Journal of Agricultural Science; Vol. 5, No. 12; 2013
ISSN 1916-9752 E-ISSN 1916-9760
Published by Canadian Center of Science and Education

Economic Efficiency of Different Agricultural Practices of "*Panicum virgatum* L. (switchgrass)" for Fodder Production

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Received: September 22, 2013 Accepted: October 8, 2013 Online Published: November 15, 2013
doi:10.5539/jas.v5n12p132 URL: http://dx.doi.org/10.5539/jas.v5n12p132

Abstract

Switchgrass is a multipurpose perennial crop characterized by high yield (for fodder or raw material for pellet production) under low inputs conditions. This study sought to analyse the economic efficiency of different cultivating practices of switchgrass for hay or silage production. To assess the economic efficiency, three-year field experiments were established in two contrasting environments in central Greece (Palamas and Velestino) and contained two experimental factors: quantity of irrigation water (two levels: 0 and 250 mm) and applied nitrogen fertilization (four levels: 0, 80, 160 and 240 kg N ha^{-1}). Moreover, the costs of four different harvest methods (three different types of straw-bales for hay production and silage) were taken into account. The results demonstrated that production cost is largely depended on the harvesting practice. In addition, an attractive income of 1,745 €/ha (the higher one at Palamas site) for fodder production was found. The efficiency scores follow the same tendency at both sites, verifying that there is no necessity of high levels of nitrogen fertilization in order to improve switchgrass production efficiency. These data suggest that switchgrass is attractive as a fodder crop in regions with high precipitation or in areas with a moderately shallow groundwater table and should be seriously taken into consideration for future land use systems in Greece and more generally in the Mediterranean basin.

Keywords: switchgrass, economic efficiency, fodder, costs, profit, data development analysis

1. Introduction

The last two decades there is a worldwide interest on renewable energy sources and especially on biomass production. The use of bio-energy through biomass production from perennial crops may reduce the greenhouse gases emissions (Lychnaras & Schneider, 2007). Moreover, it has been already worldwide accepted that the perennial ones produce high yields, while sinking large amounts of carbon into the soil (Tolbert et al., 2002; Liebig et al., 2005; Ma et al., 2000).

The perennial energy crops have received higher attention, due to their high productivity, and their low requirements (Keshwani, & Cheng, 2009) in water (Tolbert & Wright, 1998) and nutrients (P. Venturi & G. Venturi, 2003). There are many environmental benefits associated with their cultivation; due to their perennial nature, where the cultivation practices like harrowing, plowing etc., take place only once at the establishment year, preventing soil degradation during the following subsequent years (Ma et al., 2000; McLaughlin et al., 1999; Vaughan et al., 1989; Kort et al., 1998; McKendry, 2002).

One of these perennial crops is switchgrass "*Panicum virgatum* L." which is known since the last century. Switchgrass is a plant with high adaptability in almost all soil types and is classified in two ecotypes: i) lowland and ii) upland, depending on latitude (Casler et al., 2007). Except of providing reliable energy, switchgrass also binds C in soil (Ma et al., 2000; Liebig et al. 2005; Skinner & Adler, 2010).

Switchgrass is a perennial crop with height range from 1.5 to 2.5 m under favorable climatic conditions in Europe (Piscioneri et al., 2001; Lemus et al., 2002; Alexopoulou et al., 2008). Switchgrass develops a deep root system which exceeds a depth of 3 m (Liebig et al., 2005). The main growing factor is the air temperature (Madakadze et al., 1998) with the 10 ^{o}C being the basic growth temperature (Sanderson & Wolf, 1995). The agricultural practices depend on the specific soil and climatic conditions of the area, which also define the variety choice (Fike et al., 2006).

Switchgrass is a promising cultivation due to its high value-added use, high production yield, low input requirements and a number of positive environmental impacts (Keshwani & Cheng, 2009). There are many uses of switchgrass, such as grazing, protection from soil erosion, habitat for wildlife, but also as feed. It is rich in cellulose, thus making it attractive as a source for cellulosic ethanol (Schmer et al., 2006). Switchgrass is a nutritious and tasty food for most animals, especially for cattle (mainly used for grazing, but also for hay production) (Kansas State University, 2011). The quality of the feed is as similar as most grasses and mainly depends on crop maturity (Ball et al., 2011).

