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ENERGY USE AND ENERGY EFFICIENCY OF CORN PRODUCTION IN DIFFERENT FERTILIZATION STRATEGIES

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SUMMARY: Due to increasing energy prices, the efficient use of technical energy in cropping systems become more important. In long term trials (2007-2012) at two experimental sites ("Wagna" and "Wagendorf") in the Austrian province of South Styria, the direct energy use (fuel, heating oil, electricity) and indirect energy use (energy for the production of farm machinery, herbicide, fertilizer and seed) as well as energy efficiency in corn production were analysed. The influence of different mineral nitrogen fertilization rates (0, 90, 115, 145, 175, 210 kg N/ha as calcium ammonium nitrate) and a liquid pig manure treatment were compared. The calculated energy efficiency indicators (energy intensity, energy output/energy input-ratio, netto-energy output) showed, that the soil fertility had a big influence on energy efficiency. The energy efficiency indicators at the experimental site Wagendorf with very good soil conditions were better than at Wagna. Within the mineral nitrogen treatments in Wagna, the nitrogen fertilization rate of 90 and 115 kg N/ha reached the highest energy efficiency, whereas at Wagendorf it was at the 0 kg N/ha. Independently of the experimental site, the liquid pig manure treatment had the highest energy efficiency. The largest components of energy input in corn production with mineral fertilizer were the energy for drying (between 20.3 and 48.3 %) and energy for fertilizer production (between 20.7 and 37.2 %). For the mitigation of fossil energy input in corn production, a site specific nitrogen fertilization - at efficient with organic manure - and the application of regenerative energy carrier in corn drying are derived.

Key words: *energy consumption, energy efficiency, corn, nitrogen-fertilization, drying*

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INTRODUCTION

A goal in sustainable agriculture is to use fossil fuel energy more efficiently in crop production. Due to increasing energy prices, the efficient use of technical energy in cropping become more important. The intensity of agricultural production processes can be evaluated with the direct and indirect enrgy use. The energy input in plant cropping can be categorised in direct energy (fuel for machinery, heating oil and electricity for drying processes or conveyors) and indirect energy (process energy for the production of fertilizers, pesticides, seeds and farm machinery), Hülsbergen (2008).

For reducing the fuel consumption, there are many short-term measurements (e.g. driving with reduced engine speed, machine maintenance; adapted tire inflation pressure and optimised implement adjustment for slip reduction,...) and long-term measurements (e.g. machinery selection with reduced power requirement, change the tillage system to conservation tillage, improvement of the field shape,...), which are mentioned in Moitzi and Boxberger (2009).

Mineral nitrogen fertilizers are energy-intensive in their production and are responsible for increasing cropping yields. Many studies (Hoeppner et al. 2005, Moitzi et al. 2009, Moitzi et al. 2010, Szalay et al. 2009, Schüller et al. 2011) show, that the indirect energy input with mineral nitrogen has the largest energy contribution in conventional crop production systems.

In Austria, corn production has an importance for animal feeding and industrial processing. In the year 2012 27 % (=219702 ha) of arable land (=811509 ha) were cropped with corn, with an average yield of 10,7 t/ha (BMLFUW, 2013). This paper deals with the influence of different nitrogen fertilization strategies (mineral nitrogen: 0 kg N/ha to 210 kg N/ha and organic fertilizer with pig slurry) on energy use and energy efficiency on corn production (from seeding to drying harvested corn). The yield and management data were taken from two long term trials in South Austria.

MATERIAL AND METHODS

The two long term fertilization trials are located in the Austrian province of South Sytria, with a good climate for corn cropping (Table 1). The distance between the location "Wagna" from the location "Wagendorf" is about 5 km.

"Wagna" is above a gravel terrace of the groundwater body "Westliches Leibnitzer Feld". The fertilization field trial wih 12 different fertilization treatment was started in the year 2007. The block design consits of 6 replicates.

"Wagendorf" lies on a deep "Wagendorfer" terrace and has a very high soil fertility ("soil number" near 100). Since 2008 the influence of 13 different fertilization strategies on corn yield are studied in a block design with 4 replications.

