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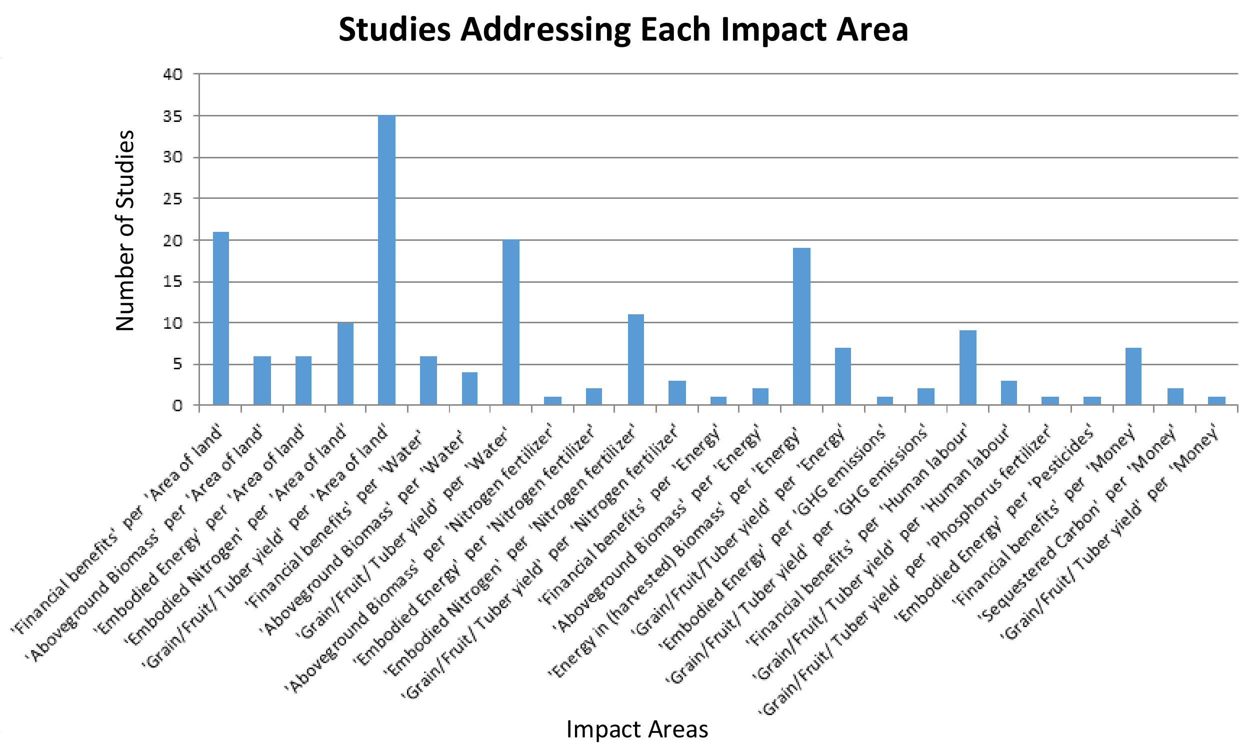


In Figure 1, the x-axis indicates the impact areas, and the number of studies is represented by the y-axis. 274 Literatures have been analyzed and among these 274 Literatures, 85 papers are accepted that address 25 impact areas.

We access the units of indicators for peer review. In order to derive the indicators for the assessment of Resource Use Efficiency in the context sorted the indicators. Figure 1 shows what indicators are addressed and how often.