The choice of switchgrass both as fodder for cattle and as biomass for energy production could offer an attractive income for farmers and breeders, as the livestock farming is serving the backbone of Greek economy, but also each rural country like Greece. Flexibility in the use of switchgrass cultivation (due to its multipurpose uses) could also provide an incentive to adopt the production as a new rural-exploitation enterprise (Fox et al., 1999; Aravindhakshan et al., 2010; Guretzky et al., 2010).

The factors that influence (individually or through interaction) the economics of switchgrass cultivation are many (Sladden et al., 1991). Few of these factors are the establishment cost which defers from region to region, the annual input requirements (water and nutrients) (Smeets et al., 2009; Khanna et al., 2008), the soil-climatic conditions which affect the harvested yield (Monti et al., 2001) and the final product price (Fike et al., 2006; Eldersen et al., 2004).

Few data are reported about the economic performance of switchgrass in Europe and only few studies in North America are published, showing switchgrass having low cost per dry tone of biomass (Hallam et al., 2001; Downing & Graham, 1996; Hanegraaf et al., 1998). There are reported different market prices but all of them are for dry biomass for solid biofuels (McLaughlin & Kszos, 2005; Hallam et al., 2001; Fox et al., 1999) and not for fodder production.

Nowadays, switchgrass is grown in Greece on experimental basis for solid biofuels and fodder production. There are no data on switchgrass cultivation costs in Greece. Considering that any assessment of land use performance needs to quantify the biophysical production potential, followed by analysis of productivity at hierarchically lower levels of inputs and management practices. The objective of this paper is to report the production costs and to find out the harvesting system which gets switchgrass cultivation economically viable in Greece and in Mediterranean region for fodder production generaly.

2. Method

2.1 Experimental Design

A three-year (2010, 2011, 2012) field experiments were conducted at two different soil-climatic environments in eastern and western Thessaly plain, central Greece as to be able to evaluate the economic efficiency of switchgrass cultivation for fodder production. The first experimental site is Palamas with soil characterized as a deep, calcareous (pH = 8.3), sandy loam to loam (sand 37-45%, loam 51-43%, clay 12%), with soil organic matter content of 0.9% at a depth of 40 cm. The soil in Palamas site is characterized by a moderately shallow groundwater table, due to the surface irrigation networks (irrigation canals) of the territory. The second experiment carried out in Velestino with soil characterized as a calcareous (pH = 8.1-8.3), clay loam to clay (sand 19-21%, loam 39-41%, clay 38-42%), with soil organic matter content of 2.3-2.7% at a depth of 40 cm. An underground pumping irrigation network is used in this territory (east Thessaly plain), which indicates a deep groundwater table.

The tested switchgrass variety was Alamo (lowland ecotype supplied from Colorado USA) at both sites, and the applied seed quantity was 7 kg ha^{-1} using a modern cereal seeding machine, in a row-distance of 12.5 cm. The experimental design was a randomized split-plot with four replications and eight plots per replication (8 x 4 = 32 plots). Plot size was 48 m^{2} (6 m width x 8 m length).

2.2 Economic Parameters

The tested factors were two different irrigation levels (I1 = 0 mm, I2 = 250 mm), and four different N-fertilization levels (N1 = 0, N2 = 80, N3 = 160, and N4 = 240 kg N ha$^{−1}$). Moreover, the costs of four different harvesting methods were measured (3 different straw-bales and silage); while the effect of the selected area was also taken into consideration due to the different crop yield and the variation of costs.

The economic costs of switchgrass were divided in two categories: i) Fixed costs, and ii) Variable costs. Fixed costs conclude depreciation, insurance for fodder production, invested capital interest, land rent and maintenance. Variable costs due to the perennial nature of switchrgrass cultivation were divided in two sub-categories: a) establishment costs, and b) annual cultivation costs. As establishment costs were calculated the plowing, cheelering, harrowing, sowing, herbicide application, seeds and labour costs for the preparation of the above practices (€/hour multiplied with the sum of the needed hours per hectare). These costs were divided for 10 years (switchgrass life cycle). Annual cultivation costs include irrigation, fertilization, labour for annual practices and harvesting costs which depend on the kind of practice (€/bale for hay or €/ha for silage).

