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Keshavarz-Afshar, Reza, and Chengci Chen. "Intensification of Dryland Cropping Systems for Bio-feedstock Production: Energy Analysis of Camelina." BioEnergy Research 8, no. 4 (December 2015): 1877-1884. DOI: 10.1007/s12155-015-9644-8.

Intensification of Dryland Cropping Systems for Bio-feedstock Production: Energy Analysis of Camelina

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Abstract

Camelina sativa, as a bioenergy and bio-product feedstock, may be grown as a rotation crop in the wheat-based cropping system to increase land use efficiency in the Northern Great Plains (NGP). In this study, we evaluated the energy balance of the camelina-winter wheat (CAM-WW) compared with traditional fallow-winter wheat (FAL-WW) and barley-winter wheat (BAR-WW) cropping systems from 2008 to 2011 in Central Montana. Results indicated that 52 and 57% more energy input was invested in CAM-WW and BAR-WW compared to FAL-WW system (9182 MJ ha^{-1}), respectively. In all rotations, nitrogen fertilizer was the most energy consuming input and accounted for 76, 68 and 71% of the total energy used in wheat, barley and camelina production, respectively. Averaged over three years, CAM-WW and BAR-WW systems yielded 34 and 29% greater gross energy output compared with FAL-WW. The CAM-WW and BAR-WW also outperformed FAL-WW by 30 and 6% in terms of net energy output. No significant differences in energy efficiency were between the FAL-WW and CAM-WW systems. Taking into account the greater net energy as well as similar values of energy use efficiency, CAM-WW system apparently performed better in than the traditional FAL-WW system in this dryland farming system. There is a good potential to improve the energy efficiency of the CAM-WW cropping system (by more than 26%) through refinement of agronomic practices, mainly nitrogen fertilization and herbicide application, which can further enhance the sustainability of camelina feedstock production.

Keywords: Camelina, Cropping system, Energy input, Energy output, Energy efficiency, Sustainability

Abbreviation: CAM-WW, Camelina-Winter Wheat; BAR-WW, Barley-Winter Wheat; FAL-WW, Fallow-Winter Wheat; NGP, Northern Great Plains.

Introduction

Camelina (*Camelina sativa* L. Crantz) is an annual oilseed crop belonging to the *Brassicaceae* family [10]. Oil of this crop has been recognized as an outstanding feedstock for bioenergy purposes and recent studies have confirmed its superiority as a biodiesel and aviation fuel [10, 14, 32]. In the recent years, extensive efforts have been made to characterize camelina's agronomic potential for the western and northern of the U.S. Great Plains and Canada [10, 11, 20]. Results of these studies confirmed that camelina can suitably fit with the environmental conditions and boundaries of the Northern Great Plains, thus, has potential to fill the fallow period of the wheat-based cropping systems to increase land use efficiency [6, 20]. Chen at al. [6] reported that total biomass and grain yield are greater in camelina-wheat annual cropping system than that in traditional fallow-wheat systems of Central Montana. Nevertheless, the sustainability of camelina-wheat (*Triticum aestivum* L.) rotation (CAM-WW) compared to traditional fallow-wheat (FAL-WW) system needs to be investigated. Effective use of non-renewable energy sources is considered as a major component of sustainability in the agricultural activity, especially bio-feedstock productions, thus; energy analysis is one useful indicator of environmental and long-term sustainability of the cropping systems [2, 24]. Moreover, energy analysis provides opportunities toward optimization of non-renewable energy consumption, thereby contributing positively to reducing greenhouse gas emissions and to enhancing the long-term environmental sustainability of the cropping systems [4, 27].

There were continuous debates on energy use efficiency or net energy gain for bioenergy production of grain and biomass. Energy analysis of predominant bioenergy feedstocks such as corn (*Zea mays* L.) [15, 23, 26], soybean (*Glycine max* L. Merr.) [9, 19, 26] and rapeseed (*Brassica napus* L.) [22, 29, 31] has been extensively investigated. Energy from biomass crops (second generation feedstock) such as cardoon (*Cynara cardunculus* L.) giant reed (*Arundo donax* L.), and Miscanthus spp. also has received sufficient attention from researchers [3, 7, 16]. It has been argued that suitable bio energy crops must yield significantly more energy that that used in their production process (Lewandowski and Schmidt, 2006). Despite the great potential of camelina for production of a climate friendly biofuel feedstock, the energy efficiency or energy balance in this crop is not well documented yet.

