

ENERGY EFFICIENCY OF NITROGEN FERTILIZATION IN DURUM WHEAT AND SORGHUM GRAINS

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Abstract: The objective of this study was to assess the energy efficiency of nitrogen fertilization in durum wheat and sorghum grains in the period 2017-2019. Bulgarian durum wheat variety Predel was studied at a stationary fertilizer trial on soil type *Pellic vertisols* at the Institute of Field Crops in Chirpan, Bulgaria. Grain sorghum hybrid EC Alize was investigated on the experimental field of the Agricultural University of Plovdiv, Bulgaria, on soil type *Mollic Fluvisols*. The crops were grown under non-irrigated conditions. The studied nitrogen rates were 0, 60, 120, 180, and 240 kg N.ha⁻¹. In durum wheat, nitrogen was applied two times: one third at sowing, and the rest - as top dressing in the tillering stage. In sorghum, the total nitrogen was applied as pre-sowing fertilization before sowing. The nitrogen fertilizer was applied as NH₄NO₃. The experimental design was a randomized, complete block design with four replications with a size of experimental plots of 20 m² for both crops. The energy efficiency of nitrogen fertilization (η) was calculated as the ratio between the received energy from additional grain yield of wheat and sorghum, respectively, and the invested energy from fertilization. It was established that energy efficiency of nitrogen fertilization depended on the nitrogen rate and hydro-thermal conditions during the vegetation period of durum wheat and sorghum. The bioenergy coefficient of durum wheat widely varied from 0.79 (N₂₄₀ in 2018) to 4.44 (N₆₀ in 2017). The average for the period, the highest value of energy efficiency of nitrogen fertilization was obtained at the low rate N₆₀. The higher nitrogen rate of 240 kg N.ha⁻¹ was slightly effective. Under drought conditions during the vegetation period of sorghum, most effective was the application of rates N₁₂₀ with the highest energy coefficient of 1.23. The application of 180 kg N.ha⁻¹ to sorghum was the most energy efficient under the favorable hydro-thermal conditions in 2018 and 2019, and the average for the period 2017-2019. A low N₆₀ rate in grain sorghum was inefficient from an energy point of view. Durum wheat showed higher energy efficiency of nitrogen fertilization compared to grain sorghum.

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Introduction

The intensive agricultural technologies and increased yields are accompanied by an increase in the cost of non-renewable or exhaustible energy. One of the most important resources within agriculture is nitrogen (N), and depletion of N resources is an important element in the evaluation of sustainability in agriculture. Energy is directly used in land preparation, tillage operations, sowing, irrigation, harvesting; and indirectly used in inputs such as seed, fertilizers, pesticides and irrigation water. The comparison of energy productivity of different crops can be used as an effective tool to prioritize crops planting in each area. The output energy is obtained in the form of feed, fodder, fruits, vegetables, seed and grain. Therefore, energy efficiency from fertilization needs to be taken into account in sustainable agriculture. Agricultural production efficiency is defined as the ratio between the amount of input energy, including N fertilizers and the energy contained in the obtained products. In an energy crop context, sustainability in crop production could aim at enhanced energy output with maintained or reduced depletion of N resources (Pourazaria et al., 2015). Crop energy accumulated in crops is estimated in mega joules (MJ) and reported in basic production, total production and additional production. The authors reported as the main components of the energy balance of field crop rotations the use of machinery, fuel, irrigation and fertilization, and recommended minimum treatments, lower fertilization rates, timely updating the machines and the use of renewable energy sources (Azarpour, 2012; Meyer-Aurich et al., 2012). The manufacture of mineral fertilizers, package, transport and usage occupy about 45% of the used energy in agriculture (Mudahar and Hignett, 1987). In this context, the used fertilizer is actually equivalent to the input energy in agricultural production. Nitrogen fertilization is a main cost of non-renewable energy sources in agriculture and in terms of insufficient energy resources it is important to find ways to increase its energy efficiency (Hosseinpahani and Kafi, 2012). A significant increase of grain yield was achieved through the use of both new cultivars and the input of a larger amount of energy in the form of fertilizers, mechanization and pesticides (Faidley, 1992). According to Piringer (2006) in the total energy input of US grown wheat, the share of only

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nitrogenous fertilizer was 47 %, whereas in a study of Australia, the share of all fertilizers (i.e. nitrogen, phosphorus, and potash) was 47 %.

