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Energy balance in crop-farming system under soil management and cover crops

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ABSTRACT

Energy balance is a way of evaluating the efficiency of the management of agricultural production systems. The objective of this work was to compare, from the energy point of view, two forms of soil management and with variation in the management of different winter cover crops. The experiment was conducted in a family-based property located in the municipality of Anta Gorda/RS, in 2010/2011 and 2011/2012, in Neossolo Regolítico distrófico típico. The experimental design was in randomized blocks with subdivided plots and three replicates. The main treatments consisted of two forms of soil management: no-tillage and no-tillage and chiseling at two-year intervals, being subdivided in winter by crops of black oats (*Avena strigosa*), vetch (*Vicia sativa* L.) and grazed black oats. As a result, it was verified that all management systems had a positive energy balance. No-tillage resulted in lower intake, higher output, net energy and energy efficiency in relation to no-tillage and chiseling every two years. Among the winter cover crops, oats without grazing were those whose cultivation resulted in higher net energy and energy efficiency.

Key words: chiseling; corn silage; energy efficiency; no-tillage; winter cover crops

Balanço energético em integração lavoura pecuária leiteira sob manejos de solo e culturas de cobertura

RESUMO

O balanço de energia é uma forma de avaliar a eficiência do manejo de sistemas de produção agropecuários. O objetivo do trabalho consistiu em comparar, sob o ponto de vista energético, duas formas de manejo do solo e com variação no manejo de diferentes plantas de cobertura de inverno. O experimento foi conduzido em uma propriedade de base familiar localizada no município de Anta Gorda/RS, em 2010/2011 e 2011/2012, em Neossolo Regolítico distrófico típico. O delineamento experimental foi em blocos ao acaso, com parcelas subdivididas e três repetições. Os tratamentos principais foram constituídos por duas formas de manejo do solo: semeadura direta e semeadura direta escarificada a cada dois anos, sendo subdivididos pelo cultivo, no inverno, de aveia preta (*Avena strigosa*), ervilhaca (*Vicia sativa* L.) e aveia preta pastejada. Como resultado verificou-se que todos os sistemas de manejo apresentaram balanço energético positivo. A semeadura direta resultou em menor entrada, maior saída, energia líquida e eficiência energética em relação à semeadura direta escarificada a cada dois anos. Entre as plantas de cobertura do solo de inverno, a aveia sem pastejo foi aquela cujo cultivo resultou em maior energia líquida e eficiência energética.

Palavras-chave: escarificação; silagem de milho; eficiência energética; semeadura direta; culturas de cobertura de inverno

Introduction

The search for less energy-wasting management models plays a vital role in the identification of sustainable agricultural production systems. The study of the energy used in agricultural production systems, their flows, distributions and conversions are an important instrument in the evaluation of these systems, especially considering the crises in the energy sector (Souza et al., 2009). Campos et al. (2004) point out that the determination of the efficiency of agricultural production systems must take into account the energy flow of the production system and not only the cost/profit relation. In this context, the energy balance emerges as a tool to aid in the search for these alternatives since it quantifies, in the same unit, all inputs consumed and generated in one or more production cycles.

Among the technological options developed with the aim of reducing these costs and making the rural properties economically viable, we highlight the cultivation of winter forages, the integration between agriculture and livestock (Junior et al., 2009), the anticipation of fertilization and sowing (Bertoloni & Gamero, 2010), the use of leguminous plants (Fontaneli et al., 2010), and especially the no-tillage system (Fernandes et al., 2008).

Despite the significant technological changes, some studies have emphasized that there is great energy dependence on fertilizers (Santos & Simon, 2010; Melo et al., 2007), on diesel fuel (Campos et al., 2009) and on agrochemicals (Santos & Simon, 2010) in crop production and management, which justifies the need for further studies.

