Ecological Indicators 87 (2018) 144–151

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Original Articles

Emergy synthesis of conventional fodder maize (*Zea mays* L.) production in Denmark

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ARTICLE INFO

Keywords:
Fodder maize
Solar transformity
Emergy yield ratio
Environmental loading ratio
Environmental sustainability index

ABSTRACT

With the demand for animal protein on the rise, there is need for phenomenal increase in production of animal feed to meet the increasing demand. Among the feed production systems, conventional fodder maize acreage is increasing due to high yields and nutritional value of maize silage over other feeds. However, conventional fodder maize production systems are input intensive and there is a need to assess resource use in fodder maize production in Danish agriculture and in Europe in general. Hence, the objective of the study was to carry out emergy synthesis to evaluate the resource use in conventional fodder maize production. Among the renewables, rain input (3.08E + 14 seJ/ha) was the largest renewable component input and considered as the total renewable input into the production system. The purchased resources was the significant input constituting 80.5% (1.54E + 15 seJ/ha) of the total emergy. Among the purchased inputs, nitrogen consisted of the bulk of the input of 37.6% (7.18E + 14 seJ/ha), followed by phosphorus (19.5%) and diesel input (16.4%). The fodder maize yield was 3.12E + 7 kg ha^{-1} equivalent to output (Y) of 4.60E + 11 J/ha. The solar transformity was 4.15E + 03 seJ/J and the fraction of local renewables was 16%. Emergy yield ratio was 1.24 and environmental loading ratio was 5.2 whereas emergy sustainability index was 0.24. The study quantified the different inputs of renewables, local non-renewables and purchased inputs and used a range of emergy indicators to identify the gaps in resource use in fodder maize production. It was evident that purchased resources were the bulk of the input and management measures to improve the use efficiency of these inputs will enhance the emergy use efficiency. Hence, the study outputs are a useful resource for informed decision making to devise management measures by farmers, agricultural advisors and policy makers to optimize the inputs for sustainable production of fodder maize.

1. Introduction

The projected 70% increase in food production to feed 9.1 billion people by 2050 (Fess et al., 2011) is a daunting challenge faced today in the context of addressing global challenges of food security, climate change and sustainable energy supply (Hall et al., 2017). The conventional production system with intensive inputs of fertilizers and chemicals has increased the food and fodder to meet the increasing demand (Dawson et al., 2016; Roy, 2010). However, the conventional production systems are resource intensive and has adverse environmental impacts due to loss of applied fertilizers and chemicals into our environment, causing environmental and human health hazards (Mozner et al., 2012). Hence, there is need to account for economic and the environmental inputs in production systems to identify the sustainable food and fodder production systems. In this context, emergy synthesis (Jiang et al., 2007; Odum, 1996; Wu et al., 2014; Yang et al., 2010) is proposed, which takes into account economic and environmental inputs into consideration for comparison of and evaluation of resource use in production systems under different farming contexts (Bastianoni et al., 2001; Franzese et al., 2009; Ghaley and Porter, 2013; Hu et al., 2010; Lefroy and Rydberg, 2003; Singh et al., 2016; Wang et al., 2017, 2014).

Among the conventional input intensive production systems, conventional fodder maize production is gaining importance due to high yields and preference of maize silage for high nutritional content (Kumar et al., 2016; Rafiuddin Abdullah et al., 2017; Sah et al., 2017). With the increase in demand for animal feed, there is a trend in increasing fodder maize production, evident from the increase in fodder maize acreage in Europe and beyond (Ertiro et al., 2013). In Denmark in 2015, the farmed area of maize for fodder was 182,400 ha, an increase of 276% and 41% compared to 1999 and 2004 respectively

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https://doi.org/10.1016/j.ecolind.2017.12.027
Received 26 July 2017; Received in revised form 4 October 2017; Accepted 11 December 2017

(www.statbank.dk, accessed on 20.03.2017). The increase is attributed to the increase in fodder demand, facilitated by availability of robust maize cultivars for production in Danish pedo-climatic conditions (Odgaard et al., 2011). Given the phenomenal increase in production of fodder maize, there is a need to provide a field-based evidence of economic and environmental inputs in fodder maize production in Danish agriculture and in Europe, to facilitate informed decision-making by the farmers, advisory services and the policy makers. Hence, the objective of the study was to carry out emergy synthesis to evaluate the resource use in conventional fodder maize production in Denmark.