According to various sources the specific energy content in N fertilizers is 58-90 MJ per kg N, in phosphorus is 44 MJ per kg P_2O_5 and in potassium – 2.27 MJ per kg K_2O (Mineev, 2004). The efficiency of agriculture productivity is defined as the correlation between the amount of input energy (which could be in the form of N or other fertilizers) and the energy of production (Hulsbergen et al., 1997).

Considerable research has been conducted on the energy use pattern of field crops under different management practices in the world. Most of the work related to the energy use pattern for different crops was for wheat (Mirasi et al., 2014; Moghimi et al., 2013) and cotton (Zahedi et al., 2014). The results of long-term studies in Iran show that nearly 80% of the consumer energy in Iran's agriculture is non-renewable (Beheshti et al., 2010). According to Glogova (2013) the highest energy yield for sugar and popcorn maize is realized with the use of fertilizer rate $N_{220}P_{100}K_{80}$ and in comparison with the control $N_0P_0K_0$ in the same fertilizer rate the effect of fertilizers is the highest, 35% by sugar maize and 23% by popcorn maize.

Ozkan et al. (2004) reported that animal manures have more effective nutritional effects than chemical fertilizers and also their production requires less energy consumption, so that the consumption of one ton of animal manure equals to only 300 MJ ha^{-1} which is equivalent to only 5 kg N fertilizer. So the consumption of fertilizers with natural origin helps to much reduce the energy consumption in the production system and increase its productivity.

The most common biomass production includes corn, wheat, sugarcane, sugar beet, and sweet sorghum (López-Sandin et al., 2018; Vermerris & Saballos, 2013). However, yields vary according to variety, cultivation conditions (soil, water, climate, pests, and diseases), inputs, and agronomic practices (Mishra et al., 2017). In comparison with other crops, yield has a lower use of inputs due to the favorable combination of its agronomic and technological characteristics, making it one of the best raw materials in the production of sugar and biofuels (Bonin et al., 2016).

In Bulgaria, the energy efficiency of nitrogen was studied only for some field crops (Kostadinova and Yordanova, 2010; Kostadinova et al., 2010; Rachovski et al., 2010). There are no studies for grain sorghum and for durum wheat.

The negative effects associated with increased energy production may be mitigated if renewable energy sources are employed and increased efficiency of the related production processes is attained, so that energy consumption decreases without affecting quality of life (Rocha et al., 2018).

The aim of this research was to study the energy efficiency of nitrogen fertilization in sorghum and durum wheat grains and to establish in which crop nitrogen fertilization leads to higher energy efficiency. The results are discussed in an agricultural sustainability perspective.

Data and methodology

The investigation was carried out in Southern Bulgaria in 2017-2019 under non-irrigated conditions. The experimental design for sorghum and durum wheat was a randomized, complete block design with four replications with a size of experimental plots of 20 m^2 . The rates of applied nitrogen fertilization as NH_4NO_3 for both crops were 0, 60, 120 180 and 240 $kg \cdot ha^{-1}$. The nitrogen fertilization was on the background $P_{50}K_{50}$ fertilization as triple superphosphate and potassium chloride, respectively. Standard farming practices for both crops for the region of Southern Bulgaria were applied.

The investigation on the sorghum hybrid EC Alize was carried out on the experimental field of the Agricultural University of Plovdiv. The predecessor was wheat. Total nitrogen was applied pre-sowing. The soil type of the experimental field is alluvial-meadow Mollic Fluvisols (FAO, 2006) with a slightly alkaline reaction $pH_{H_2O} = 7.80$. The content of available nutrients in the soil before sowing of the sorghum was mineral N - 27.6 $mg \cdot N \cdot kg^{-1}$; available phosphorus (Egner-Ream) 158 $mg \cdot P_2O_5 \cdot kg^{-1}$ and exchangeable potassium 210 $mg \cdot K_2O \cdot kg^{-1}$.

The investigation on durum wheat was also carried out on the testing field of the Field Crop Institute, Chirpan, near Plovdiv, at cotton-durum wheat crop rotation. Nitrogen was applied two times - 1/3 pre-sowing and 2/3 as early spring dressing. The soil was Pellic Vertisols (FAO, 2006). Soil analysis

before the experiment indicated sorbium capacity – 35-50 mequ /100g soil; bulk weight – 1.1-1.2 g.cm⁻³; specific gravity – 2.6-2.7; organic matter – 2.0-2.4; mineral N –30-35 mg N.kg⁻¹; available phosphorus and potassium – 70-90 mg P₂O₅.kg⁻¹ and 240-280 mg K₂O.kg⁻¹, respectively.