Table 1. Yearly mean temperature and precipitation at the site Wagna-Leibnitz (ZAMG)

	2007	2008	2009	2010	2011	2012
Yearly mean temperature (° C)	10.4	10.4	10,2	9,6	11,0	11,2
Yearly precipitation (mm)	883	902	1312	1016	724	998

The soil (55 % sand, 33 % silt and 12 % clay; 2,4 % humus) at the location
The soil (9 % sand, 72 % silt and 19 % clay; 2,4 % humus) at the location
Table 2 shows the N-fertilization variants at location "Wagna" (period: 2007-2012) and "Wagendorf" (period: 2008-2012).

Table 2. Nitrogen fertilization rates at "Wagna" and "Wagendorf"

N-fertilization rate	„Wagna" 2007-2012	„Wagendorf" 2008-2012
0 kg N		
90 kg N	45 kg N + 45 kg N as CAN [1]	45 kg N + 45 kg N as CAN
115 kg N	55 kg N + 60 kg N as CAN	55 kg N + 60 kg N as CAN
Pig slurry 1 Application: surface broadcast 2. Application: band spreading with trailing hoses	*2007: 146 kg N_{ff}* [2] *2008: 164 kg N_{ff}* *2009: 117 kg N_{ff}* *2010: 142 kg N_{ff}* *2011: 115 kg N_{ff}* *2012: 124 kg N_{ff}* Ø: 135 kg N/ha	*2008: 121 kg N_{ff}* *2009: 115 kg N_{ff}* *2010: 96 kg N_{ff}* *2011: 115 kg N_{ff}* *2012: 94 kg N_{ff}* Ø: 108 kg N/ha
145 kg N	55 kg N + 90 kg N as CAN	55 kg N + 90 kg N as CAN
175 kg N	55 kg N + 60 kg N + 60 kg N as CAN	55 kg N + 60 kg N + 60 kg N as CAN
210 kg N		70 kg N + 70 kg N + 70 kg N as CAN

[1] CAN: Calcium Ammonium Nitrate
[2] N_{ff}= 87 % from N_{total}
[3] Slurry amount between 23 and 45 m^3/ha
[4] Slurry amount between 29 and 58 m^3/ha

The ripeness number of the corn variety was at Wagna 320 and at Wagendorf 400. Fuel consumption was calculated with the fuel calculator from KTBL (Association for Technology and Structures in Agriculture, www.ktbl.de) for a used mechanisation with tractors of 90 and 120 Hp. Energy consumption for drying of the harvested corn was calculated with the basic data from Rossrucker (1977). Heat value of corn: 18,6 MJ/kg DM (Hülsbergen, 2008).
The used energy-equivalents are shown in table 3.

Table 3. Energy-equivalents

	Farm facilities	Energy-equivalent	Source
Direct energy	Fuel. Heating oil	47,8 MJ/l	*CIGR, 1999*
	Electricity	12 MJ/kWh	*CIGR 1999*
Indirect energy	Mineral N-fertilizer	60 MJ/kg N	CIGR, 1999 angepasst
	Mineral P-fertilizer	17,4 MJ/kg P_2O_5	*CIGR, 1999*
	Mineral K-fertilizer	13,1 MJ/kg P_2O_5	*CIGR, 1999*
	Synth. Herbizide	242 MJ/kg	*Hülsbergen 2008*
	Seed	100 MJ/kg	*Hülsbergen 2008, CIGR, 1999*
	Machinery	1956 MJ/ha	*Biedermann 2009*

The energy efficiency was evaluated with three indicators:

$$\textbf{Energy intensity (MJ/kg)} = \frac{\text{Energy input (MJ/ha)}}{\text{Corn yield}_{(14\%\ w.b.)}\text{(kg/ha)}}$$

$$\textbf{Energy output/Energy input-ratio} = \frac{\text{Energy output (MJ/ha)}}{\text{Energy input (MJ/ha)}}$$

Netto-energy output (GJ/ha) = Energy output$_{Corn\ (14\%\ w.b.)}$ (GJ/ha) – Energy input (GJ/ha)

RESULTS AND DISCUSSION

Corn yield

The location in Wagendorf with the fertile soil reached an average yield of 13.651 kg/ha and was 4.534 kg (= 50 %) higher than in Wagna (Table 4). The average moisture content of the harvested corn was in Wagna 22 % w.b. and in Wagendorf 24 % w.b.