2. Materials and methods

2.1. Data collection on conventional fodder maize production

The information on the conventional fodder maize production was collected from five farms in Zealand and one farm in Fyn in Denmark. In these five farms, 40 fields with conventional fodder maize was identified and information on inputs of fertilizers and chemicals applied to these fields were collected. To maintain uniformity in fields identified, fields with coarse sandy, fine sandy, fine sandy clay and clay loam soils were selected. The information on the soil types and inputs in each field were provided by two farmer advisory services (Gefion and Patriotisk Selskab). The data on input application in each field are maintained by farmers in 'field sheets' and the advisory services provided the information with consent from the farmers. Where the data was missing, the information was supplemented from the local agriculture guidelines on fodder maize production.

2.2. Emergy synthesis

Emergy is the total energy used in creation of a product or a service and sometimes referred to as 'energy memory' and emergy of a product is the total energy used in the production or creation of the particular product or service (Brown et al., 2016; Brown and Ulgiati, 2016a; Tilley, 2015). The production or creation of products or services in ecological or economic systems makes use of various inputs like solar radiation, precipitation, machinery, fuel, fertilizer etc. and these inputs can be converted to a common unit of solar equivalent joules or solar emJoules (seJ) (Brown and Ulgiati, 2010). Emergy synthesis is an evaluation tool, which takes into account of the bought inputs from the economy and the 'free' inputs from the environment to assess a production process or product in terms of emergy use as a measure of sustainability (Chen et al., 2006). Higher emergy value is synonymous to higher time, material and energy input in the creation of the product or a process. Higher emergy value can also be defined as a process where higher amounts of energy is lost or dissipated in the creation of a product or process. Hence, emergy synthesis provides an integrated measure of resource use efficiency in a production activity or process taking account of the economic and ecological inputs on an equal footing to assess the environmental loading or impacts of the activity in question.

2.3. Emergy synthesis of conventional fodder maize production

For the emergy synthesis, boundaries are drawn at the outset of the study to take account of the different inputs and outputs crossing the boundary of the production system. The boundary in this study is the field border, where crops are produced but does not include the transport following harvest. The inventory of inputs are shown in Fig. 1 and categorized as local renewables (R), local non-renewables (N) and purchased (F) and the sum total of R + N + F = U is the emergy value of the production system(Amaral et al., 2016; Shao and Chen, 2016). R inputs can be replaced at a faster rate than its use and includes solar radiation, wind and precipitation. In contrast, N inputs are used at a faster rate than its replacement and includes top soil loss. F are the inputs from the economy like machinery, fuel, manure, fertilizers, human labour and services. Human labour consisted of man-hours required for preparation of land, sowing, weeding, fertilization and harvesting whereas services account for the purchased inputs (item 5–13 in Table 1) except human labour to avoid double counting. The diversity of inputs in joules, grams and dollars were converted into common unit of seJ by multiplying with the solar transformity coefficients. The solar transformity coefficients are based on the updated global emergy flow of 15.83E24 seJ/year (Odum et al., 2000).

2.4. Emergy indices

Emergy Indices are useful tools to compare the production systems by taking account of the economic and environmental inputs on equal footing. The emergy indices (Brown and Ulgiati, 2016b; De Vilbiss et al., 2016; Wright and Ostergard, 2016) used in this study are