Santos et al. (2011), evaluating energy conversion and balance of crop-farming integration systems under no-tillage system, verified that the corn crop had a higher energy return in comparison to the other grain producing crops and to the evaluated winter and summer pastures. The authors state that crop-farming integration strategies under no-tillage system are more energetically efficient than isolated monocultures and have positive energy conversion and balance.

Based on the above, the objective of this study was to compare, from the energetic point of view, two forms of soil management (no-tillage and no-tillage and chiseling) every two years) cultivated with winter cover crops (black oats with and without grazing, and vetch) in a crop-farming integration system in a family-based farm.

Material and Methods

The experiment was installed and conducted in the agricultural years of 2010/2011 and 2011/2012 in a family-based farm located in the municipality of Anta Gorda, RS, in the Fisiographic Region of the Lower Slope of the Northeast (28º 59' 44" S and 52º 01' 46" W). The soil of the experimental area was classified as *Neossolo Regolítico distrófico típico* (EMBRAPA, 2013) with 22% of clay in the 0.0 to 0.20 m layer. The experimental design was in randomized blocks with subdivided plots (8 m x 4.5 m) and three blocks, totaling 18 experimental units. The main treatments consisted of two forms of soil management, no-tillage (NT) and no-tillage and chiseling every two years (NTC). The subdivisions were composed by winter crops of black oats without grazing (O), black oats with grazing (OG) and vetch without grazing (V).

Only in the agricultural year 2010/2011, before sowing of winter crops, in the NTC management system, a JAN® branded chisel plowing was used, composed of five stems spaced at 0.39 m, provided with narrow tips (0.075 m wide), with approximately 600 kg and regulated to operate at a 0.26 m depth.

In the winter crops sowing occurred on 05/05/2010 and 04/12/2011, in the first and second year of research, respectively, 150 kg of formulated fertilizer NPK 8-16-20 were applied. When 50% of the plants of treatments O and OG reached the stage between peeling and elongation of the stem, 40 $kg.ha^{-1}$ of urea were applied in the coverage (CQFS RS/SC, 2016). Only in the OG treatment it was applied, after each grazing (two), 40 $kg.ha^{-1}$ of urea in coverage. The grazing was always performed after milking in the morning by 25 cows of the Dutch breed (average live weight of 450 kg), when the pasture reached an average height of 0.40 m in an area of 900m² (area of the plots with OG treatment, adding the area between the blocks), and the withdrawal of the animals occurred when the plants regressed to the average height of 0.10 m.

The determination of the period of entry and exit of the animals of the OG treatment was obtained through the random measurement of the average height of the oat plants contained in ten measurement points in each plot by using a centimeter-graduated ruler disposed vertically between the soil surface and the top of the oat plants. To avoid that animals grazed on treatments O and V and left to the adjacent areas to the experiment, an electric fence was installed isolating these plots, as well as surrounding the total area of the experiment (sum of the plot area and between blocks), and consequently allowing the animals to move freely from one grazed plot to another using the areas between the blocks.

The selection of the area for dry matter (DM) sampling of the winter crop in the treatments O, OG and V was obtained by randomly launching a metal frame with 0.25 m² area on each experimental unit, twice. Then, the plant material (PM) contained in the perimeter inside the metal frame was cut close to the ground, and this material was placed in an oven with forced ventilation at a temperature of 60ºC until reaching constant weight and later weighed in a digital scale.

In the treatments O and V, the collection occurred when approximately 50% of the plants were in full bloom stage and at early grain formation (Demétrio et al., 2012). In the OG treatment, the plant matter was collected before each grazing (two in total, with an interval of approximately 50 days between the first and second grazing), and before desiccation of the winter crops contained in all treatments (O, OG and V).

After the installation of the treatments in the whole experimental area, the sowing of the corn crop for the production of whole plant silage was carried out on 10/25 and 11/28, in the 2010/11 and 2011/12 crops, respectively. A Semeato seeder, model SHM11®, was used to obtain a population of 63 thousand plants per hectare, with a 0.9 m space between rows and weight of 2,100 kg. In the 2010/11 crop, the 30B39 hybrid from Pioneer® Seeds was sown and, in the 2011/12 crop, the Agroceres® 8011 hybrid was sown, both with YieldGard technology®.