The values of temperature and precipitations during the vegetation period characterized the hydro-thermal conditions of 2017 as warm and dry. In contrast, the months of May, June and July of 2018 were very humid. The amount of precipitation exceeded nearly twice the values of the long-term norm. The conditions during the vegetation of 2019 were similar to those in 2018.

The energetical efficiency of fertilization was defined by the use of the following indexes (Mineev, 2004):

1. The amount of stored energy in the main agricultural production resulting from fertilization: $E = D.R.L$, where: E - content of energy in the main production, resulting from fertilization, kg.ha⁻¹; D - additional yield from main production as a result of fertilization, kg.ha⁻¹; R - coefficient of re-estimation of an agricultural production unit to dry matter; L - content of total energy in 1 kg dry matter from the main production, MJ. The values of parameters L and R for durum wheat are respectively 19.13 MJ and 0.86, and for sorghum - 18.34 MJ and 0.86.

2. The consumption of energy (A) of the nitrogen fertilizers input: $A = R_N \times 86.6$, (MJ.ha⁻¹), where R_N is the nitrogen rates in a kg of active matter per hectare. The amounts of energy for nitrogen is 86,6 (MJ for 1 kg active matter).

3. The energy efficiency of the N fertilizers used (η): $\eta = E / A$, where: η - energetical efficiency (energy use efficiency); E - amount of energy, received in the additional main production by input of N in MJ; A – consumed energy for input nitrogen fertilizers, MJ.

For a statistical estimation of fertilization energy efficiency (η) a test analysis of variance by Duncan (1955) at $P < 0.05$ was used.

Results and Discussion

The amount of additional yield of durum wheat and sorghum grain resulting from the applied nitrogen fertilization of 60, 120, 180 and 240 kg N.ha⁻¹ depends on the weather conditions during the growing season of the two crops.

The lowest additional average yield of 1198 kg.ha⁻¹ of durum wheat was obtained in 2018 (Table 1). The average additional yield of wheat in 2017 and 2018 was higher by 26.7% and 50.1%, respectively. Nitrogen fertilization increased the additional wheat grain yield to the low rate N₆₀. The only exception to this dependence was observed in the high fertilization rate N₂₄₀ in 2017, when 16.1% lower additional wheat grain yield was obtained. Nitrogen fertilization on durum wheat at a rate of 180 kg N.ha⁻¹ resulted in the highest additional grain yield in 2018 - 1700 kg.ha⁻¹ and in 2019 - 2450 kg.ha⁻¹. The additional yield at this rate, average for the study period, was by 89.6, 19.3 and 39.8 % more than the additional yield obtained at fertilization with N₆₀, N₁₂₀ and N₂₄₀, respectively.

Table 1: Additional grain yield and energy in additional grain yield of durum wheat depending on nitrogen fertilization

Year \ Fertilization	2017	2018	2019	2017-2019
Additional grain yield, kg.ha ⁻¹				
N ₆₀	1370	790	930	1030
N ₁₂₀	1840	1300	1770	1637
N ₁₈₀	1710	1700	2450	1953
N ₂₄₀	1150	1000	2040	1397
Average	1518	1198	1798	
Energy in additional grain yield, MJ.ha ⁻¹				
N ₆₀	22539	12997	15300	16945
N ₁₂₀	30271	21387	29120	26926
N ₁₈₀	28133	27968	40307	32136
N ₂₄₀	18920	16452	33562	22978
Average	24966	19701	29572	

Source: Authors

The energy in the additional grain yield follows the pattern of the amount of additional yield resulting from the applied nitrogen fertilization of wheat and the influence of weather conditions during the growing season. The lowest energy in the additional grain yield of wheat - 12997 MJ.ha⁻¹ was found to be obtained by fertilization with N₆₀ in 2018 and the highest - 40307 MJ.ha⁻¹ at N₁₈₀ in 2019. On an average of three years, the greatest amount of energy in the additional grain yield was obtained at the rate of N₁₈₀. The high nitrogen rates N₂₄₀ reduced the amount of energy in the additional grain yield of durum wheat by 28.5% on average compared to fertilization with N₁₈₀. Results of Ziaei et al. (2015) showed that total energy inputs of wheat fields of all agricultural activities were 32492 MJ.ha⁻¹. Total energy outputs for wheat and barley fields were 48517 and 49801 MJ ha⁻¹, respectively. Based on these results the amount of energy use efficiency for wheat fields were 1.49, and the amount of energy productivity were 0.056. The results of Jadida et al. (2012) revealed that wheat production consumed a total of 37 694.6 MJ/ ha of which fertilizers was 52.8%, followed by diesel fuel (15.3%).

