# ENERGY BALANCE EVALUATION OF WINTER TRITICALE PRODUCTION

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**Abstract.** This study has been carried out to assess the energy efficiency of a production technology used to grow a cultivar of semi-dwarf winter triticale called *Gniewko*. The research data consisted of the results of a three-year field experiment conducted at the Experimental Station in Bałcyny near Ostróda (Poland). Three technologies selected for comparison produced the lowest, medium and highest grain yields. The compared technologies differed in the dosage of nitrogen fertilization and the level of fungicidal control. In all the analyzed technologies, mineral fertilization was the most energy demanding link in the agronomic practice of growing winter triticale. The highest yield technology was markedly less energy efficient than the medium and lowest yield technologies.

**Key words:** winter triticale, production technology, energy inputs, energy effectiveness.

## Introduction

Triticale is a hybrid between rye and wheat, made by using conventional plant breeding methods. No triticale varieties are genetically modified (GM). Current grain yields are competitive with the highest yielding wheat varieties, and may exceed that of barley, and the high quality of protein has been maintained (expressed as a high percentage of lysine in the protein). New varieties have also been bred with superior forage yield potential that are especially suitable for silage, for early and late spring grazing, for swath grazing, for mixed cropping with other forage species, or for green-feed or haylage. Triticale can be called "the crop for all seasons". Triticale has also demonstrated tolerance to drought and acidic soils, and is grown commercially worldwide [1].

Energy use in agricultural production has been increasing faster than that in many other sectors of the world economy because agricultural production has become more mechanized, and use of substitutes for land, such as commercial fertilizers, has increased [2]. Owing to the high energy consumption during the production of agricultural inputs, in particular mineral nitrogen fertilizers, it is often questioned as to whether agricultural production is still energy efficient [3].

In agriculture, because of the multi-stage character of production processes, the question of energy efficiency of production technologies becomes focal [4]. In the contemporary farming practice, it is necessary to make a constant effort at reducing production inputs in order to maintain profitability. One of the methods for studying the profitability of agricultural production is the accumulated energy consumption method [5]. Węgrzyn and Zając [6] underline that rational economic activity is characterized by economic and efficient use of resources of human labour and production means, but above all every attempt is made to maximize the energy efficiency of production while minimizing the inputs. Efficient energy use is one of the principal requirements to establish sustainable agriculture [7].

According to Pawlak [8], what forces producers to improve the energy efficiency of agricultural production is the increasing cost of energy carriers. This necessitates the search for solutions that will enhance the efficiency of energy inputs, which is one of the prerequisites for achieving a competitive edge in economics. However, it is essential to monitor modifications on the level of production energy efficiency. Similar ideas are presented by Gündogmus and Bayramoglu [9]. The authors said that efficient energy use allows financial savings and also can lead to more environment-friendly production systems.

Energy parameters seem to be suitable to estimate the influence of different management intensities with respect to their environmental effects, such as fertilizer application and pesticide use, if both energy outputs and inputs are considered [10]. Energy intensity (energy input per unit grain equivalent) and the output/input ratio are suitable to asses the environmental effects associated with the production of crops, thus these parameters can be used to determine the optimum intensity level of land and crop management and provide important information on cropping system properties [10-12].

The aims of this study were to determine the total amount of input energy used in winter triticale production, to exhibit the distribution of different energies utilized during management practices and to evaluate the efficiency of input energy consumption depending on the employed production means.