a. Relative yields: Relative yields of compared field studies were carried out by taking fodder maize yield in Denmark as 1 and calculating other crop yields as a percentage of fodder maize
b. Output (Y): The output of a production system is the sum total of main yields and by-product yields expressed in kgs and joules.
c. Total emergy use (U): Total emergy use is the sum total of local renewables, local non-renewables and purchased inputs.
d. Solar transformity (U/Y): The ratio of the total emergy used in creation or production of a product to the available energy in the product and expressed as seJ/J. Emergy transformity is a measure of the energy quality of a product and higher the transformation of energy in the formation of the product, higher is the energy quality.
e. Emergy yield ratio (EYR): It is the ratio of the total emergy input per purchased inputs (U/F): and the ratio is used as the indicator of purchased inputs use efficiency by the production system and its contribution to the wider economy. The value of EYR can be one or higher. Higher EYR is synonymous to higher yields per purchased inputs with positive knock-on effects on wider economy and lower EYR indicates inefficiency.
f. Percentage of local renewable resource use (R/R + N + F) is the percentage of local renewable resource use of the total emergy use in the production system.
g. Environmental loading ratio (ELR): It is the ratio between the total purchased and local non-renewables to the local renewables ([(F + N)]/R). Higher ELR indicates higher environmental adverse impacts and lower sustainability in a production system and vice versa.
h. Emergy sustainability index (ESI): It is the integrated measure of economic and environmental sustainability of a production system and calculated as a ratio of EYR/ELR. Higher ESI values indicate sustainable practice with minimum environmental loadings.

2.5. Uncertainty in study methodology

The fodder maize yields can vary from year to year, depending on the combination of environmental, management, plant-related and soil-based factors. Our study used inputs and fodder yields from only one growing cycle, which may have high uncertainty. We addressed the uncertainty attached to single year data by collecting the data from several fields in each farm (40 fields in five farms) to work out mean inputs and yields to reduce the uncertainty in study outcome. The nitrogen and phosphorus input emergy constituted more than half of the total emergy use and the individual management measures at the farm level to substitute part of nitrogen fertilizer with manure or use nitrogen-fixing legumes to compensate for nitrogen fertilizer, can reduce total emergy use substantially, indicating the uncertainty of the study methodology and its relevance under diverse farming environments.

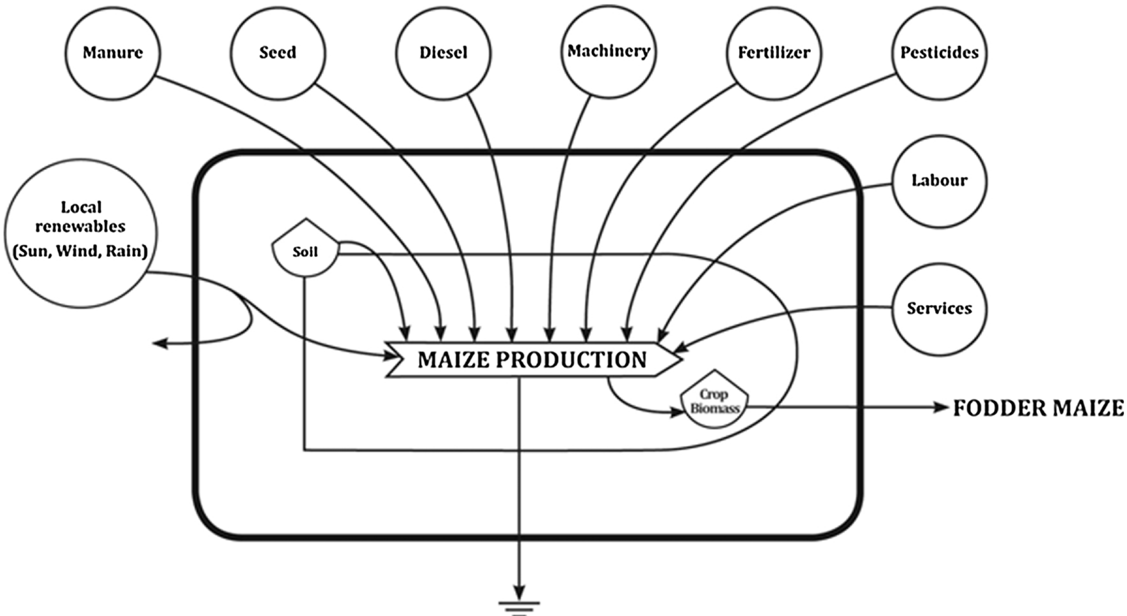

Fig. 1. Overview of inputs used for Emergy synthesis of conventional fodder maize production.