Table 4. Mean corn yields (kg/ha at 14 % w.b.); Different letters indicate significant differences (Student-Newman - Keuls Test, α = 0.05) between nitrogen fertilization rates

	0 kg N	90 kg N	115 kg N	Pig slurry	145 kg N	175 kg N	210 kg N	Mean
Wagna 2007-2012	5.033^{a} ±1.624	8.962^{b} ±1.313	9.848^{b} ±1.875	8.897^{b} ±1.966	10.797^{c} ±2.380	11.163^{c} ±1.803		9.117 ±2.726
Wagendorf 2008-2012	10.662^{A} ±1.993	13.818^{BC} ±1.014	14.223^{C} ±884	13.337^{B} ±1020	14.485^{C} ±976	14.634^{C} ±831	14.402^{C} ±908	13.651 ±1.715

Energy input

The energy input-data in MJ/ha are shown in figure 1 and 2. The energy of drying increases with the corn yield. The heating oil consumption for drying of the harvested corn to a moisture content of 14 % w.b. ranged from 57 to 124 l/ha at Wagna and from 152 to 205 l/ha at Wagendorf.

The energy input increased with increasing mineral N fertilization from 22,2 GJ/ha to 28,7 GJ/ha (Figure 1). In the pig manure fertilization treatment, the total energy input decreased to 15,5 GJ/ha and was around 1 GJ/ha higher than the zero treatment. The surface-related energy input in the pig manure fertilization treatment at the site Wagna was lower by 37 % and 41% in comparison to the mineral nitrogen rates of 115 kg N/ha and 145 kg N/ha. At the site Wagendorf 27 % and 32 % less energy were used in the pig manure fertilization treatment. A Canadian study showed that the substitution of mineral nitrogen fertilization by organic fertilization can save 36-52 % of energy in the production system of maize grains (McLaughlin et al., 2000). Here in the mineral nitrogen fertilization rates (60-164 kg N/ha) energy-input from 19,1 to 22,3 GJ/ha with corn yields of 6,8 to 8,8 t/ha were calculated.

By fertilization with pig slurry the energy-input was reduced to 11,9-12,9 GJ/ha (McLaughlin et al., 2000). In Italian investigations, it could be demonstrated that organically produced corn needed 58 % lower energy than the conventional production system with mineral fertilizers (Sartori et al. 2003).

In the N fertilization rate (90 kg N/ha) the drying energy was on the similar level as the energy required for the production of mineral N fertilizer (figure 1). The percentage of energy use by the mineral nitrogen fertilizer was at 90 kg N/ha 24,3 %, at 115 kg N/ha 28,5 %, at 145 kg N/ha 32,7 % and at 175 kg N/ha 36,6%. For comparison, McLaughlin et al. (2000) calculated on heavy soil at 60 kg and 77 kg mineral nitrogen rate an energy share of 35 % , on medium soils at 164 kg and 144 kg mineral nitrogen rate an energy share of 54 % and on light soils with a mineral nitrogen rate of 118 kg/ha an energy share of 33 %.

The amount of drying energy in total energy use was at the mineral N-fertilization treatments between 20,3% and 23,6 % (Figure 1). With increasing N fertilization the percentage of fuel energy of 21,1 decreased to 16.5%.