## Materials and methods

The analysis of energy efficiency presented in this paper was performed on data resulting from three-year field experiments on the semi-dwarf cultivar of winter triticale called *Gniewko*. The field trials were carried out at the Experimental Station in Bałcyny near Ostróda (Poland 53.60º N; 19.85º E), in 2009-2011. A two-factorial experiment was set up in a split-plot design (with four replications). It was established on grey-brown podzolic soil, classified as good wheat complex. The soil was cultivated as generally recommended. The energy efficiency of winter triticale grain production was assessed for the lowest, medium and highest yield obtained in the experiment. The calculations included the average (from three years) yields of winter triticale grain. A quartile was used as a statistical tool to select technologies. Fertilization with phosphorus in a dose of 70 $kg \cdot ha^{-1}$ $P_2O_5$ and potassium in a dose of 90 $kg \cdot ha^{-1}$ $K_2O$ was carried out before sowing triticale. In each technology, weed control consisted of a single autumn spraying treatment with a mix of herbicides: Boxer 800 EC 2 $L \cdot ha^{-1}$ (active ingredient *prosulfocarb*), Glean 75 WG 5 $g \cdot ha^{-1}$ (a.i. *chlorosulfuron*), Legato 500 SC 0.5 $L \cdot ha^{-1}$ (a.i. *diflufenican*). The three technologies differed in the amount of applied nitrogen and the level of fungicidal control. The lowest yield technology included mineral fertilization with 30 $kg \cdot ha^{-1}$ N (in the form of 34 % ammonium nitrate), seed dressing with Baytan Universal 094 FS (a.i. *triadimenol* + *imazalil* + *fuberidazole*) and spraying with the preparation Input 460 EC (in the phase BBCH 31) in the amount of 1 $L \cdot ha^{-1}$ (a.i. *spiroxamine* 300 $g \cdot ha^{-1}$ + *prohtioconazole* 160 $g \cdot ha^{-1}$). The medium yield technology was composed of nitrogen fertilization with 120 $kg \cdot ha^{-1}$ (in a split dose of 90+30, supplied as 34 % ammonium nitrate). Fungal control (seed dressing + 1 spraying treatment with fungicide) was analogous to that in the low yield technology. The highest yield technology involved mineral fertilization in the amount of 150 $kg \cdot ha^{-1}$ N (in a dose of ammonium nitrate divided into 90+60), seed dressing with Baytan Universal 094 FS (a.i. *triadimenol* + *imazalil* + *fuberidazole*), spraying with Input 460 EC (in the phase BBCH 31) in the amount of 1 $L \cdot ha^{-1}$ (a.i. *spiroxamine* 300 $g \cdot ha^{-1}$ + *prothioconazole* 160 $g \cdot ha^{-1}$) and with Prosaro 250 EC (in the phase BBCH 58) in a dose 0.6 $L \cdot ha^{-1}$ (a.i. *tebuconazole* 75 $g \cdot ha^{-1}$ + *prothioconazole* 75 $g \cdot ha^{-1}$).

The analysis of energy efficiency took account of the accumulated energy efficiency of production means. The analysis was performed in line with the method recommended by FAO [13]. The energy output is defined as the calorific value of the main product. The main yield of winter triticale (grain) was converted to dry matter yield. It was assumed that triticale grain contained 87 % of dry matter. Another assumption made was that 1 kg of grain dry matter represented the energy value equal 18.36 MJ. After making these assumptions, energy inputs for the subsequent soil tillage and plant cultivation treatments were calculated in each of the production technologies. The energy inputs for drying, storage and transport from the farm to the consumers were also not considered. Also, no allowance was made for energy removed from the soil in the form of plant nutrients or for energy involved in terms of soil organic matter increases or losses [14].

The energy inputs due to the materials consumed was expressed in megajoules (MJ) according to the unit energy consumption factors, adapted to local conditions [5] (table 1). Volumes of the energy and material inputs were analyzed in four specific energy streams: tractors and machines, fuel, materials and human labour. The energy efficiency assessment included the concepts of accumulated energy gain and the unit energy consumption factor. The output/input ratio was derived from the relation between the energy value of the yield and energy inputs used to obtain that yield. In addition, the energy efficiency assessment employed the unit energy consumption index [13].

## Results and discussion

In literature there is enormous variation in energy equivalents used to express the input of energy associated with the manufacture of production means in terms of primary energy input [15]. This is the result of differences in the methods of calculation and in spatial and temporal system boundaries [11]. The energy equivalents are not fixed once and for all, they must be adapted to the local conditions and to the changes in the manufacturing process [16].

Table 1

**Energy coefficients for selected production inputs**

| Specification | Unit | Energy equivalent |
|---|---|---|
| Fuel (diesel) | $MJ \cdot kg^{-1}$ | 48 |
| Mineral fertilizers | | |
| N | $MJ \cdot kg^{-1}$ | 77 |
| $P_2O_5$ | $MJ \cdot kg^{-1}$ | 15 |
| $K_2O$ | $MJ \cdot kg^{-1}$ | 10 |
| Pesticides | $MJ \cdot kg^{-1}$ a.i. | 300 |
| Machines | $MJ \cdot kg^{-1}$ | 110 |
| Human labour | $MJ \cdot h^{-1}$ | 80 |

The total energy inputs on plant production depend mostly on the species of a grown crop [17], but also on the applied technology and number of agronomic treatments [18]. In the experiment described herein the total energy inputs on winter triticale production were on average 17.98 $GJ \cdot ha^{-1}$ (Table 2), being the highest in the high yield technology (21.74 $GJ \cdot ha^{-1}$), i.e. a variant of the highest nitrogen fertilization and complete fungicidal control. A similar level of inputs expended on growing triticale was observed by Raczkowski [19]. In contrast Dopka [20], who also studied winter triticale, noticed a much higher level of energy inputs (34.27 $GJ \cdot ha^{-1}$). In an experiment reported by Czarnocki and Starczewski [21] the inputs on triticale production did not exceed 13.62 $GJ \cdot ha^{-1}$. The most energy consuming production treatment turned out to be mineral fertilization, which was responsible for energy consumption in the range of 37.7 to 64.6 % of the total energy expended on growing winter triticale.