Table 1
Inventory of inputs in 1 ha conventional fodder maize production in Denmark.

Input category	Inputs	Units	Input amounts	Solar emergy/unit (seJ/unit)	Ref. for transformity	Solar emergy (seJ/ha)	Emergy%
Local renewable resources (*R*)							
1	Solar radiation	J/ha	3.05E + 13	1.00E + 00	[1]	3.05E + 13	1.6
2	Wind	J/ha	4.68E + 10	2.45E + 03	[1]	1.15E + 14	6.0
3	Rain	J/ha	1.02E + 10	3.02E + 04	[1]	3.08E + 14	16.1
Sum of R						**3.08E + 14**	
Local non-renewable resource (*N*)							
4	Top soil loss	J/ha	5.14E + 08	1.24E + 05	[2]	6.37E + 13	3.3
Sum of N						**6.37E + 13**	
Purchased resources (F)							
5	Diesel	J/ha	2.82E + 09	1.11E + 05	[3]	3.13E + 14	16.4
6	Machinery	$/ha	4.50E + 02	1.95E + 10	[3]	8.78E + 12	0.5
7	Seed	g/ha	3.08E + 04	3.90E + 08	[3]	1.20E + 13	0.6
8	Pesticides	$/ha	6.03E + 02	1.95E + 10	[3]	1.18E + 13	0.6
9	Nitrogen	g/ha	2.98E + 04	2.41E + 10	[3]	7.18E + 14	37.6
10	Phosphorus	g/ha	1.69E + 04	2.20E + 10	[4]	3.72E + 14	19.5
11	Sulphur	$/ha	1.74E + 00	1.95E + 10	[4]	3.39E + 10	0.0
12	Magnesium	$/ha	2.56E-01	1.95E + 10	[4]	4.99E + 09	0.0
13	Manure	g/ha	3.68E + 05	2.13E + 08	[5]	7.84E + 13	4.1
14	Labour	$/ha	2.25E + 02	1.95E + 10	[5]	4.39E + 12	0.2
15	Services	$/ha	9.33E + 02	1,95E + 10	[5]	1.82E + 13	0.9
Sum of (F)						**1.54E + 15**	
Total emergy use (U)						**1.91E + 15**	
Output (Y)							
16	Fodder Maize production	gm/ha	3.12E + 07		[6]	4.60E + 11 J/ha	
		J/gm	1.47E + 04				

Solar transformity values are based on update global emergy value of 15.83E + 24 SeJ/year. Appendix A shows the calculations under input amounts in Table 1. Reference sources:
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3. Results

3.1. Local renewables and local non-renewables

Among the renewables, rain input (3.08E + 14 seJ/ha)(Table 1) is the largest renewable component input and is considered as the total renewable input into the production system due to the fact that solar radiation, wind and rain are co-products of coupled climatological processes. Rain input constituted 16.1% of the total emergy use in the fodder maize production system, compared to solar radiation and wind constituting only 1.6 and 6.0% of total emergy use respectively.

Soil erosion is counted as non-renewable because the soil loss accruing due to the production cannot be replaced within the cultivation year and can take decades for the same amount of soil to be formed and replaced. Soil erosion depends on the vegetation type and soil cover and fields cropped with annual row crops like maize are particularly vulnerable to soil erosion due to wind, precipitation and surface run-off. Soil erosion constituted 6.37E + 13 seJ/ha (Table 1), equivalent to 3.3% of the total emergy use.