Individual crops vary in their energy input and output; crop rotation, therefore, can impact energetics of entire cropping systems. Zentner et al. [33] reported that non-renewable energy consumption for the entire cropping systems was differed significantly with crop rotations in the Canadian Prairies. Since nitrogen fertilizer is the most energy demanding input in most cropping systems [12, 21], Zentner et al. [33] reported that the inclusion of pulse crops such as peas (*Pisum sativum* L.) into the cropping systems can significantly reduce total energy input to the systems due to their role in minimizing external nitrogen input. Burgess et al. [5] evaluated the energy balance of 14 paired pulse -wheat and wheat-wheat crop sequences in Montana. They concluded that diversification of the cropping systems in Montana with pulse crops will have positive impacts on energy balance of the system.

In order to make camelina a viable bioenergy crop and to be able to produce the feedstock efficiently and sustainably, the energetic performance of this crop should be evaluated. In the present study, energy balance indicators, including energy efficiency and net energy, were used to evaluate energy performance of CAM-WW and barley (*Hordeum vulgare* L.)-wheat (BAR-WW) rotations compared with traditional FAL-WW cropping system in a dryland environment of the NGP. Potentials to improve the energy efficiency of these rotations through optimization of the agronomic practices are also discussed.

Materials and methods

Site description and experimental details

The study was conducted at the Central Agricultural Research Center (47^0 03’ N, $109^0$57’W; 1400 m elevation) of Montana State University near Moccasin, MT. The soil at this site is classified as a Judith clay loam (fine–loamy, carbonatic, frigid Typic Calciustolls) with the water holding capacity being limited by gravel content and a shallow soil profile (60 cm). Long term (l909 - 2013) average crop growing season (September to August) precipitation in this area is about 390 mm with mean air temperature of about 5.8 $^{\circ}$C. In Table 1 the monthly precipitation and average temperature during the study as well as the 20-yr long-term averages are presented.

The experiment was conducted from 2008 to 2011 in a land that was fallowed in the previous year (2007). Experimental plots were laid out in a randomized complete block design with four replicates. To avoid the confounding effect of varying weather conditions on crop rotation effects, each phase of the crops was designed to appear in each rotation year. The details of operation practices for each crop are shown in Table 2.

Energy balance

Energy balance was evaluated using the process analysis methodology [8], accounting for energy used for manufacture and operation of farm machinery, fuel, lubricants, fertilizer, and pesticides. Inputs were converted to energy equivalents using standard coefficients (Table 3). Among the available coefficients, we selected the most up-to-date values that have been used for energy analysis in similar environments. The primary source of energy coefficients of machineries was Burgess et al. [5], which accounted for fuel and lubrication consumption as well as energy to manufacture machinery and amortized over its useful life. Energy coefficients for herbicides are derived from Krohn and Fripp [14]. Grain used as seed was not included as energy input; instead, it was subtracted from the harvested grain [13]. Neither environmental inputs (solar radiation, precipitation water, wind, nutrient dry and wet deposition, and so forth) nor labor inputs were considered in the energy input calculation since labor usually has an insignificant share in total energy inputs of the mechanized farming systems [33]. Energy costs for delivering the products to off-farm location, storage, and drying were not also considered. The total energy input (MJ ha^{-1}) of each crop was calculated by summing all inputs used in the production procedure (Fig. 1). Energy input used in whole rotation was also calculated by summing the energy used for each crop in the rotation (Table 4).

Energy output was determined as a function of grain yield and grain higher heating values obtained from bomb calorimeter combustion (18.5, 18.2, and 26.5 MJ kg^{-1} for winter wheat, barley and camelina respectively). Crop residue did not get an allowance in energy analysis since they remained on the field and returned to the soil [33]. The energy balance of each cropping system was evaluated using two energy performance indicators as follow:

- Energy efficiency: Energy Output (MJ ha^{-1}) / Energy Input (MJ ha^{-1})

- Net energy (MJ ha^{-1}): Energy Output (MJ ha^{-1}) - Energy Input (MJ ha^{-1})

In this paper, the term energy efficiency will be used in the common general sense of efficiency (greater efficiency being desirable). We first focused on energy analysis of the cropping systems based on the common practices done for each crop in the region. Thereafter, we evaluated the possible options to improve energy balance of the systems.