Table 2

**Structure and accumulated energy outlays to grow 1 ha winter triticale, according to agrotechnical measures**

| Agrotechnical measures | Technology variant production | | | | | |
|---|---|---|---|---|---|---|
| | the lowest yield | | middle yield | | the highest yield | |
| | $MJ \cdot ha^{-1}$ | % | $MJ \cdot ha^{-1}$ | % | $MJ \cdot ha^{-1}$ | % |
| Soil cultivation | 1 540 | 13.0 | 1 540 | 8.2 | 1 540 | 7.2 |
| Sowing and sowing material | 4 311 | 36.3 | 4 311 | 22.8 | 4 311 | 20.2 |
| Mineral fertilization, including | 4 478 | 37.7 | 11 487 | 60.8 | 13 797 | 64.6 |
| nitrogen | 2 310 | 19.4 | 9 240 | 48.9 | 11 550 | 54.1 |
| Weed control | 712 | 6.0 | 712 | 3.8 | 712 | 3.3 |
| Chemical diseases control | 227 | 1.9 | 227 | 1.2 | 390 | 1.8 |
| Harvesting | 610 | 5.1 | 610 | 3.2 | 610 | 2.9 |
| Total | 11 877 | 100 | 18 887 | 100 | 21 360 | 100 |

The findings of the author of the article confirmed the results of other authors, who individuated either N fertilization or mechanical operations (tillage in particular) as those inputs requiring the most energy, depending on the design of the cropping systems they compared

A similar contribution of fertilization to the structure of total energy inputs was noticed by Dopka [20]. The results of the current experiment are congruent with the research conducted by Budzyński et. al. [22]. According to the cited authors, fertilization and plant protection may correspond to as much as 60 % of the energy accumulated in the structure of energy inputs. In most cropping systems, the energy input of mineral fertilizer, mainly N, has the largest share of the total energy input [11; 23]. Deike et. al. [24] amounted to approximately 28 % of the total energy input due to relatively small application rates of mineral N fertiliser. According to Kuesters and Lammel [3] there is a clear linear relationship between increasing the N fertiliser rate and the total energy input. Among remaining agronomic treatments, other important contributors to the energy consumption, regardless of the technological variant, were the sowing and seeds (from 20.2 % in the highest yield technology to 36.3 % in the lowest yield variant) and pre-sowing soil tillage (from 7.2 to 13.0 %, respectively). The pesticide treatments did not demand high energy inputs and were within the range of 5.0 to 7.9 % of the total energy consumption. By Deike et. al. [24] 5 % of the total energy input are associated with pesticide utilization. Even less energy was expended on harvest (from 2.9 do 5.1 % of the total energy consumption). In an experiment by Budzyński et. al. [22], soil tillage corresponded to just 10-15 % of the total energy spent on triticale production, while the crop harvest consumed as much as 20 % of the said total energy. In the current experiment, lower energy inputs were needed to protect the crops against fungi, ranging from 1.2 to 1.9 % of the total energy consumption.

When analyzing the structure of accumulated energy inputs according to energy flows, it was found that the highest share was contributed by materials (from 75.4 to 85.3 %) (Table 3). Such high contribution of this energy flow was mainly due to the high inputs into mineral fertilizers and seeds. Klikocka and Sachajko [25] also underlined a high share of raw and other materials in the structure of energy inputs needed to grow triticale (from 71.2 to 75.4 %). Apart from materials, another important item contributing to the structure of inputs comprised energy carriers (8.8-14.5 %). However, Raczkowski [22] obtained a much smaller share of this flow (17.2-21.5 %) in the total energy consumption. Next position in the structure of inputs is occupied by tractors and other machines, between 3.5 and 5.7 %. The smallest share was contributed by human labour (2.3 %). As summarized by Borin et. al. [26], energy associated with human labour accounts for less than 0.2 % of total energy input for most modern cropping systems, and is therefore neglected. Refsgaard et al. [27] concluded that human labour, which includes physical and additionally intellectual work, is too different to be handled with the same term. According to Diepenbrock [16] human labour is not usually considered in the energy balance of agricultural production systems.