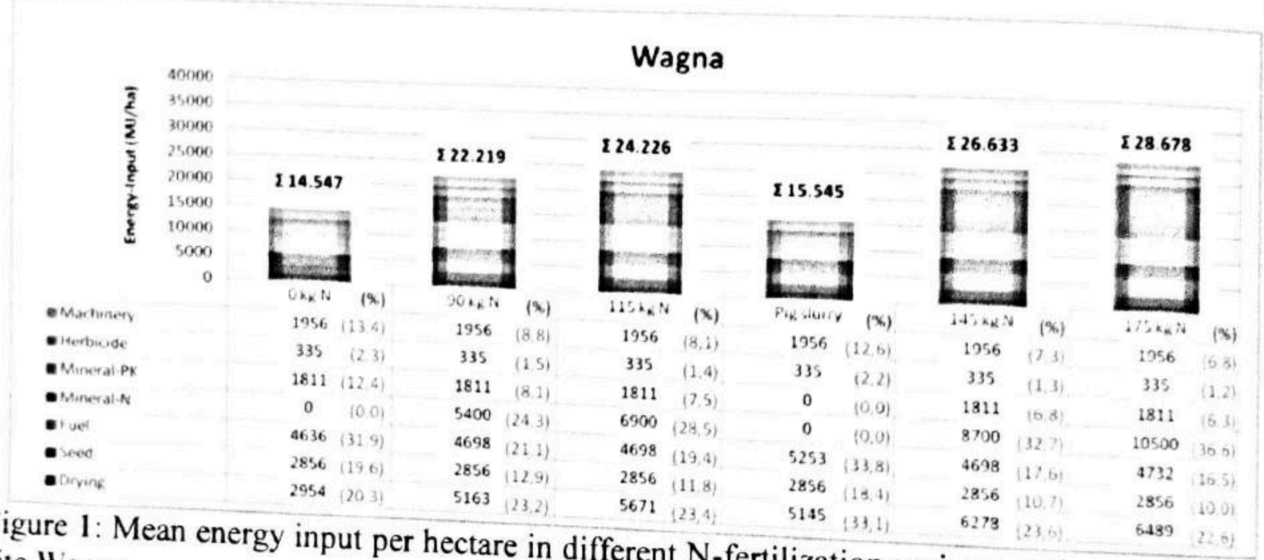

Figure 1: Mean energy input per hectare in different N-fertilization variants at the experimental site Wagna.

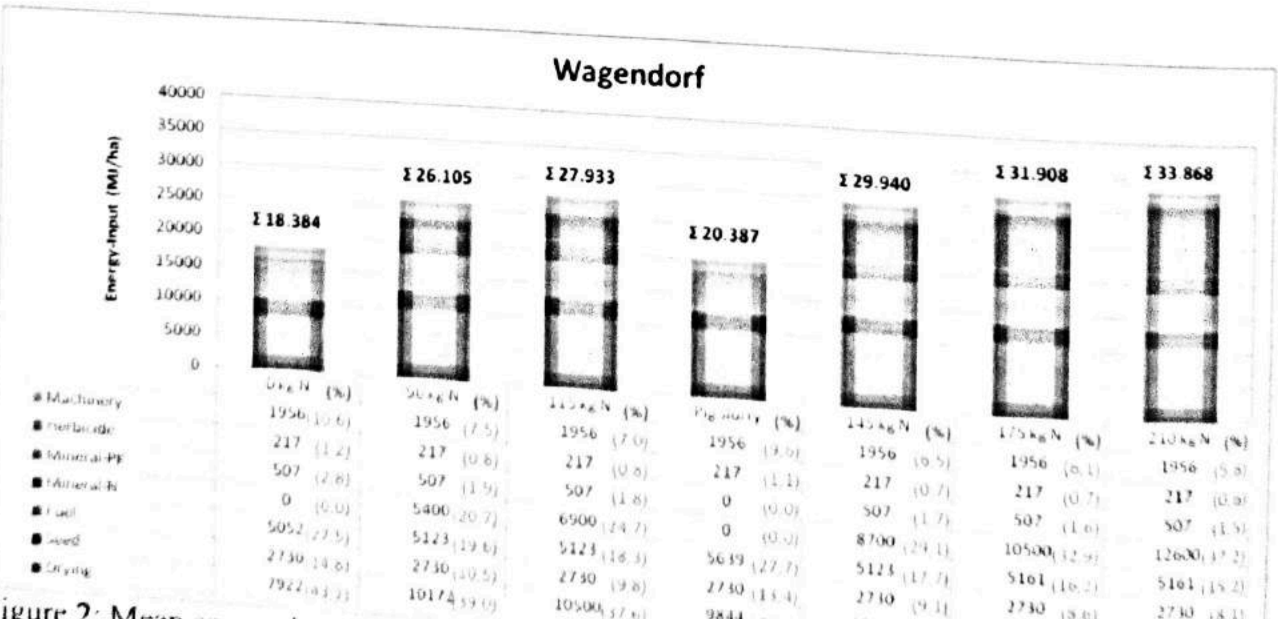

Figure 2: Mean energy input per hectare in different N-fertilization variants at the experimental site Wagendorf.

