscanthus for the production of biofuels in the western part of the forest-steppe Ukraine. Kyiv, 213.

Lawlor, D.W. (1995). Photosynthesis, productivity and environment. *Journal of Experimental Botany,* **46:** 1449-1461.

Maleski, J.J., D.D. Bosch, R.G. Anderson, A.W. Coffin, W.F. Anderson and T.C. Strickl (2019). Evaluation of miscanthus productivity and water use efficiency in southeastern United States. *Science of The Total Environment,* **692:** 1125-1134.

Mitchell, J.L.B., M. Halter, C.N. Jr. Stewart and E.T. Nilsen (2014). Cool temperature effects on photosynthetic parameters of two biomass fuel feedstocks in a low light intensity environment: low light intensity alters the significance of cold tolerance to productivity in cool climates. *Biofuels,* **5:** 533-544.

Monteith, J.L. and J. Elston (1972). Micrometeorology and crop production. In: Wareing PF, Cooper JP, eds. Potential crop production: a case study, London, Heinemann, 23-42.

Morandi, F., A. Perrin and H. Østergård (2019). Miscanthus as energy crop: Environmental assessment of a miscanthus biomass production case study in France. *Journal of Cleaner Production,* **137:** 313-321.

Moritz, C., A. Mangold, Y. Iqbal, J. Hartung, I. Lewandowski and A. Kiesel (2019). How to Generate Yield in the First Year-A Three-Year Experiment on Miscanthus (*Miscanthus × giganteus* (*Greefet Deuter*)) Establishment under Maize (*Zea mays* L.). *Agronomy,* **9(5):** 237.

Naidu, S.L., S.P. Moose, A.K. Al-Shoaibi, C.A. Raines and S.P. Long (2003). Cold tolerance of C4 photosynthesis in

Miscanthusgiganteus: adaptation in amounts and sequence of C4 photosynthetic enzymes. *Plant Physiology,* **132:** 1688-1697.

Oliver, R.J., J.W. Finch and G. Taylor (2009). Second generation bioenergy crops and climate change: a review of the effects of elevated atmospheric CO_2 and drought on water use and the implications for yield. *Global Change Biology Bioenergy,* **1:** 97-114.

Pidlisnyuk, V., T. Stefanovska, E.E. Lewis, L.E. Erickson and L.C. Davis (2014). Miscanthus as a Productive Biofuel Crop for Phytoremediation. *Critical Reviews in Plant Sciences,* **33(1):** 1-19. https://doi.org/10.1080/07352689.2014.847616.

Popp, J., Z. Lakner, M. Harangi-Rakos and M. Fari (2014). The effect of bioenergy expansion: food, energy and environment. *Renewable and Sustainable Energy Reviews,* **32:** 559-578.

Roik, M.V. and V.M. Sinchenko (2019). MiscanthusinUkraine, Êyiv, 256.

Szulczewski, W., A. Żyromski, W. Jakubowski and M. Biniak-Pieróg (2018). A new method for the estimation of biomass yield of giant miscanthus (*Miscanthusgiganteus*) in the course of vegetation. *Renewable and Sustainable Energy Reviews,* **82(2):** 1787-1795.

Tomi, F., T. Kricka, S. Matic and I. Simunic (2011). Potentials for biofuel production in Croatia, with respect to the provisions set out by the European Union. *Journal Environ Protect Ecol.,* **12(3):** 1121-1131.

Wang, D., A.R. Portis, S.P. Moose and S.P. Long (2008). Cool C4 photosynthesis: Pyruvate Pi dikinase expression and activity corresponds to the exceptional cold tolerance of carbon assimilation in Miscanthusgiganteus. *Plant Physiology,* **148:** 557-567.

Wang, D., L.N. Shawna, R.P. Archie, P.M. Stephen and P.L. Stephen (2008). Can the cold tolerance of C_4 photosynthesis in *Miscanthus×giganteus* relative to *Zea mays* be explained by differences in activities and thermal properties of Rubisco? *Journal of Experimental Botany,* **59(7):** 1779-1787.

Yan, J., W. Chen, F. Luo, H. Ma, A. Meng, X. Li, M. Zhu, S. Li, H. Zhou and W. Zhu (2011) Variability and adaptability of Miscanthus species evaluated for energy crop domestication . *GCB Bioenergy,* **4:** 49-60.

Zhang, X. and X. Cai (2011). Climate change impacts on global agricultural land availability. *Environmental Research Letters,* **6:** 123-126.

Zinchenko, V. O. (2008) Miskantus – dzhereloenerhetych-noibiomasy [Miskanthus - the source of energy biomass]. *News of the Agricultural Technology,* **3(63):** 40-41.

Zub, H.W., S. Arnoult, J. Younous, I. Lejeune-Hénaut and M. Brancourt-Hulmel (2012). Differences between clones are influenced by leaf-stage and acclimation. *European Journal of Agronomy,* **36(1):** 32-40.