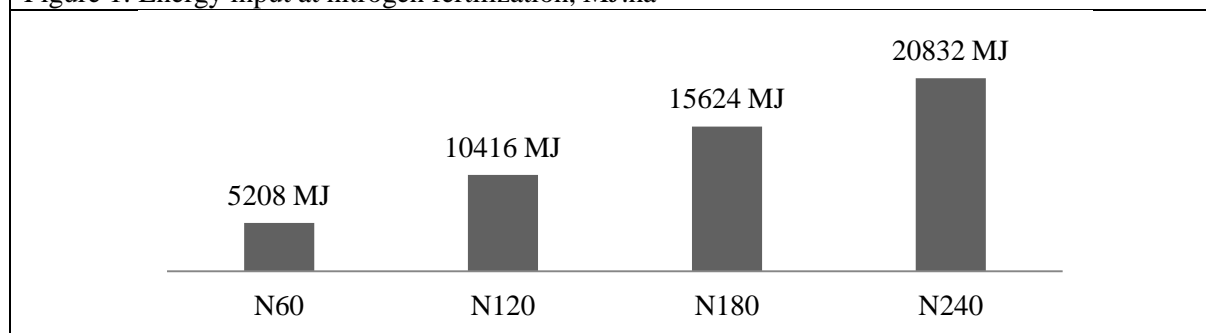
The amount of additional grain obtained from sorghum had the lowest average value in 2017 due to very dry conditions during the vegetation of plants (Table 2). The favorable weather conditions during the vegetation period of 2018 and 2019 led to a higher average additional yield by 62.9% and 33.7%, respectively, compared to 2017. The lowest additional grain yield of sorghum in the range 270 - 420 kg.ha⁻¹ was obtained at the low nitrogen levels of N₆₀. Sorghum reacted very positively to nitrogen fertilization. The average for the period, the application of rates N₁₈₀ and N₂₄₀ increased the amount of additional yield by 4.33 - 4.41 times compared to rate N₆₀. With sorghum, the lowest and highest energy values of the additional yield were obtained at fertilization with 60 kg N.ha⁻¹ in 2019 (4260 MJ.ha⁻¹) and N₂₄₀ in 2018. The resulting energy in additional yield was higher in all variants of nitrogen fertilization in 2018, which was characterized by more rainfall during the growing season of sorghum. On average, over the three-year experimental period, the highest amount of energy in the additional grain yield was 23661 MJ.ha⁻¹ – obtained at the high rate N₂₄₀. Our results corroborated that the N level and the year of cultivation exerted important effects on durum wheat and sorghum grain production.

Table 2: Additional grain yield and energy in additional grain yield of sorghum depending on nitrogen fertilization

Fertilization	Year	2017	2018	2019	2017- 2019
	Additional grain yield, kg.ha ⁻¹				
N ₆₀		1370	790	930	1030
N ₁₂₀		1840	1300	1770	1637
N ₁₈₀		1710	1700	2450	1953
N ₂₄₀		1150	1000	2040	1397
Average		1518	1198	1798	
Fertilization	Energy in additional grain yield, MJ.ha ⁻¹				
N ₆₀		5205	6624	4260	5363
N ₁₂₀		12776	16876	13720	14457
N ₁₈₀		18611	28233	22870	23238
N ₂₄₀		13880	30441	26661	23661
Average		12618	20544	16878	

Source: Authors

Figure 1: Energy input at nitrogen fertilization, MJ.ha⁻¹



Source: Authors

Cabrera-Ariza et al. (2019 and Díaz et al. (2018) reported that crop management had important effects on sorghum energy balance. The energy produced varied between 126 and 365 GJ ha⁻¹ depending on crop management, hybrid and growing season.

The amount of fertilizer energy input increased in parallel with the value of nitrogen rate (Figure 1). The nitrogen energy input varied from 5208 MJ at the low N₆₀ to 20832 MJ.ha⁻¹ at N₂₄₀. Ansari et al. (2018) indicate that the average energy consumption in wheat production for nitrogen is 6878 MJ.ha⁻¹, which is lower than the received our results.

The energy efficiency of nitrogen fertilization in durum wheat and sorghum varied depending on the amount of incorporated nitrogen and the energy produced in the additional grain yield (Table 3).