Data Analysis

Data from the first year of the experiment (2008) was not included in the statistical analysis. Data of energy output and energy balance indices were subject to ANOVA using PROC GLM of SAS software. Fisher's least significant difference test (LSD) at $P< 0.05$ was employed to separate the means when F-test indicated significant differences.

Results and discussion

Energy Input

Comparing energy input used for the production of individual crops, winter wheat was the most energy-demanding crop with 8284 MJ ha^{-1} non-renewable energy input requirement (Fig. 1). This value of energy input is quite similar to the average energy input of 9053 MJ ha^{-1} reported for winter wheat in the Canadian Prairies [33]. Barley and camelina were ranked following winter wheat with the total energy input of 6156 and 5968 MJ ha^{-1}. Energy input used in fallow period was considerably lower (898 MJ ha^{-1}) than those used for crop production.

Very limited information exists in the literature regarding energy input of camelina. Petre et al. [25] reported 31404 MJ ha^{-1} energy input for camelina in Romania which is considerably higher than that used in the current study. The discrepancy between energy requirements for camelina in these studies are due to differences in system boundaries and management practices, especially high levels of chemical fertilizer, high rate of herbicide, and intensive soil preparation in Petre et al., [25] work. Compared to similar biofuel crops such as canola, camelina in the condition of current study had lower energy input. Fore et al. [9] reported 9506 MJ ha^{-1} and Smith et al. [30] reported 7651 MJ ha^{-1} energy input requirement for canola production in Minnesota and western Canada. For other biofuel crops such as soybean, energy input has been varied from 4588 [9] to 15506 MJ ha^{-1} [26].

The energy expenditure for fallow period in the current study is also lower than that (ranged from 1332 to 1581 MJ ha^{-1} depending on the management practice) reported by Zentner et al. [33] in the Canadian Prairies, which could be related to no till practices implemented in the current study.

Except in the fallow period in which herbicide was the only energy consuming input, nitrogen fertilizer was the most energy demanding input accounting for 76, 68 and 69% of the total energy input used in wheat, barley and camelina, respectively. Our results agreed with reports by other researchers [5, 33] who reported a proportion of more than 70% o nitrogen in total energy input of the cropping systems in the northern Great Plains as well as most previous studies in other regions [12, 21, 29]. This is while the national U.S. average of nitrogen proportion in total energy expenditure in winter wheat is about 47% [27]. Higher share of nitrogen in the current study is due to relatively low constitution of other inputs in this dryland farming system.

Considering the total energy expenditure in the complete rotation, the lowest energy input was used in the traditional WW-FAL (9182 MJ ha^{-1}) whereas 57 and 55% more energy input was invested in WW-BAR and WW-CAM compared to WW-FAL, respectively (Fig.1).

Energy Output

The energy output of individual crops, therefore the cropping systems varied considerably across the years (Table 4). When comparing energy yield of winter wheat in different rotations, always greater energy was obtained from wheat rotated with fallow. Lower grain yield thus energy output of wheat in rotation with camelina and barley is attributed to lower content of stored water in the soil which limited moisture availability for wheat in the intensified cropping systems compared to that in WW-FAL rotation (for details see Chen et al. [6].

Camelina gross energy output in this study ranged from 31740 to 11690 MJ ha^{-1} (Table 4). Limmited data are available reporting energy output of camelina especially in dryland farming systems. However, compared to irrigated canola [22, 31], energy output of camelina was lower which was due to low grain yield harvested in this dryland system. As shown in table 4, camelina energy yield was extremely low in 2011. Excessive rainfall received during May and June (when camelina was blooming) adversely influenced camelina pollination and grain formation in this year.

Total energy output of the cropping systems also varied across the experimental years (Table 4). In 2009 and 2010 WW-BAR and WW-CAM rotations produced 49 and 44% (averaged over two years) greater gross energy output compared to WW-FAL. However, in 2011 due to a considerably low yield of all crops, energy output of intensified cropping systems declined; no significant differences were observed between cropping systems in this regard (Table 4).

Averaged over three years of the experiment, the highest energy output was belonged to WW-CAM rotation, though it was not significant with that of WW-BAR. Both of alternative rotations produced significantly greater energy output than traditional WW-FAL rotation.