3.2. Purchased resources

The purchased resources was the significant input constituting 80.5% (Table 1) of the total emergy use in fodder maize production. Among the purchased inputs, nitrogen consisted of the bulk of the input of 37.6% (7.18E + 14 seJ/ha), of the total emergy use, followed by phosphorus (19.5%) and diesel input (16.4%) (Table 1). Nitrogen and Phosphorus input consisted of 57.1% of the total emergy use in fodder maize production system, demonstrating the dependence of the fodder maize production on non-renewable purchased resources. Manure provided 7.84E + 13 seJ/ha, constituting 4.1% of the total emergy use. The other inputs like seeds, pesticides, labour and services were minimal and each of these inputs were < 1% of the total emergy use.

3.3. Emergy indices for evaluation of fodder maize production system

The different emergy indices, used to evaluate the fodder maize production in Denmark is provided in Table 2. The fodder maize yield was 3.12E + 7 kg/ha equivalent to output (Y) of 4.60E + 11 J/ha and the solar transformity was to 4.15E + 03 seJ/J. The fraction of local renewables was 16% implying that 16% of the total emergy use was local renewables (rain input). EYR was 1.24 and EYR is the efficiency of investment from the economy to exploit the local resources and the value can be one or higher and higher EYR implied more efficient use of inputs. ELR was 5.2, which is the ratio of purchased and local non-renewables input to local renewable input and higher ELR indicates more environmental stress and vice versa. ESI value was 0.24, which is the ratio of EYR/ELR, an integrated measure of ecological and economical resource use and higher values indicates more compatibility with the local environment and vice versa.

Table 2
Emergy indices for evaluation of conventional fodder maize in Denmark.

Emergy indices	Formula	Conventional fodder maize
Output (J/ha/year)	Y	4.60E + 11
Solar transformity (seJ/J	U/Y	4.15E + 03
Fraction of local renewables	R/[(R + N + F)]	0.16
Emergy yield ratio (EYR)	U/F	1.24
Environmental loading ratio (ELR)	(F + N)/R	5.20
Emergy sustainability index (ESI)	EYR/ELR	0.24

4. Discussion

Different emergy indices were used to evaluate the fodder maize production in Denmark (Table 2). To compare the fodder maize productivity with other similar studies, relative yields from other field studies were compared with fodder maize yield in Denmark. Among the production systems investigated, conventional fodder maize had the highest yields, followed by maize production (0.66) in China (Wang et al., 2014), and CFE (0.61) in Denmark (Ghaley and Porter, 2013) whereas the lowest relative yields were obtained in lupin-wheat (0.08) rotation in Australia (Lefroy and Rydberg, 2003) and corn production (0.24) in Italy (Franzese et al., 2009). Hence, fodder maize production was higher than the other production systems compared in Denmark. The high production is the outcome of the combined effect of fertilizer and chemical input and robust maize cultivars available in Denmark. High production potential of fodder maize made use of the resource inputs more efficiently compared to the other production systems in the local context.

The output (Y) indicates the efficiency of the production system in converting the inputs into economic yields. The Y of fodder maize production system was higher by 67% and 39% compared to conventional wheat production system and combined food and energy production (CFE) systems respectively in Denmark (Ghaley and Porter, 2013). The higher yields in fodder maize production is evident as the whole plant was harvested while they are still green for fodder compared to grain yields. In a wheat-maize double cropping system in China, the Y of wheat was 43% lower (Wang et al., 2017) compared to this fodder maize study whereas a study on corn production system in Italy found 76% (Franzese et al., 2009) lower Y compared to this study. Hence, fodder maize production was higher compared to grain yield production, as evident from this study.

The percentage of renewable resource use exhibits the extent of the use of the locally available resources like wind, solar radiation and precipitation for the production activity and the reliance on the economy to support the production system. Of the total emergy use in fodder maize production, the renewable resource input was significantly higher (16%) (Table 2) compared to the conventional wheat production system (3%) but lower than combined food and energy production system (19%) (Ghaley and Porter, 2013). As the input of the renewable input of rain was compared per hectare in the same locality/region in Denmark, the fields received similar inputs of rain and the difference in renewable input fraction depended on the share of the renewable resource inputs out of the total emergy use. The higher percentage of renewable emergy input in combined food and energy is due to the fact that no inputs of chemicals and fertilizers were applied to the system and, so the total emergy used is less and the fraction of renewable resource input is higher relative to the total emergy use. Conversely, conventional wheat production system is characterized by high emergy use due to application of fertilizers and chemicals and hence the fraction of renewable resource input is smaller relative to the higher emergy use. This demonstrated that fodder maize production system is less emergy-demanding compared to the conventional wheat production and compares well with the combined food and energy production system (Ghaley and Porter, 2013) with no external inputs.