Table 3: Energy efficiency (η) of nitrogen fertilization in durum wheat and sorghum					
Fertilization	Year	2017	2018	2019	2017-2019
Durum wheat					
N ₆₀		4.33	2.50	2.94	3.26 ^a
N ₁₂₀		2.91	2.05	2.80	2.59 ^{ab}
N ₁₈₀		1.80	1.79	2.58	2.06 ^b
N ₂₄₀		0.91	0.79	1.61	1.10 ^c
Average		2.49	1.78	2.48	
Sorghum					
N ₆₀		1.00	1.27	0.82	1.03 ^b
N ₁₂₀		1.23	1.62	1.32	1.39 ^a
N ₁₈₀		1.19	1.81	1.46	1.49 ^a
N ₂₄₀		0.67	1.46	1.28	1.14 ^b
Average		1.02	1.54	1.22	

Source: Authors

The energy efficiency of nitrogen fertilization in durum wheat decreased with the increase in the amount of applied nitrogen fertilizer. On average, the use of N₁₂₀, N₁₈₀ and N₂₄₀ reduced the energy efficiency of fertilization by 20.6, 36.8 and 66.3% respectively, compared to N₆₀. The application of increased rate N₂₄₀ in 2017 and 2018 was not an effective agronomic activity from an energy point of view, due to the values of energy efficiency (η) lower than one, which indicated that the energy in the additional grain yield was less than the energy input from nitrogen fertilization. From an energy point of view, durum wheat had effective low to moderate nitrogen fertilization. At rates N₆₀₋₁₂₀ the values of coefficient η ranged within 2.05 - 4.33.

The energy efficiency of nitrogen fertilization in sorghum varied within a narrower range compared to durum wheat. The bioenergy coefficient (η) over the experimental period of three years ranged from 0.67 (N₂₄₀ in 2017) to 1.81 units (N₁₈₀ in 2018). The severe drought during the sorghum growing period in 2017 reduced the energy efficiency of nitrogen fertilization at the studied rates N₆₀₋₂₄₀. Fertilization of sorghum at rates N₁₂₀ and N₁₈₀ had a high significant energy effect and values of 1.39 and 1.49 of bioenergy coefficient η. Low energy efficiency was found at N₂₄₀. This high rate decreased the energy efficiency of fertilization and its application to sorghum is not suitable in terms of energy.

According to Pourazaria et al. (2015) in Central Sweden the N uptake efficiency and yield-specific N efficiency were higher in maize than wheat and ley. The yield N concentration was higher in the perennial ley than the annual crops, and lowest in maize. Energy output per N lost in the harvested product was greater in maize compared to wheat and ley. Khan et al. (2010) found that energy efficiency was higher in wheat crop (9.21) compared to rice (6.70) and barley where it was 8.21. Piringer (2006) points out that the benefit-cost ratio remained the highest on rice crop (3.33) compared to wheat (2.82) and barley (2.50). Uhr & Vasileva (2015) indicated that maximum parameters of gross energy yield of wheat grain yields were reported at fertilization with 0.18 t/ha fertilizer nitrogen in cereal predecessor and 0.06 t/ha after cereal, and increasing the fertilizer rate of 0.0 t/ha to 0.18 t/ha nitrogen reduced the difference in the gross energy productivity of legume crops. In the case of Turkey the study showed that the inputs used in agricultural production were not used efficiently and led to many environmental problems (Canakci et al., 2005; Hatirli et al., 2005; Kardoni et al., 2015). Hence, they suggested that sustainable agriculture should be extended, and conscious farming should be

provided. According to the report by Moore (2010) to achieve a sustainable system of food production, the amount of energy efficiency and the share of renewable energies should be increased in agricultural systems. A high consumption of non-renewable energies will reduce the energy use efficiency in production systems, because the production of chemicals and the use of machinery as the main index of common systems require large amounts of energy consumption.

Conclusions

The results of this study indicate that energy efficiency of fertilization is dependent on the nitrogen rate and weather conditions during the vegetation period of durum wheat and sorghum. The energy input from nitrogen fertilization should be reduced to increase energy efficiency of durum wheat and sorghum production. The highest value of energy efficiency of nitrogen for durum wheat was obtained at the low rate N_{60} and with sorghum most effective was the application of rates N_{120} . The higher nitrogen rate of $240 \text{ kg} \cdot \text{ha}^{-1}$ was slightly effective. Durum wheat showed higher energy efficiency of nitrogen fertilization compared to grain sorghum. The results are discussed in an agricultural sustainability perspective.

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