The sowing fertilization of the corn crop consisted of the application of 400 kg of fertilizer formulated NPK 05-30-15. When the crop reached the phenological stage V6, nitrogen fertilization was carried out with 250 and 200 kg ha^{-1} of urea in the corn distributed in the plots in which the oat cover plants with and without grazing and cover vetches were cultivated, respectively (CQFS RS/SC, 2016). In the control of weeds, during the development of the corn crop, Primextra Gold® at a 1 L ha^{-1}dose was applied with a mounted bar sprayer, Jacto® brand, Condor M12 model, bars with 24 nozzles spaced at 0.50 m, tank with capacity for 600 liters and weight of 255 kg. Due to the hybrids used, there was no need for pest control.

The corn plants were harvested using an one-line Nogueira harvester, Pécus 400® model, when the corn grains had the "milk line" between their half and two thirds. Chiseling, sowing and harvesting of corn silage were performed with a Massey Ferguson® tractor model 275 with 55 kW of power in the engine and auxiliary front wheel drive (AFWD).

In order to determine the energy inputs, all operations were qualified and quantified, and all inputs used in the management systems were considered. On the other hand, the energy outputs of the management systems were obtained based on the dry mass production of the aerial part of the winter and summer crops.

In order to obtain the energy balance (net energy), the units of the input and output components of the management systems were multiplied by their energy coefficients (Table 1), following the method described by Assenheimer et al. 2009).

The energy required by the tractors, hatversters and equipment in general was obtained using Eq. 1, used by Riquetti et al. (2012).

$$SED = \frac{(M \times EC) \times UT}{UL}$$

in which:

DEE - specific energy demand;
M - mass of machines or equipment (kg);
CE - energy coefficient of machines or equipment (kg);
VU - useful life (h); and,
TU - usage time (h).

Table 1. Energy equivalents in (MJ kg^{-1}) of input and output components of management systems.

Input	Energy coefficient in (MJ kg^{-1})	Source
General equipment	69.0	Monti & Venturi (2003)
Tractors and harvesters	158.9	Monti & Venturi (2003)
Diesel fuel	43.7	Bueno (2002)
Lubricating oils	38.5	Bueno (2002)
N (urea form)	69.1	Hetz & Barrios (1997)
N (formulated fertilizer)	63.9	Ulbarene (1988)
Phosphorus - P_2O_5	14.0	Ulbarene (1988)
Potassium - K_2O	9.8	Ulbarene (1988)
Herbicide (glyphosate)	454.0	Monti & Venturi (2003)
Herbicides (general)	288.0	Hülsbergen et al. (2001)
Black oatmeal seed	18.6	Siqueira (1999)
Hybrid corn seed	104.6	Borin et al. (1997)
Vetch seed	18.7	Borin et al. (1997)
Aerial part of black oats (kg DM)	17.0	Borin et al. (1997)
Aerial part of vetch (kg DM)	9.4	Borin et al. (1997)
Aerial part of corn (kg DM)	16.0	Borin et al. (1997)

In order to evaluate the fuel consumption, the values of 80 mL kw^{-1} h^{-1} in operations considered as light (distribution of urea to the hail and spraying), 100 mL kw^{-1} h^{-1} in operations considered as medium (sowing) and 120 mL kw^{-1} h^{-1} in operations considered as heavy (chiseling and harvesting of corn for silage) (ASAE, 2003). The energy consumption related to lubricating oils, filters, grease, was considered 5% of that calculated for fuel.