Furthermore, to calculate economic returns (per hectare) from switchgrass cultivation; existing market prices (from fodder crops prices-alfalfa hay 0.17-0.18 € kg^{-1} and silage 0.039-0.044 € kg^{-1}, during 2011-12) were considered. The economic analysis is for the 2nd and 3rd growing years (2011 and 2012). Finally, sensitivity analysis was used to estimate the effect of product price to crop income benefits for the most viable case of switchgrass cultivation.

2.3 Methods of Economic Assessment

Efficiency and performance are a core concept of economics research. The relationship between them will be analyzed under the non-parametric method of Data Envelopment Analysis (DEA), based on a finite sample of observed production units, which uses a linear programming method and does not need to estimate a pre-established functional form. It follows the Farrell approach (1957) and was proposed in 1978 by Charnes, Cooper and Rhodes. The advantage of DEA is its flexibility and the possibility of using it for different scenario analysis.

In this paper the input-oriented envelopment model is applied assuming Constant Return to Scale (CRS) as well as Variable Returns to Scale (VRS). In CRS model the measure of global technical efficiency may be obtained by comparing large scale units with small scale units and vice versa. VRS model allows for variations in returns to scale. In this case an additional constraint is necessary that ensures the evaluation of pure technical efficiency regardless of issues of scale. Input oriented models try to maximize the proportional decrease in input variables, while output oriented ones will maximize the proportional increase in the output vector. The choice of one model or the other is based on the characteristics of the dataset analyzed. Every cultivating method is being assessed is named Decision Making Unit (DMU) when this methodology is being applied. The CRS DEA model assumes that the DMUs are operating at an optimal scale. This model permits a measure of global technical efficiency to be obtained without variations in returns to scale. In the real world, however, this optimal behaviour is often precluded by some factors such as imperfect competition, constraints, finance, etc. To take this circumstance into account, Banker, Charnes and Cooper (1984) have extended DEA to the case of variable returns to scale (VRS). This model distinguishes between pure technical efficiency and scale efficiency (SE), identifying if increasing, decreasing or constant returns to scale are present. The implementation of both methodologies provides the prospect of comparing efficiency scores of different cultivation practices under dissimilar levels of competition. Increased similarity of efficiency scores signifies high levels of competitiveness, while noteworthy differences provide considerable hints for low competitiveness globally.

The following equations are calculated in order to measure the technical efficiency of switchgrass cultivation:

CRS Model

$$\min \theta - \varepsilon \left(\sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+ \right) \quad (1)$$

Subject to

$$\sum_{j=1}^{n} \lambda_j \chi_{ij} + s_i^- = \theta x_{io}, \ i=1,2,\ldots,m \quad (2)$$

$$\sum_{j=1}^{n} \lambda_j y_{rj} - s_r^+ = y_{ro}, \ r=1,2,\ldots,s \quad (3)$$

$$\lambda_j \geq 0\ ,\ j=1,2,\ldots,n \tag{4}$$

VRS Model Add

$$\Sigma_{j-1}^{n} \lambda_j = 1 \tag{5}$$

where j is the number of observations of the DMUs. Each observation DMU_j (j=1, 2, …, n), uses m inputs x_{ij} (i=1, 2, …, m) to produce s outputs y_{rj} (r=1, 2, …, s). The efficient frontier is determined by these n observations. There are two properties to ensure that a piecewise linear approximation has been developed to the efficient frontier and the area dominated by the frontier. $\sum_{j=1}^{n} \lambda_j \chi_{ij}$ (i=1, 2, …, m) and $\sum_{j=1}^{n} \lambda_j y_{rj}$ (r=1, 2, …, s) are possible inputs and outputs achievable by the DMU_j, where λ_j (j=1, 2, …, n) are nonnegative scalars that $\Sigma_{j=1}^{n} \lambda_j = 1$. The same y_{rj} can be obtained by using $\hat{x}_{ij}$, where $\hat{x}_{ij} \geq x_{ij}$ and the same x_{ij} can be used to obtain $\hat{y}_{ij}$, where $\hat{y}_{ij} \geq y_{ij}$.

3. Results

3.1 Yield

Palamas site is characterized by a moderately shallow groundwater table, and is classified as Aquic Xerofluvent according to USDA (1975). It was observed that switchgrass reaches full production at the 2nd year after establishment.