Energy efficiency

The lowest energy intensity at the highest energy output/input-ratio was reached with 110 kg N/ha at the site Wagna (Figure 3). The highest net energy output with 179 GJ/ha was achieved at a nitrogen rate of 175 kg/ha. The curve of the ratio of net energy output corresponds to the law of diminishing returns by E. A. Mitscherlich (1874-1956). The organic nitrogen fertilization treatment (pig manure with mean 135 kg N/ha), showed at an average netto-energy output of 150 GJ/ha , the lowest energy intensity of 1,75 MJ /kg of maize grain and the highest energy output/energy input-ratio of 10,6:1.

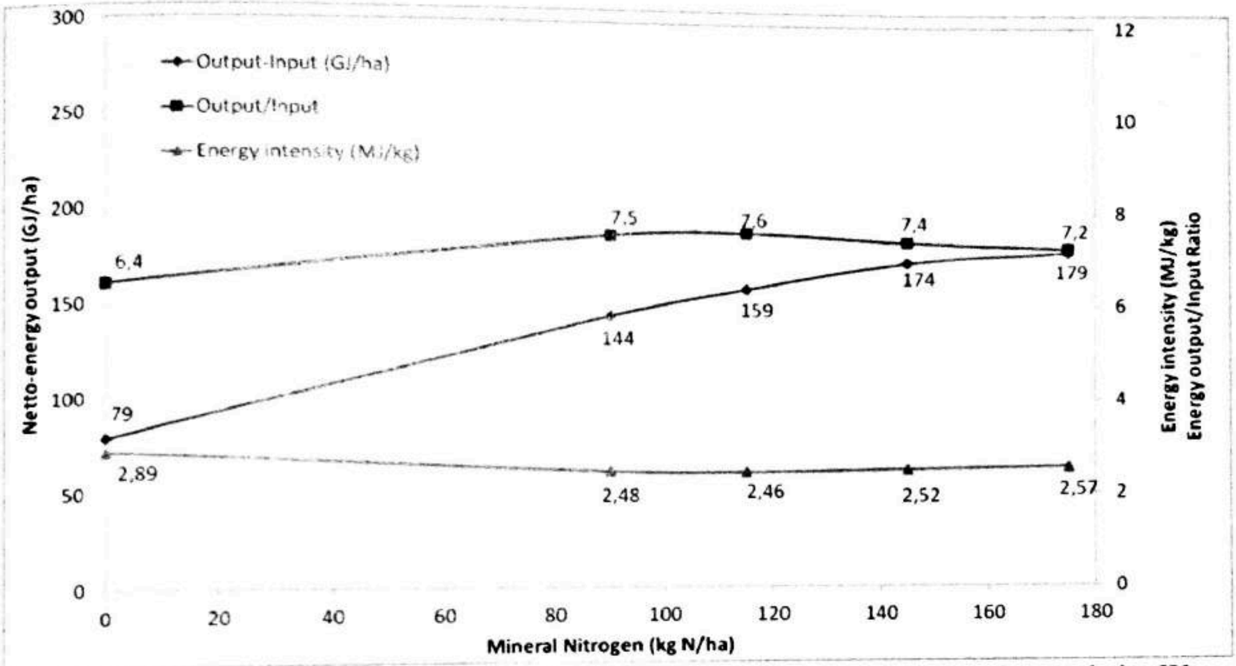

Figure 3: Energy efficiency at mineral N-fertilization variants at the experimental site Wagna