The energy efficiency (η) was obtained using the Eq. 2 employed by Melo et al. (2007), which consists in dividing the total output energy by the total input energy of the evaluated management systems.

$$\eta = \frac{\sum E\ Output}{\sum E\ Input}$$

in which:

η - energy efficiency;

Output Energy - estimated energy withdrawn in the production process (in product form); and,

Input Energy - estimated energy consumed throughout the production process.

No statistical analysis of the research data was performed, since the total energy expenditure was obtained by the sum of some factors that are not common to the soil management systems and winter cover crops. Thus, we sought to qualify the energy relationship input:output seeking to make the inferences by comparing the most efficient systems with those that had lowest efficiency, pointing out the main processes that contributed to this dynamic.

Results and Discussion

Among the winter crops, oats under grazing (OG) produced the highest energy expenditure (input), followed by non-grazed oats (O) and finally by vetch (V) treatment, regardless of the mode of soil management (Table 2). This is due to the greater use of nitrogen fertilizers in the OG treatment, since after each grazing urea was applied in the cover, while in oats without grazing only one dose of nitrogen was applied in the V4 stage of development. On the other hand, the V treatment provided the lowest energy expenditure as it does not require the application of nitrogen fertilization because this crop is be able to fix atmospheric nitrogen in symbiosis with native *Rizobium* strains naturally present or added to the soil. This information is relevant because, considering the total energy consumption for the implantation of winter crops, fertilizers represented approximately 75% of total energy expenditure, followed by seeds (11.9%), both in NTC and NT.

Analyzing the soil management systems, it can be verified that the NTC resulted in energy expenditure 6.6% higher in relation to the NT due to the higher cost with machines, equipment, fuels and lubricants resulting from the need of chiseling. These results corroborate with those obtained by Woods et al. (2010), who state that current agriculture has a considerable dependence on agricultural machinery and equipment.

Table 2. Energy inputs and outputs of the agricultural years (2010/11 and 2011/12) in soil management systems and winter cover crops.

Energy source	Management systems					
	NTC[4]			NT[5]		
	OG[1]	O[2]	V[3]	OG[1]	O[2]	V[3]
	(MJ ha^{-1})					
Inputs						
Machines and Equipment	371.1	343.4	324.9	248.6	220.8	202.4
Fuels and Lubricant	987.0	899.8	841.7	575.1	487.9	429.8
Fertilizers	7,554.3	5,681.1	4,437.3	7,554.3	5,681.1	4,437.3
Agrochemicals	-	-	-	-	-	-
Seeeds	1,209.0	1,209.0	840.6	1,209.0	1,209.0	840.6
Total	10,121.4	8,133.3	6,444.5	9,587.0	7,598.8	5,910.1
Mean		8,233.0			7,698.6	
Outputs						
Dry material	109,950.3	126,473.9	47,753.5	120,033.5	136,500.8	57,155.9
Mean		94,725.9			104,563.4	

[1] Oats with grazing; [2] Oat without grazing; [3] Vetch; [4] No-tillage and chiseling every two years; [5] No-tillage.

Regarding the outputs (energy gain), this is higher in the O treatment than in the OG and V treatments (Table 2). This is due to the fact that the non-grazed oat crop presented a higher dry matter (DM) yield in relation to the other treatments, independently of the soil management systems. It should be noted that the OG treatment had a slow re-growth development after dairy cow grazing probably caused by animal trampling associated with excessive rainfall, cloudiness and low temperatures occurred during the two years of evaluation.

In both NTC and NT, V treatment had energetic gain, approximately 58% lower than the others. This result is associated with the fact that DM of the vetch has an energy conversion factor of 9.4 MJ kg^{-1} of DM compared to 17.0MJ kg^{-1} of DM of oats (Table 1).

Similar to the type of winter crop used (O, OG and V), NT had an energy gain of 9.4% higher than NTC (Table 2). This result is conditioned by the higher average of DM yield in the OG, G and V treatments developed in the area under no-tillage in relation to the same treatments conducted in the chiseling area. Thus, chiseling, in addition to providing greater energy input, also allowed a lower output, indicating that it is an unnecessary practice in the management systems under crop-farming integration.