Table 1. Irrigation and fertilization effect on switchgrass harvest yield (t ha^{-1}) for fodder production (silage)

	Palamas		**Velestino**	
	2nd Year	**3rd Year**	**2nd Year**	**3rd Year**
Irrigation levels				
Rainfed	48.6	51.1	15.4	20.94^a
Irrigated (250 mm)	50.6	50.8	20.4	29.56^b
$LSD_{0.05}$	ns	ns	ns	8.363
Fertilization levels (kg N ha^{-1}**)**				
0	46.4	44.3	15.0	27.71
80	45.1	53.5	19.4	23.53
160	53.6	54.4	21.6	23.58
240	52.8	51.8	15.6	25.78
$LSD_{0.05}$	ns	ns	ns	ns

*LSD: least significant difference at P<0.05, **ns: not significant, *** a, b: Duncan criterion, 2nd year: 2011 and 3rd Year: 2012.

Table 1 shows the significant differences (P>0.05) that were found among irrigation levels and N-fertilization levels in the case of silage harvesting method. It was found that switchgrass yield for silage production (65% moisture content) was significantly affected (P<0.05) by irrigation level (Table 1) only at Velestino site during the 3rd year of establishment. Moreover, switchgrass yield for silage was not influenced by N-fertilization (P<0.05). The higher yield of 54.4 t ha^{-1} was recorded for the N-fertilized plots with 160 kg N ha^{-1} at Palamas experimental site during the 3rd year of establishment.

Harvesting method of bales (15% moisture content) shown that there were not significant differences among irrigation and N-fertilization levels (Table 2). It was found that switchgrass yield for hay production was higher (21.9 t ha^{-1}) on fertilized plots with 160 kg N ha^{-1} at Palamas experimental site during the 3rd year of establishment.

Table 2. Irrigation and fertilization effect on switchgrass harvest yield (t ha^{-1}) for fodder production (hay bale)

	Palamas		Velestino	
	2nd Year	**3rd Year**	**2nd Year**	**3rd Year**
Irrigation levels				
Rainfed	18.3	21.1	7.0	11.0
Irrigated (250 mm)	19.2	20.1	8.8	13.3
$LSD_{0.05}$	ns	ns	ns	ns
Fertilization levels (kg N ha^{-1}**)**				
0	18.1	18.0	6.5	12.9
80	17.5	21.4	9.0	11.8
160	20.0	21.9	9.4	11.3
240	19.4	21.1	6.7	12.6
$LSD_{0.05}$	ns	ns	ns	ns

*LSD: least significant difference at P<0.05, **ns: not significant, 2nd year: 2011 and 3rd Year: 2012.

Table 3. Switchgrass cultivation costs

€/ha	**Palamas**	**Velestino**
Fixed Costs		
Depreciation	200	200
Insurance	68	68
Invested Capital Interest	267.4	267.4
Land Rent	700	700
Maintenance	6	6
Total	1241.4	1241.4
Variable Costs		
Establishment costs		
Plowing	90	70
Cheelering	40	20
Harrowing	60	40
Sowing Machine	20	20
Herbicide application	20	20
Seeds	462	462
Labour	59.2	59.2
Total	751.2	691.2
Annual Costs		
Establishment*	75.12	69.12

* Establishment costs are divided with 10 years which are the minimum years that switchgrass cultivation re-grows.

3.2 Production Costs

Table 4. Switchgrass variation cultivation costs due to area and annual yield

€/ha	Palamas		Velestino		Palamas		Velestino		Palamas		Velestino		Palamas		Velestino	
	Year				Year				Year				Year			
	2nd	3rd	2nd	3rd	2nd	3rd	2nd	3rd	2nd	3rd	2nd	3rd	2nd	3rd	2nd	3rd
	22kg Bales				250kg Round-Bales				Silage				250kg Square-Bales			
Establishment*	75		69		75		69		75		69		75		69	
Labour																
I1N1	11				11				0				11			
I1N2-I1N3-I1N4	13				13				2				13			
I2N1	15				15				4				15			
I2N2-I2N3-I2N4	17				17				6				17			
Irrigation																
I1	0		0		0		0		0		0		0		0	
I2	40		60		40		60		40		60		40		60	
Fertilization																
N1	0		0		0		0		0		0		0		0	
N2	128		123		128		123		128		123		128		123	
N3	241		236		241		236		241		236		241		236	
N4	354		349		354		349		354		349		354		349	
Harvest																
I1N1	377	404	163	310	331	355	102	193	300	300	280	280	331	355	102	193
I1N2	357	484	210	292	315	426	131	182					315	426	131	182
I1N3	463	504	224	307	407	444	140	191					407	444	140	191
I1N4	471	526	170	294	415	462	106	183					415	462	106	183
I2N1	446	415	194	394	393	366	121	245					393	366	121	245
I2N2	439	395	282	352	387	348	175	219					387	348	175	219
I2N3	448	493	291	312	394	434	181	194					394	434	181	194
I2N4	411	434	196	391	362	382	122	244					362	382	122	244