Energy Indices

Except in 2011, the lowest net energy was belonged to WW-FAL rotation (Table 4). Averaged over three years, WW-CAM produced the greatest net energy which was 30 and 6% greater than that obtained from WW-FAL and WW-BAR rotations. Liska and Cassman [18] proposed net energy as a standard metric for energy productivity of biofuel production systems. This indicator can be suitably used to compare the different cropping systems in terms of energy productivity [12, 22, 29, 33]. In dryland farming systems crops performance is greatly influenced by the environmental conditions, which can also impact the energy performance of the cropping systems. In the present study and under favorable environmental conditions (like 2010) intensified cropping systems yielded greater net energy than WW-FAL rotation. It shows that higher energy invested in the alternative systems was completely offset by greater energy output of these cropping systems.

Considering camelina net energy yield, net energy of 18283 MJ ha^{-1} was obtained from this crop (averaged over three years). As mentioned previously, one necessary criterion for a biofuel to be a sustainable alternative to the petroleum fuels it displaces is a positive net energy balance [9]. Camelina net energy yield in the current study is considerably greater than that reported for generic biofuel crops such as soybean and canola [9], but lower than biomass crops [1, 3, 7, 16]. This clearly shows the potential of camelina as a biofueld feedstock as considerably less fossil energy inputs in the production processes than the energy contained in the product.

Energy efficiency of the cropping systems is shown in table 4. Values of energy efficiency of the cropping systems were relatively high, especially in 2010, showing that non-renewable energy sources were efficiently consumed in these cropping systems. No significant differences were found between energy efficiency of the three rotations in 2009 and 2010 whereas WW-FAL outperformed alternative rotations in 2011 (Table 3). According to Anova, no statistical significant difference was found between energy efficiency of WW-FAL and WW-CAM rotation averaged over three years of the experiment. Taking into account the greater net energy of WW-CAM as well as similar efficiency in consumption of non-renewable energy, it can be concluded that WW-CAM outperformed the traditional WW-FAL rotation in energetic perspective.

Potentials to improve energy efficiency

The sustainability of the alternative cropping systems could be further improved through enhancing the energy efficiency, by either increasing energy output (yield) or reducing energy inputs. The former can be achieved through the selection of high yielding cultivars. Recently, several newly developed camelina cultivars have been tested and some of them have shown considerable yield advantages over existing cultivars (Chen unpublished data). The later (reducing energy input) can also be achieved through the optimization of the agronomic practices. In the recent years, extensive research efforts have been made to determine the optimum practices for different cropping systems in this area. Based on our experiences, the following refinements can be recommended to reduce energy input in the studied cropping systems without any unfavorable effects on the system productivity (crop yield):

For the fallow period, instead of 1.68 L ha^{-1} 2, 4-D which is usually used in early to midsummer, 0.7 L ha^{-1} 2, 4-D can be used to reduce the total energy input of fallow period by 13.7%. Also, instead of 90 kg N ha^{-1} which is usually broadcast for winter wheat at late-tillering stage, a rate of 67 kg N ha^{-1} may be sufficient. These two adjustments in agronomic practices will lower total energy input of wheat by 12.7%. For barley following winter wheat also one extra application of glyphosate in early spring (1.12 L ha^{-1}) is necessary. However, instead of broadcasting 52 kg N ha^{-1}, application of 35 kg N ha^{-1} may be sufficient. Therefore, 11.1% of energy will be saved for barley production if these changes are applied in the production process. Among the crops we evaluated in this study, energy efficiency of camelina has the biggest potential to be improved through the optimization of management practices. Our previous experiments showed that the application of starter fertilizer is not necessary for camelina after winter wheat as N, P and S carry over from the previous crop is sufficient for the crop requirements. The same amount of nitrogen (52 kg ha^{-1}), however, is necessary to be broadcasted at rosette stage to meet the crop demand. Also application of a grassy herbicide (Poast or any other herbicides) is not essential. Through the optimization of fertilizer and herbicide consumption, almost 29% of total energy input of camelina can be saved which in turn will greatly influence energy use efficiency in CAM-WW rotation. For example, considering the actual yield of the current study and assuming that the inputs are optimized, energy efficiency of CAM-WW rotation will raise from 4.6 to 5.8, which is almost than 26% improvement.

Conclusion

According to the results of the present study, intensified cropping systems required more energy input compared with the traditional FAL-WW rotation. The greater amount of energy expended in the intensified cropping systems, however, was completely offset by more energy output of the alternative system (e.g. CAM-WW). Net energy obtained from the intensified cropping systems was considerably greater than the control (depending on the environmental conditions) whilst these systems did not differ in term of energy efficiency. It can be concluded that the alternative cropping systems including the bio-energy crop (CAM-WW) outperformed traditional FAL-WW system in energetic perspective. In all rotations, nitrogen fertilizer was the most energy consuming input and accounted for nearly 70% of the total energy input used in this dryland farming system. There is a big potential to improve the energy performance of the alternative cropping systems, especially CAM-WW in this region. Refinement of management practices will even more improve the sustainability of the alternative cropping systems in terms of energy balance.