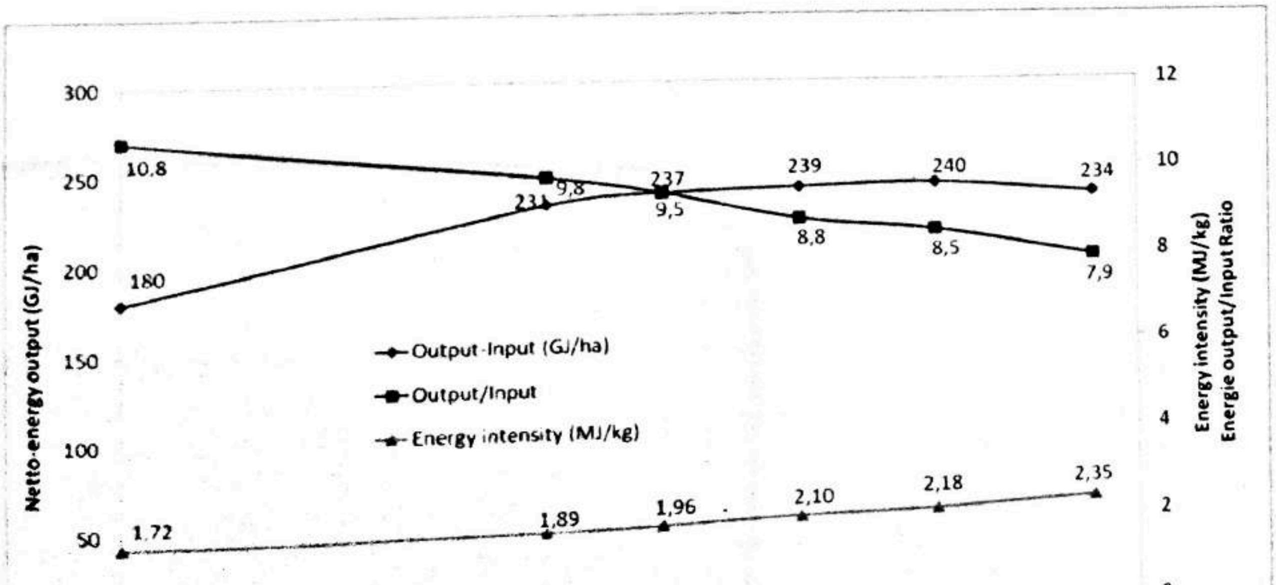

Figure 4: Energy efficiency at mineral N-fertilization variants at the experimental site Wagendorf

With the exception of the net energy output, the curves of the indicators energy intensity and energy output/energy input-ratio for the mineral N-fertilization treatments differed at the site Wagendorf (Figure 4). Compared with all mineral N-fertilization treatments showed the zero treatment (=0 kg N/ha), the lowest energy intensity of 1,72 MJ / kg with the highest energy output/energy input-ratio of 10,8:1. With increasing mineral fertilization the energy indicators (energy intensity and energy-output/energy-input ratio) were worse.

The fertilization variant with pig slurry reached at a net energy output of 228 GJ/ha , the lowest energy intensity of 1,53 MJ/kg and the highest energy-output/energy-input ratio of 12,2:1. The liquid organic manure is a valuable fertilizer in agriculture and provides with environmentally-friendly spreading technology (band spreading with trailing hoses) good yields with high energy efficiency.

CONCLUSION

The site with its characteristic soil and climate conditions had a large influence on energy efficiency in corn production. The nitrogen mineralisation for the organic matter at the very fertile site Wagendorf caused high corn yields. An additional soil organic matter and nitrogen balance can bring further insight, with which mineral N fertilization rate the humus-content can be sustainably stabilized. In comparison to the mineral nitrogen fertilization variants, the liquid organic manure variant reached the highest energy efficiency. Within the mineral nitrogen fertilization treatment at the site Wagna, the highest energy efficiency was achieved at 90 and 115 kg N/ha, while at the site Wagendorf it was in the zero treatment (0 kg N/ha). The following measures for the reduction of fossil energy use in grain maize can be derived: Location adapted nitrogen fertilizer - preferably with organic manure - and the use of renewable energy sources (heat from biomass district heating supply systems or biogas plants) in the maize grain drying.

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