* Establishment costs are divided with 10 years which are the minimum years that switchgrass cultivation re-grows, Irrigation: I1-0 mm, I2-250 mm, N-fertilization: N1-0, N2-80, N3-160, N4-240 kg N ha^{-1}.

Switchgrass cultivation costs are presented in Figure 1 and Tables 3, 4. Higher average production costs were reported in the case of small square bales of 22 kg, during the 3rd growing year in Palamas area. The required expenses for this case are 2,249 € ha^{-1}. On the other hand the case with the lower average production costs was the bales of 250 kg (round or square) during the 2nd (2011) growing year in Velestino area; where the yield was the lower, and the required expenses are 1,473 € ha^{-1}.

Farmers' profit from switchgrass cultivation for hay or silage production is illustrated in Figure 2. It is clearly shown that farmers' profit is almost positive in every case of hay at both sites when switchgrass is in full production. At Velestino site during the 2nd growing year (2011) farmer's profits are positive only for hay production in treatment of irrigated plots with 80 kg N ha^{-1}. The case of silage at Velestino site has negative values for farmer's income.

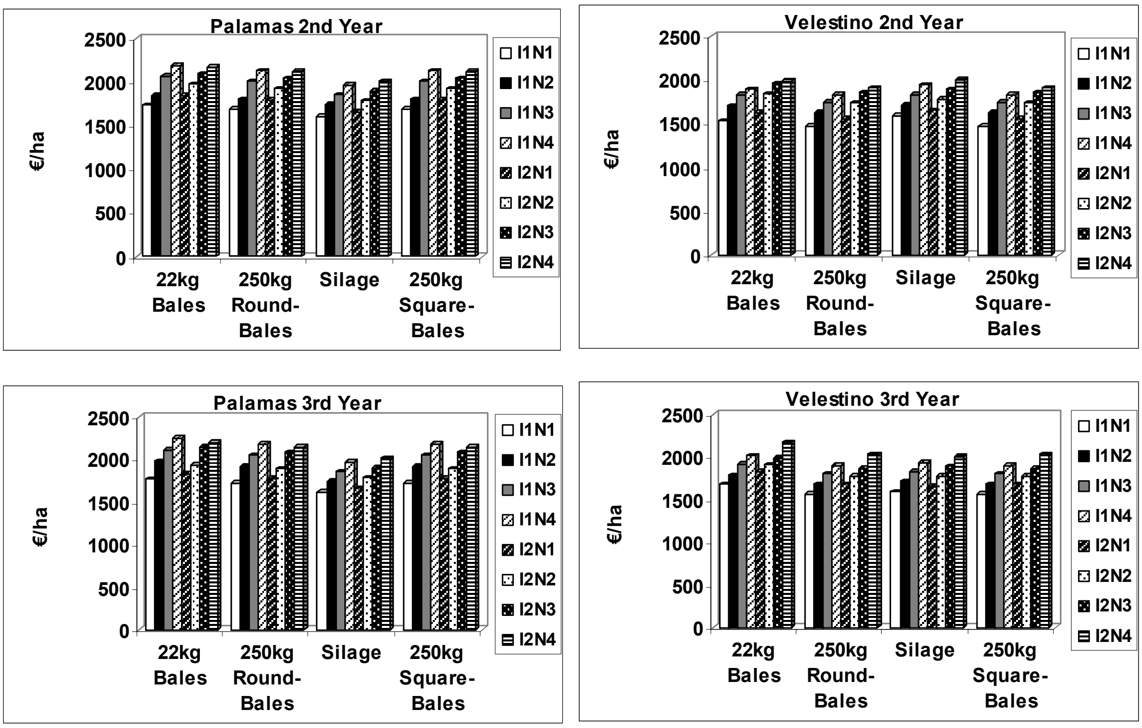

Figure 1. Switchgrass cultivating costs as observed at the study sites (Palamas and Velestino) during the 2nd and 3rd year of establishment as affected by 2 irrigation and 4 N-fertilization levels under 4 different harvesting managements