Compliance with Ethical Standards

We declare that:

- The data presented in this paper is original and have not been manipulated
- The manuscript has not been submitted to more than one journal for simultaneous consideration
- The manuscript has not been published previously (partly or in full)
- Proper acknowledgements and citations to other works are given
- The manuscript has been approved by all the authors and consent to submit has been received explicitly from all co-authors, as well as from the responsible authorities
- Authors whose names appear on the submission have contributed sufficiently to the scientific work
- Chengci Chen, Reza Keshavarz-Afshar, and Karnis Neill declare that they have no conflict of interest (financial or non-financial).

- This study is supported by USDA Western Sustainable Research and Education grant, No. 080019002; Montana Agricultural Experiment Station; and USDA-NIFA BRDI grant, No. 2012-10006-20230.

- This article does not contain any studies with human or animal subjects.

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Acknowledgements:

The authors like to thank Karnes Neill, Johnna Heser, and Kelly Arnold for technical support in the field and laboratory. The funding support of this project came from USDA Western Sustainable Research and Education grant, No. 080019002; Montana Agricultural Experiment Station; and USDA-NIFA BRDI grant, No. 2012-10006-20230.

Table 1: Monthly precipitation and average air temperature during the study and long term average (LTA) at Moccasin, Montana.

Month	Precipitation (mm)					Month	Temperature (ºC)				
	2008	2009	2010	2011	LTA		2008	2009	2010	2011	LTA
Sep	28.2	32.3	20.6	49.0	35.8	Sep	13.6	12.4	17.3	12.8	12.7
Oct	23.6	19.1	73.9	11.2	23.1	Oct	8.7	9.2	1.8	10.6	7.2
Nov	23.1	14.2	4.8	40.9	14.5	Nov	1.4	4.7	3.9	-2.2	0.5
Dec	0.5	8.9	8.6	17.0	13.7	Dec	-3.3	-8.8	-9.1	-3.3	-3.9
Jan	4.8	11.2	10.7	8.1	14.0	Jan	-5.6	-3.0	-3.0	-5.0	-5.8
Feb	5.3	5.1	5.1	15.0	11.4	Feb	-1.9	-1.5	-1.5	-8.3	-4.1
Mar	2.8	15.0	4.6	15.5	18.0	Mar	0.5	-0.6	4.8	-1.1	-4.1
Apr	11.2	36.6	27.9	59.9	30.5	Apr	2.8	4.2	5.3	3.3	5.0
May	109.7	14.2	85.3	186.7	65.5	May	9.8	10.2	7.6	8.3	10.1
Jun	74.7	23.9	66.3	107.4	79.5	Jun	13.6	13.7	13.6	13.3	14.3
Jul	11.4	54.9	37.3	20.8	42.4	Jul	19.3	18.6	17.6	19.4	18.8
Aug	22.6	39.6	96.0	18.0	41.7	Aug	19.4	18.3	18.1	20.0	18.3
Total	317.9	275.0	441.1	549.5	390.1	AVG.	6.5	6.5	6.4	5.7	5.8

Table 2: Details of agronomic practices used for each crop

	Weed management	Fertilization	Planting and harvesting details
Fallow	1.12 L ha^{-1} of glyphosate[a] in the fall. 1.12 L ha^{-1} glyphosate in the early spring. 1.12 L ha^{-1}of glyphosate plus 1.68 L ha^{-1} 2,4-D[b] in early to midsummer.		
Winter wheat (cv. Yellowstone)	1.12 L ha^{-1} of glyphosate in early September. 1.68 L ha^{-1} bronate[c] (broadleaf herbicide).	112 kg ha^{-1} starter fertilizer N-P_2O_5-K_2O-S (20-20-20-10). 90 kg N ha^{-1} at late-tillering stage.	Direct-seeded with a ConservaPak no-till air-seeder[e] at the rate of 67 kg seed ha^{-1}. Harvested using a Wintersteiger plot combine[f] at late July to early August.
Barley (cv. Haxbey)	1.12 L ha^{-1} of glyphosate in early September. 1.68 L ha^{-1} bronate.	112 kg ha^{-1} starter fertilizer N-P_2O_5-K_2O-S (20-20-20-10). 52 kg N ha^{-1} at late-tillering stage.	Direct seeded using a ConservaPak no-till air-seeder at a seeding rate of 76 kg ha^{-1}. Harvested in late July using a Wintersteiger plot combine.
Camelina (cv. Blaine Creek)	1.12 L ha^{-1} of glyphosate in the early September. 1.12 L ha^{-1} of glyphosate in prior to planting. 1.12 L ha^{-1} Poast[d] (a grassy herbicide) at late rosette stage.	112 kg ha^{-1} starter fertilizer N-P_2O_5-K_2O-S (20-20-20-10). 50 kg N ha^{-1} was in the spring at rosette stage.	Direct seeded (late March to early April) using a ConservaPak no-till air-seeder at a seeding rate of 5.6 kg ha^{-1}. Harvested in early to mid-July using a Wintersteiger plot combine.