Analyzing the energy expenditure (inputs) of corn production for silage in the areas where winter crops were grown, 67% of total energy consumption is associated with fertilizer use and 15% is related to fuel consumption and lubricants (Table 3).

These results are associated, respectively, with the higher demand of nutrients required by corn in relation to winter crops and the fact that the corn silage process requires intensive use of machines, equipment, fuels and lubricants.

Beutler (2005), evaluating the energy and economic balance of the production of corn grain in DP, in succession to soil cover plants and native field, verified a cost of 248.5 MJ (2.31%) with machines and equipment and of 26.4 MJ (0.25%) with fuels and lubricants. This lower energy expenditure, compared to the results obtained in this study, of 1,035 and 3,437 MJ in the NTC, and of 913 and 3,026 MJ in the NT with machines and equipment, and fuels and lubricants, respectively, is basically due to the type of harvest. While harvesting corn for grains allows the cutting of several planting lines simultaneously, harvesting corn for silage usually occurs with a single-row forage harvester with a speed below grain harvest, and it still needs to grind the entire plant into particles smaller than 1 cm.

When comparing the energy balance of corn cultivated under OG and G treatments with V (Table 3), it is observed that there was lower energy expenditure in the management of corn under vetch due to the lower use of nitrogen fertilizer n in this crop, resulting in a saving of 13.9% in the energy cost with fertilizers. With the decomposition of the legumes, the nitrogen (N) fixed is made available to the subsequent crop, reducing the need for application of mineral N. This is relevant for the reduction of the energy expenditure since the nitrogen fertilization is an important component in the production cost of corn crop. According to Fiorin et al. (1998), the use of

Table 3. Inputs and outputs of silage corn crop in the crop seasons 2010/11 and 2011/12 in soil management systems and winter cover crops.

Energy source	Management systems					
	NTC[4]			NT[5]		
	OG[1]	O[2]	V[3]	OG[1]	O[2]	V[3]
	(MJ ha^{-1})					
Inputs						
Machines and Equipment	1,035.1	1,035.1	1,035.1	912.6	912.6	912.6
Fuels and Lubricant	3,437.4	3,437.4	3,437.4	3,025.5	3,025.5	3,025.5
Fertilizers	15,467.3	15,467.3	13,912.5	15,467.3	15,467.3	13,912.5
Agrochemicals	1,296.0	1,296.0	1,296.0	1,296.0	1,296.0	1,296.0
Seeeds	1,713.4	1,713.4	1,713.4	1,713.4	1,713.4	1,713.4
Total	22,949.2	22,949.2	21,394.4	22,414.8	22,414.8	20,860.0
Mean		22,430.9			21,896.5	
Outputs						
Dry material	218,083.2	224,514.7	231,060.6	231,204.3	231,279.7	213,786.3
Mean		224,552.8			225,423.4	

[1] Oats with grazing; [2] Oat without grazing; [3] Vetch; [4] No-tillage and chiseling every two years; [5] No-tillage.

Table 4. Inputs, outputs, net energy and energy efficiency in agricultural crops (2010/11 and 2011/12) in management systems.

Evaluated components	Management systems					
	NTC[4]			NT[5]		
	OG[1]	O[2]	V[3]	OG[1]	O[2]	V[3]
	(MJ ha^{-1})					
Inputs (MJ ha^{-1})	33,070.5	31,082.4	27,838.9	32,001.7	30,013.6	26,860.1
Mean		30,663.9			29,625.1	
Outputs (MJ ha^{-1})	328,033.5	350,988.6	278,814.1	351,095.1	367,780.5	270,942.2
Mean		319,278.7			359,437.8	
Net Energy (MJ ha^{-1})	294,963.0	319,906.2	250,975.2	319,093.4	337,766.9	244,082.1
Mean		288,614.8			300,314.1	
Energy efficiency (%)	9.92	11.29	10.02	10.97	12.25	10.08
Mean		10.41			11.1	

[1] Oats with grazing; [2] Oat without grazing; [3] Vetch; [4] No-tillage and chiseling every two years; [5] No-tillage.

leguminous plants as winter cover crops predecessor to corn allows 50 to 70% reduction in nitrogen fertilization of this crop, which positively impacts the energy balance of systems using leguminous plants as predecessor crops, such as is the case.