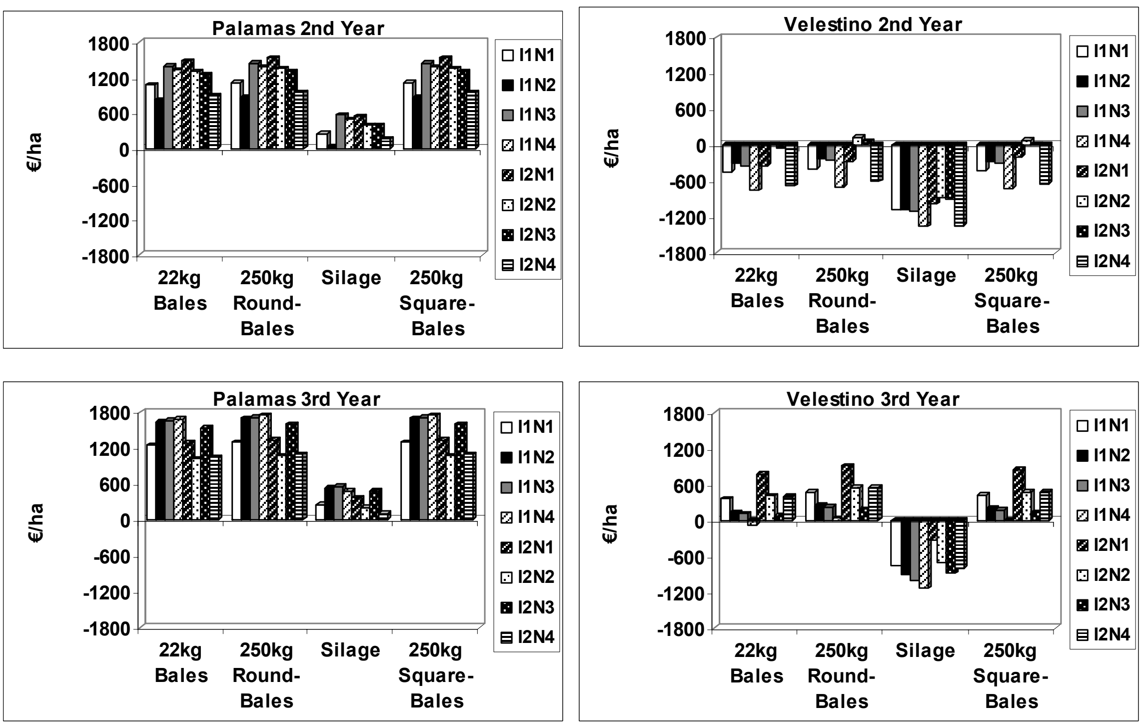

Figure 2. Farmer-profit from switchgrass cultivation as observed at the study sites (Palamas and Velestino) during the 2nd and 3rd year of establishment as affected by 2 irrigation and 4 N-fertilization levels, under 4 different harvesting managements

Silage can give an average profit of 350 € ha^{-1} at Palamas area while at Velestino area this amount is negative. On the other hand, in case of big hay-bales (square or round), average farmers' profit increased up to 1,443 and 398 € ha^{-1} at Palamas and Velestino, respectively.

Harvesting method of higher income is big hay bales at Palamas for non-irrigated and fertilized with 160 and 240 kg N ha^{-1}. These methods increase farmers' profit up to 1,745 € ha^{-1}. In this case, a reduction of about 45% on hay price is limited for switchgrass cultivation according to sensitivity analysis (Figure 3).