[a] N-[phosphonomethyl] glycine

[b] 2,4-dichlorophenoxyacetic acid

[c] Bromoxynil

[d] 2-[1-(Ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cycloxexen-1-one

[e] ConservaPak, Indian Head, SK, Canada

[f] Wintersteiger Inc., Salt Lake City, UT

Table 3: Energy coefficients used to convert inputs to their energy equivalents

Input	Energy coefficient (MJ/input)	Reference
Herbicides (L a.i.)	274.63	Krohn and Fripp [14]
Fertilizer (kg)		
N	56.7	Burges et al. [5]
P2O5	9.5	Burges et al. [5]
K2O	9.9	Burges et al. [5]
S	1.12	Zenter et al. [5]
Machinery (ha)[a]		
Air Seeder	408	Burges et al. [5]
Sprayer	126	Burges et al. [5]
Granular applicator	91	Burges et al. [5]
Combine	350	Burges et al. [5]

[a] Including energy for manufacturing, operating, maintenance, fuel and lubrication.

Table 4: Energy balance indicators (means± standard errors) for two-year crop rotations in a dryland farming system of Central Montana.

Cropping system	**2009**	**2010**	**2011**	**Average**
Gross Output Energy (MJ ha^{-1})				
WW-FAL	43042 (±1681)b	60211(±3510)b	46775 (±3924)a	50009 (±2556)b
Wheat	43042	60211	46775	50009
Fallow	0	0	0	0
WW-BAR	66075 (±3568)a	87654 (±1063)a	40544 (±3500)a	64758 (±2080)a
Wheat	29047	49941	20618	33202
Barley	37027	37712	19927	31555
WW-CAM	61066 (±3654)a	89001 (±6572)a	51778 (±3399)a	67282 (±3014)a
Wheat	32429	57261	40087	43259
Camelina	28637	31740	11690	24022
Net Output Energy (MJ ha^{-1})				
WW-FAL	33860 (±1681)b	51029 (±3510)b	37593 (±3924)a	40827 (±2556)b
Wheat	34758	51927	38491	41725
Fallow	-898	-898	-898	-898
WW-BAR	51639 (±3568)a	73218 (±1063)a	26108 (±3500)a	50322 (±2080)ab
Wheat	20763	41657	12334	24918
Barley	30875	31560	13775	25403
WW-CAM	47042 (±3654)a	74977 (±6572)a	37754 (±3399)a	53258 (±3014)a
Wheat	24145	48977	31803	34975
Camelina	22898	26000	5951	18283
Energy Efficiency				
WW-FAL	4.7 (±0.19)a	6.6 (±0.38)a	5.1 (±0.43)a	5.4 (±0.28)a
Wheat	5.2	7.3	5.6	6.0
Fallow	-	-	-	-
WW-BAR	4.6 (±0.25)a	6.1 (±0.07)a	2.8 (±0.24)b	4.5 (±0.14)b
Wheat	3.5	6.0	2.5	4.0
Barley	6.0	6.1	3.2	5.1
WW-CAM	3.9 (±0.42)a	6.4 (±0.47)a	3.7 (±0.24)b	4.6 (±0.22)ab
Wheat	3.9	6.9	4.8	5.2
Camelina	5.0	5.5	2.0	4.2

Mean were separated using LSD test at $P<0.05$ (only energy indicators of cropping systems were compared not each individual crop). Means within a column with a common letter are not statistically different.

Figure Caption:

Fig. 1: Energy input used for each crop (above) and total energy input used for each cropping systems (below).