Solar transformity in fodder maize production was 54% lower compared to CFE system (Ghaley and Porter, 2013) in Denmark indicating that fodder maize production is more efficient in emergy use per kg of yield produced compared to the CFE. The solar transformity in conventional wheat production was 20.8 times higher compared to fodder maize production and higher productivity in fodder maize production is the reason for low transformity even though intensive inputs of chemicals and fertilizers, were applied in both production systems. The corn production in Italy had 17.7 times (Ulgiati, 2001) higher transformity compared to the current fodder maize study as the corn production accounts for only grain yield whereas the fodder maize production has much higher biomass yields. Hence, the fodder maize production is an efficient production system compared to other systems compared herein, due to high biomass yields.

Emergy yield ratio (EYR) is the total emergy use per unit of purchased input and higher values indicate more efficient emergy use and vice versa. In agriculture production, the local renewable inputs like solar radiation, rain and wind are combined with local non-renewable and purchased inputs and EYR is the emergy use per unit of purchased inputs. The fodder maize production had higher EYR (1.24) compared to CFE (1.03) but lower than conventional wheat production (1.26) system in Denmark (Ghaley and Porter, 2013) demonstrating that emergy use efficiency per unit of purchased inputs was higher in fodder maize production compared to CFE but lower than conventional wheat (Ghaley and Porter, 2013). The present study had EYR value of 1.24, in similarity, to a study on wheat-maize system (1.26) with mineral fertilizer inputs (Wang et al., 2017) but lower EYR than wheat-maize study (2.35) (Wang et al., 2014) in China. The traditional EYR values are criticized for not taking account of the emergy input in the form of recycled biomass in agricultural systems and its effects on system's sustainability. If the recycled biomass was taken into account in EYR value, the modified EYR, in our study, will decrease, as evident from the decrease of modified EYR to 1.02 from 1.26 in the wheat-maize production system in China (Wang et al., 2017). Environmental loading ratio (ELR) of the fodder maize production system was much lower (5.20) compared to the conventional wheat production (37.77) but higher than CFE system (4.21) (Ghaley and Porter, 2013). This indicated that conventional wheat production was using much more purchased and non-renewable inputs per unit of local renewable inputs and so, the fodder maize and CFE are more environment friendly and less demanding to the environment.

The fodder maize ELR (5.2) was similar to lupin/wheat rotation system (5.5) (Lefroy and Rydberg, 2003) in Southwestern Australia whereas higher ELR were reported in intensive wheat-maize production system (6.72) (Wang et al., 2014) and lower ELR (2.67) was reported from traditional maize production system in China (Zhang et al., 2012). A study on grape cultivation had lower ELR of 4.37 compared to the current study (Feng et al., 2015). The fodder maize had lower ELR except CFE and traditional maize production system in China indicating that the system is less environment damaging compared to other systems compared in this study.

Emergy sustainability index (ESI) is the ratio of EYR to ELR. Higher ESI value indicate higher ecological and economic sustainability and the fodder maize production systems had higher (0.24) sustainability compared to conventional wheat production systems (0.03) but lower than CFE (0.30) (Ghaley and Porter, 2013). The fodder maize exhibited lower ESI (0.24) compared to wheat-maize system (0.70) in China (Wang et al., 2017). In similarity to EYR, the mode of ESI calculations are criticized for not taking account of the emergy input in terms of recycled biomass to calculate a modified ESI. The modified ESI will decrease in our study, as shown in the wheat-maize study in China (Wang et al., 2017), where modified ESI decreased to 0.57 from 0.70. ESI values indicated that the fodder maize production system was less sustainable compared to wheat-maize production in China (Wang et al., 2017). In a study in China, grains produced in large scale farms had higher ESI value of 5.02 (Wang et al., 2014) compared to fodder maize production system. In another traditional maize production system in China, an ESI value of 0.45 was reported (Zhang et al., 2012), much higher than our findings but in similarity to ESI value of 0.23 in grape cultivation (Feng et al., 2015). Hence, ESU values provides an integrated assessment for comparison of production systems in terms of sustainability.