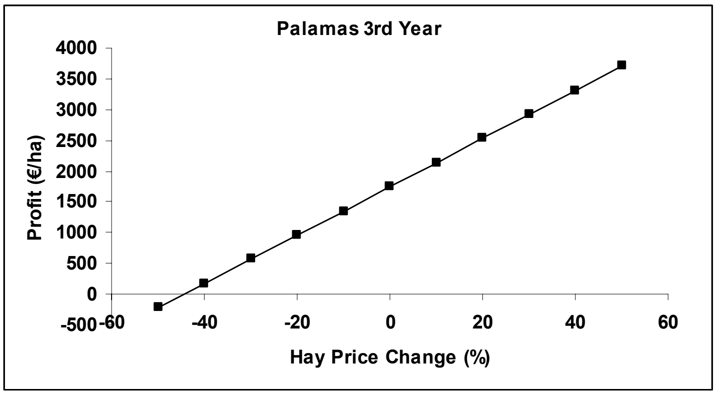

Figure 3. Effect of hay price change on farmer's profit in case of 250 kg bales

3.3 Data Envelopment Analysis (DEA)

As it has been already mentioned the production costs for different cultivating and harvesting methods were used as inputs. More specifically, the four inputs being used were the production costs when the switchgrass is being harvested by 250 kg round bale, 250 kg square bale, 22 kg small square bale, and silage. As outputs, were used the revenues being achieved for the four different cultivating and harvesting methods already mentioned. As DMUs, were used the 8 different combinations of irrigation and fertilization being applied in both Palama and Velestino site, having in total 16 DMUs. Two separate computations have been applied for the second and third year of the cultivation. The following table shows the efficiency scores for both the CRS and VRS methods

Table 6 shows the efficiency scores being achieved, when the two different DEA methods are being applied, with the CRS scores to be lower than the VRS ones. The most interesting issue is the significant decrease of efficiency scores when the nitrogen levels are being increased. In both cases of Palama and Velestino the efficiency scores follow the same tendency, verifying that there is no necessity of high levels of nitrogen fertilization in order switchgrass cultivation efficiency to be improved, as it shown in Table 8.

Table 5. Descriptive Statistics

	VRS	CRS
	2nd Year	
Mean	0.65999	0.59815
Standard Deviation	0.197647	0.181266
Min	0.37805	0.37622
Max	1	1
	3rd Year	
Mean	0.76329	0.64061
Standard Deviation	0.210331	0.209881
Min	0.40856	0.38063
Max	1	1

Table 6. CRS and VRS DEA Results

Cultivation sites	DMU Name	Input-Oriented VRS Efficiency	Input-Oriented CRS Efficiency
		2nd Year	
PALAMAS	I1N1	1.00000	0.93849
PALAMAS	I1N2	0.78294	0.68023
PALAMAS	I1N3	0.58810	0.53307
PALAMAS	I1N4	0.53029	0.43935
PALAMAS	I2N1	1.00000	0.70396
PALAMAS	I2N2	0.69522	0.54854
PALAMAS	I2N3	0.57244	0.44902
PALAMAS	I2N4	0.46974	0.37995
VELESTINO	I1N1	1.00000	1.00000
VELESTINO	I1N2	0.72535	0.71304
VELESTINO	I1N3	0.66987	0.66838
VELESTINO	I1N4	0.56185	0.56011
VELESTINO	I2N1	0.61609	0.61422
VELESTINO	I2N2	0.47413	0.47277
VELESTINO	I2N3	0.49575	0.49308
VELESTINO	I2N4	0.37805	0.37622
		3rd Year	
PALAMAS	I1N1	1.00000	0.93844
PALAMAS	I1N2	1.00000	0.68409
PALAMAS	I1N3	0.83122	0.53643
PALAMAS	I1N4	0.59987	0.43964
PALAMAS	I2N1	1.00000	0.70626
PALAMAS	I2N2	0.84921	0.55014
PALAMAS	I2N3	0.80242	0.45130
PALAMAS	I2N4	0.56348	0.38063
VELESTINO	I1N1	1.00000	1.00000
VELESTINO	I1N2	1.00000	1.00000
VELESTINO	I1N3	0.80147	0.80100
VELESTINO	I1N4	0.76154	0.75976
VELESTINO	I2N1	0.57974	0.57942
VELESTINO	I2N2	0.58335	0.58269
VELESTINO	I2N3	0.43176	0.43170
VELESTINO	I2N4	0.40856	0.40822

Irrigation: I1-0mm, I2-250mm, N-fertilization: N1-0, N2-80, N3-160, N4-240 kg N ha^{-1}.

Table 7. Efficiency Scores Means for different irrigation applications

	VRS	CRS
	2nd Year	
Palamas I1	0.725331	0.647784
Palamas I2	0.684349	0.520366
Velestino I1	0.739268	0.735381
Velelstino I2	0.491005	0.489074
	3rd Year	
Palamas I1	0.857772	0.649647
Palamas I2	0.803778	0.522082
Velestino I1	0.890752	0.890189
Velelstino I2	0.500854	0.500507

Irrigation: I1-0mm, I2-250mm.