Table 3

**Accumulated energy outlays and structure to grow 1 ha triticale according to energy streams**

| Stream of energy | Technology variants | | | | | |
|---|---|---|---|---|---|---|
| | the lowest yield | | middle yield | | the highest yield | |
| | $MJ \cdot ha^{-1}$ | % | $MJ \cdot ha^{-1}$ | % | $MJ \cdot ha^{-1}$ | % |
| Human labour | 393 | 3.2 | 409 | 2.1 | 436 | 2.0 |
| Tractors and machinery | 713 | 5.7 | 730 | 3.7 | 766 | 3.5 |
| Energy carriers (fuel) | 1 811 | 14.5 | 1 858 | 9.5 | 1 935 | 8.8 |
| Materials, including: | 8 960 | 75.4 | 15 890 | 84.1 | 18 222 | 85.3 |
| - seeds | 4 113 | 45.9 | 4 113 | 25.9 | 4 113 | 22.6 |
| - fertilizers | 4 190 | 43.8 | 11 120 | 67.4 | 13 430 | 71.3 |
| - fungicides | 86 | 0.9 | 86 | 0.5 | 109 | 0.6 |
| - herbicides | 571 | 6.0 | 571 | 3.5 | 571 | 3.0 |

The highest accumulated energy gain in winter triticale production was recorded in the highest yield technology (Table 4). This indicator was 23.5 % lower in the low yield technology. The highest unit energy consumption in the production of winter triticale appeared in the highest yield technology. In turn, the technology ensuring the lowest yields enabled decreasing the unit energy consumption by triticale production by 24.5 %. An index which allows us to achieve a complete comparison of the analyzed technologies and their effects is the energy efficiency index. Its actual level is mostly dependent on the level of yields and the volume of energy inputs expended to achieve it. The highest value of the energy efficiency index (9.86) was determined for the highest yield technology. The obtained index in relation to cereals is very high. Ceccon et. al. [28] in researches concerning winter

Table 4

**Energy balance indicators for winter triticale cultivation technologies**

| Description | Technology variants | | |
|---|---|---|---|
| | the lowest yield | middle yield | the highest yield |
| Energy input, $MJ \cdot ha^{-1}$ | 11 877 | 18 887 | 21 360 |
| Yield energy value, $MJ \cdot ha^{-1}$ | 117 137 | 143 392 | 158 998 |
| Net energy output, $MJ \cdot ha^{-1}$ | 105 259 | 124 505 | 137 638 |
| Energy consumption per unit, $MJ \cdot t^{-1}$ | 1 862 | 2 418 | 2 466 |
| Output/input ratio (energy efficient index) | 9.86 | 7.59 | 7.44 |

wheat achieved from 3.07 to 4.0. In the previous studies on legume plants the author obtained the efficiency index ranged from 3.84 to 10.20 [29; 30]. Some references give even higher values of this index. Klikocka et. al. [18], who investigated spring barley, recorded an average energy efficiency index from three seasons around 10.21. In the current experiment, when the nitrogen fertilization dose was raised by 90 $kg \cdot ha^{-1}$, the energy efficiency decreased by 23 % (the medium yield technology). The further increase of the nitrogen dose and an additional antifungal treatment enabled us to obtain a higher grain yield, but the high yield technology was characterized by the lowest energy efficiency index (7.44). Also, Dopka [20] noted higher values of the said index when winter triticale had been nourished with lower doses of nitrogen, irrespective of the type of pre-sowing soil tillage. Czarnocki et. al. [31] analyzed the energy efficiency of different variants of soil tillage under winter triticale, but achieved much lower values of the energy efficiency index (from 1.53 to 2.16). Wielicki [13] mentions that under average conditions on a farm 1 unit of energy inputs to plant production should generate about 4 energy units in the primary product (yield).

## Conclusions

1. The most preferable energy efficiency index (9.86) was determined for the lowest yield technology.
2. The largest contribution to the structure of total energy inputs in production of winter triticale was made by the input materials. They made up from 75.4 % of the energy inputs in the lowest yield technology to 85.3 % in the highest yield technology.
3. Less favourable energy efficiency index values were obtained by raising the intensity of winter triticale production.
4. An increase in the energy value of triticale grain did not compensate for the higher energy inputs expended to its production.

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