5. Conclusions

The study on fodder maize production demonstrated that the high biomass yield translated into higher emergy use efficiency and the output (Y) and relative yields were the highest in conventional fodder maize production. Due to high yields, the solar transformity was lower compared to CFE and conventional wheat in Denmark, indicating that lower emergy was used per unit production of output. The% renewables input was slightly lower than CFE but higher than conventional wheat production system. EYR was similar to CFE but much higher than conventional wheat in Denmark. Similarly ELR was similar to CFE but much lower than conventional wheat and ESI was higher in similarity to CFE compared to the conventional wheat in Denmark. The study quantified the different inputs of renewables, local non-renewables and purchased inputs and used a range of emergy indicators to assess the resource use in fodder maize production. It was evident from the study that the purchased resources viz. diesel, nitrogen and phosphorus constituted 73.5% of the total emergy use and management measures to either decrease the input use or increase the use efficiency to get the same yield, will improve the emergy use. The management measures can range from combination of cultural practices to reduce the machinery and diesel use, point application of nitrogen and phosphorus to reduce input and adoption of elite maize cultivars with higher physiological efficiency to convert nutrients into biomass. Hence, the study outputs are a useful resource for informed decision making to devise management measures by farmers, agricultural advisors and policy makers to optimize the inputs for sustainable production of fodder maize in Denmark.

Acknowledgements

We appreciate the financial support from SustainFARM project (Grant Agreement No: 652615) for funding the collation of field data from the farmers. The support from WATERFARMING (Grant Agreement No: 689271) and LANDMARK (Grant Agreement No: 635201) projects are acknowledged for data analysis and preparation of the final manuscript.

Appendix A

Input amounts calculation in Table 1

1. Solar radiation

Area cultivated = 10,000 m^2

Insolation = 3.81E + 09 J/m^2/ha (DMI, 2015)

Albedo = 0.2 (Haden, 2003)

Solar radiation = (Area cultivated) × (insolation) × (1-albedo) (Brandt-Williams, 2001)

= (10,000 m^2) × (3.81E + 09 J/m^2/ha) × (1–0.2)

= 3.05E + 13 J/ha

2. Wind energy

Area cultivated = 10,000 m^2

Density of wind = 1.3 kg/m^3 (Odum, 1996)

Drag coefficient = 1.00E-03 (Odum et al., 2000)

Wind velocity = 4.85 m/s (DMI, 2015)

Time = 3.15E + 07 s

Wind energy = (Area cultivated) × (density of wind) × (drag coefficient) × (wind velocity)^3 × (time) (Odum et al., 2000)
= (10000 m^2) × (1.3 kg/m^3) × (1.00E-03) × (4.85 m/s)^3 × (3.15E + 07 s)
= 4.68E + 10 J/ha

3. Rain, evapotranspiration

Area cultivated = 10,000 m^2
Precipitation average = 0.65215 m/ha (DMI, 2015)
Run-off coefficient = 0.317 (Hansen and Nielsen, 1995)
Gibbs free energy = 4.94 J/g
Conversion = 1.00E + 06 g/m^3
Rain energy = (Area cultivated) × (precipitation average) × (run-off coefficient) × (Gibbs free energy) × (conversion) (Brandt-Williams, 2001)
= (10000 m^2) × (0.65215 m/yr) × (0.317) × (4.94 J/g) × (1.00E + 06 g/m^3)
= 1.02E + 10 J/ha