Table 8. Efficiency Scores Means for different N-fertilization applications

	VRS	***CRS***
2nd Year		
Palamas N1	1	0.821225
Palamas N2	0.73908	0.614385
Palamas N3	0.58027	0.491045
Palamas N4	0.500015	0.40965
Velestino N1	0.808045	0.80711
Velestino N2	0.59974	0.592905
Velestino N3	0.58281	0.58073
Velestino N4	0.46995	0.468165
3rd Year		
Palamas N1	1	0.82235
Palamas N2	0.924605	0.617115
Palamas N3	0.81682	0.493865
Palamas N4	0.581675	0.410135
Velestino N1	0.78987	0.78971
Velestino N2	0.791675	0.791345
Velestino N3	0.616615	0.61635
Velestino N4	0.58505	0.58399

N-fertilization: N1-0, N2-80, N3-160, N4-240 kg N ha^{-1}.

In both cases of Palamas and Velestino regions, the efficiency values followed the same trend, indicating that low levels of nitrogen fertilization enhance the economic competitiveness of switchgrass cultivation. Table 5 presents the descriptive statistics of the efficiency scores of both methodologies. It is obvious that there is significant improvement of efficiency scores for both methodologies, between the second and the third year of the cultivation.

In order to realise if there are significant changes on efficiency scores between the two different irrigation applications, in Table 7 the descriptive statistics of the efficiency scores per irrigation method per cultivation year are presented. It is clear enough in both CRS and VRS methodologies there is a non significant decrease of scores for Palamas. On the contrary, the decrease of scores of the Velestino site is quite high, signifying that switchgrass cultivation for fodder production in regions with high irrigation costs should be avoided.

4. Discussion

Switchgrass is a perennial crop with high recorded yields (Lemus et al., 2002; Boyer et al., 2013). In this study it was expected that higher yields for hay production but also for silage (65% moisture) would be recorded at Palamas site due to the moderately shallow groundwater table from the territory. Therefore, it can be concluded that switchgrass cultivation can produce high yields under none or limited irrigated conditions only in soils as above or in regions of high precipitation.

Switchgrass as a perennial crop has increased establishment costs mostly depended on high seed price. This cost is not great if it will distribute to the crop life cycle. Therefore as it is shown, production costs are largely depended by harvesting practice. Hay-bales costs depend by biomass production. The costs of a small bale (22 kg) range from 0.5-0.6 €/bale and 4.25-5 €/bale for the big bales (250 kg). Therefore the case of the small bales have an increased harvesting cost of 3 € ton^{-1}.

Moreover, due to the fixed harvesting costs (280-300 € ha^{-1}), silage case is not viable for low yield productions like Velestino, in contrast to hay production which depends on final yield (€/bale). The harvesting practice of silage seems to be positive only for territories with a present moderately shallow groundwater table or areas of high precipitation where switchgrass cultivation scores high yields.

Switchgrass seems to be a promising alternative perennial crop for fodder production which could lead to an income of 1,745 €/ha. This profit is similar to alfalfa crop (1,700–1,900 €/ha) (Lony et al., 2008) but the advantage of switchgrass cultivation is that harvest period is once per year incontrast to alfalfa which has 4-5 harvests per year. Therefore, except the economical adavantges switcgrass has also environmental advantages due to less use of farming equipmnet.

Data Envelopment Analysis (DEA) showed that switchgrass cultivation does not require high amounts of nitrogen fertilization to increase its productivity. Similar attempts have as only outcome the decrease of efficiency and therefore should be avoid. Additionally, it is proved that higher efficiency can be achieved in areas with shallow moderate ground water table. The combination of these two findings is very important for both financial and environmental reasons. The adoption of this cultivation leads to satisfactory farmer income as well as low nitrogen inputs lead to satisfactory environmental protection of agricultural landscape.

In conclusion, switchgrass is a promising alternative perennial crop for fodder production, characterized by high biomass yield and an attractive income for farmers. It can be argued that switchgrass can exploit less fertile soils. Moreover, this crop has the advantage that can be also used for solid bio-fuel (pellets, briquettes) production and thus its introduction into future land use systems in Greece and Mediterranean basin more generally, should be seriously taken into consideration.

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