It can be seen in Table 3 that the energy cost was approximately 7% higher in the OG and O treatments when compared to V, regardless of mechanical soil management (NTC or NT). This finding is justified mainly by the lower use of fertilizers in the treatment V, corroborating with that previously exposed.

Regarding energy gain (outputs) obtained by the DM production of the corn crop for silage, differences in the results of the OG, G and V treatments contained in NTC and NT were observed (Table 3).

Comparing the average energy gain between NTC and NT, there was equity in the results, with a variation of less than 1%. This is due to the fact that what differs in these soil management systems is mainly the chiseling.

Inputs, outputs, net energy and energy efficiency in management systems are presented in Table 4. Total energy expenditure (input) in the mean of the agricultural years was higher in the OG, G and V treatments contained in the NTC in relation to the same treatments in NT. These results are directly associated to the lower energy cost with machines, equipment, fuels and lubricants that the NT system demands (Fernandes et al., 2008).

The analysis of the energy gains (output) allows verifying a greater energy gain in treatments O and OG in NT, when compared to the same treatments in NTC. These results are probably associated with higher DM production in NT. Mazurana et al. (2011) evaluated in a long-term experiment the yield of grains and dry mass of the annual crops according to different types of soil preparation: no tillage (NT), chiseling (C), no-tillage with chiseling every two years (NTC), chiseling with chiseler equipped with roller debris (CR) and chiseling followed by harrowing (CH). The authors concluded that crop yields were higher in systems with less soil mobilization (NT), in agreement with the results obtained in the present study.

Table 4 shows that all management systems had positive net energy, demonstrating the feasibility of applying them in monoculture systems of crop plants and integration between crop and dairy cattle farming (ICF).

Santos et al. (2011) analyzed energy conversion and balance in production systems integrating crop and farming under no-tillage system and obtained similar results and stated that corn resulted in a higher energy gain compared to other grain-producing crops and to winter and summer crops. The data of the present study indicate that the energy gain of corn crop in NTC and NT was 137 and 116% higher in relation to the winter crops, respectively. These results demonstrate the crucial importance of corn cultivation for use in ICF in small family-owned farms. However, some production systems have proven to be more energy efficient than others. In general, it can be stated that treatment O, both in NTC and NT, was more efficient than OG and V (Table 4).

After the results of input, output, energy efficiency and net energy in NTC and NT were compared, it became possible to infer that NT was more efficient because of the lower energy investment (input) and higher production of DM (output) (Table 4). Riquetti et al. (2012) evaluated the energy demand in different soil management and corn hybrids and found that transgenic corn cultivated with DP was the system with the lowest demand and the highest energy efficiency compared to the other evaluated systems (minimum cultivation with transgenic corn, minimum cultivation with conventional non-transgenic corn, conventional tillage with transgenic corn, conventional tillage with non-transgenic corn, no-tillage system with non-transgenic corn). In this context, chiseling did not contribute to the increase of net energy and energy efficiency of the evaluated production systems.

Conclusions

All management systems resulted in a positive energy balance.

Fertilizers were the materials that generated the highest energy consumption (input) in the management systems.

Among the soil management, NT was the one that had the lowest energy consumption (input) with machines, equipment, fuels and lubricants.

NT favored lower input, higher output, higher net energy and energy efficiency compared to NTC.

Among management with winter cover crops, oats without grazing resulted in higher net energy and energy efficiency.

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