4. Top soil loss

Area cultivated = 10,000 m^2
Erosion rate (cereals, loamy soil) = 4.55E + 01 g/m^2/ha (Coppola et al., 2009)
% Organic matter in soil = 5.00E-02 (Coppola et al., 2009)
Energy content/g organic = 2.26E + 04 J/g (Coppola et al., 2009)
Energy of top soil loss = (Area cultivated) × (erosion rate) × (% organic matter) × (energy content)
= (10,000 m^2) × (4.55E + 01 g/m^2/ha) × (5.00E-02) × (2.26E + 04 J/g)
= 5.14E + 08 J/ha

5. Diesel

Area cultivated = 1 ha
Quantity = 6.49E + 04 g/ha (Field data)
Energy content = 4.34E + 04 J/g
Diesel energy = (Area cultivated) × (quantity) × (energy content)
= (1 ha) × (6.49E + 04 g/ha) × (4.34E + 04 J/g)
= 2.82E + 09 J/ha

6. Machinery

Area cultivated = 1 ha
Cost = 4.50E + 02 $/ha (Videncentret for landbrug, 2014)
Total cost = (Area cultivated) × (cost)
= (1 ha) × x (4.50E + 02 $/ha)
= 4.50E + 02 $/ha

7. Seed

Area cultivated = 1 ha
Quantity = 3.08E + 04 g/ha (field data)
= (Area cultivated) × (quantity)
Total use = (1 ha) × (3.08E + 04 g/ha)
= 3.08E + 04 g/ha

8. Pesticides

Area cultivated = 1 ha
Cost = 6.03E + 02 $/ha (field data)
Total cost = (Area cultivated) × (cost)
= (1 ha) x (6.03E + 02 $/ha)
= 6.03E + 02 $/ha

9. Nitrogen

Area cultivated = 1 ha
Quantity = 2.98E + 04 g/ha (field data)
Total use = (Area cultivated) × (quantity)
= (1 ha) × (2.98E + 04 g/ha)
= 2.98E + 04 g/ha

10. Phosphorus

Area cultivated = 1 ha
Quantity = 1.69E + 02 g/ha (field data)
Total use = (Area cultivated) × (quantity)
= (1 ha) × (1.69E + 02 g/ha)
= 1.69E + 04 g/ha

11. Sulphur

Area cultivated = 1 ha
Quantity = 4.70E + 03 kg/ha (field data)
Cost = 0.37 $/kg (Videncentret for landbrug, 2014)
Total cost = (Area cultivated) × (quantity) × (cost)
= (1 ha) × (4.70E + 03 kg/ha) × (0.37 $/kg)
= 1.74E + 00 $/ha

12. Magnesium

Area cultivated = 1 ha

Quantity = 4.65E + 02 kg/ha (field data)
Cost = 0.55 $/kg (Videncentret for landbrug, 2014)
Total cost = (Area cultivated) × (quantity) × (cost)
= (1 ha) × (4.65E + 02 kg/ha/ha) × (0.55 $/kg)
= 2.56E-01 $/ha

13. Organic manure

Area cultivated = 1 ha
Quantity = 3.68E + 05 g/ha (field data)
Total use = (Area cultivated) × (quantity)
= (1 ha) × (3.68E + 05 g/ha)
= 3.68E + 05 g/ha

14. Labour

Area cultivated = 1 ha
Cost = 2.25E + 02 $/ha (Videncentret for landbrug, 2014)
Total cost = (Area cultivated) × (cost)
= (1 ha) × (2.25E + 02 $/ha)
= 2.25E + 02 $/ha

15. Services

Area cultivated = 1 ha
Cost = 9.33E + 02 $/ha (Videncentret for landbrug, 2014)
Total cost = (Area cultivated) × (cost)
= (1 ha) × (9.33E + 02 $/ha)
= 9.33E + 02 $/ha

16. Output

Area cultivated = 1 ha
Quantity = 3.12E + 04 kg/ha (field data)
Total output = (Area cultivated) × (quantity)
= (1 ha) × (3.12E + 04 kg/ha)
= 3.12E + 04 kg/ha

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