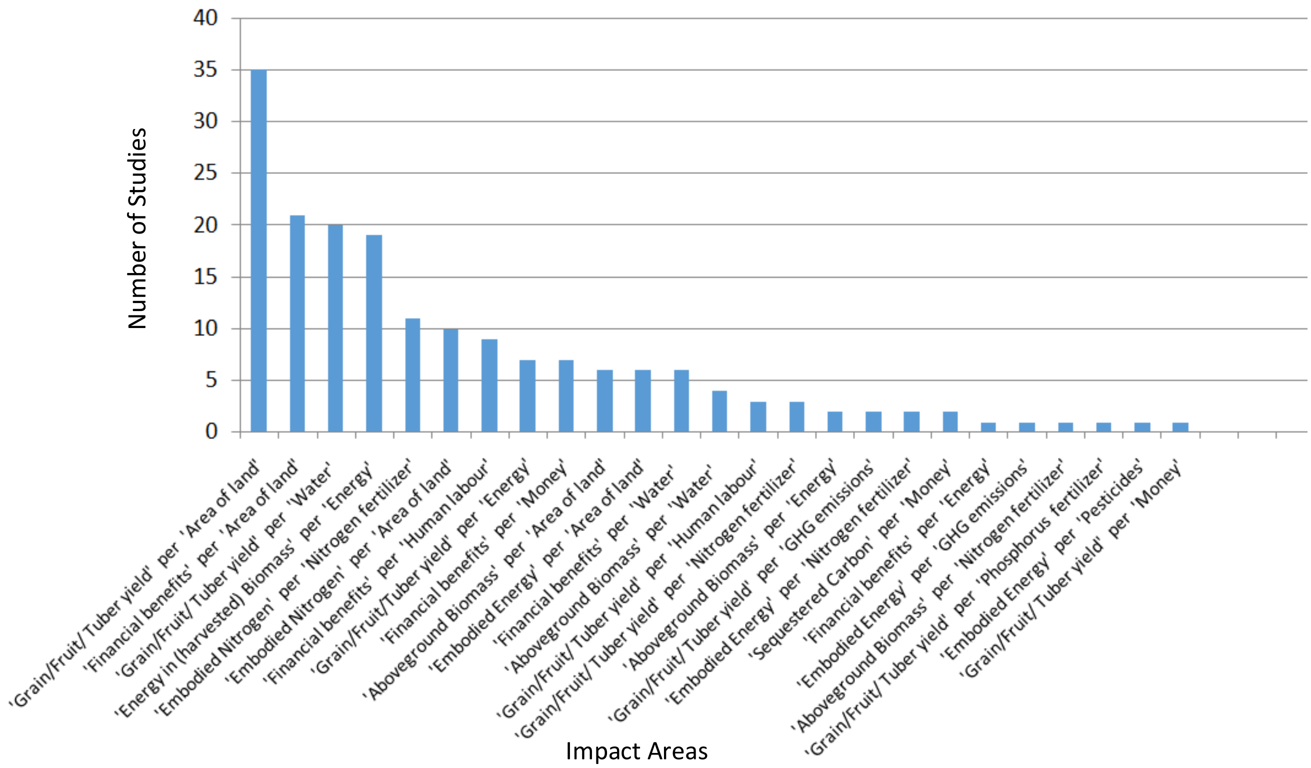


Figure 2 shows the highest to lowest numbers of studies addressing a total of 25 impact areas.

Impact Area: **Benefits** per **Area**

Definition:

$$\frac{Financial\ benefits}{Area\ of\ land}$$

Description:

Benefit: This impact area assesses benefits via their appreciation by markets (Di Maio et al., 2017). It is sensitive to various socio-economic factors because commodity prices reflect demand and are also influenced by value systems and policies through effects of financial incentives and tax regulations.

Resource: Agricultural land is always a limited resource. The type of land can be specified to distinguish between different land qualities. Distinctions are often made, for example, between cropland and pasture, high nature value (HNV) farmland and other farmland, or based on soil fertility and yield potential. For this indicator, the temporal reference must always be specified. However, in case of the standard period of one year, this information is sometimes omitted in scientific publications.

Correlation with soil management:

[26] Organic farms recorded higher operating profit (operating profit + subsidies) per hectare of farmland than conventional farms

[55] Cooperatives have higher revenue per area of land than single farms

[133] The production in agriculture is associated with quality standards of lands, nature and conditions of their use

[149] Smaller farms are more efficient in land productivity

[162] Studies proved reduction of field crop yields from organic fields in comparison to conventional ones

[182] Improving the conditions of mineral nutrition by introducing balanced doses of fertilizers for all elements contributed to a sufficiently high yield

[207] Nitrogen utilization efficiency played a significant role in determining grain yield, while a negative and poor dependence of grain yield on Nitrogen uptake efficiency was observed

[241] Highest land use efficiencies (potato yield per hectare of area) were achieved in regions that produce potatoes under irrigation in summer where solar radiation is high and lowest land use efficiencies were reported for the predominantly dry land and partially dry land regions

[248] Small rice-producing farms ranging from 0.61 to 1.0 ha yielded higher energy ratios (4.14) than larger ones

Strength &weaknesses pertaining to measurement of this impact area

Financial Benefits: Financial indicators are well suited for integrating or comparing agricultural production processes with products for very different end uses. For calculating benefit-cost ratios (BCR), indicators that reflect revenue should be used. In most other cases, indicators that reflect net benefits (after deduction of charges, costs and expenses) provide a more realistic picture of benefits generated. Price volatilities make efficiency calculations valid only for a certain point in time and space.

Area of land: While area of land is a standard measure that is used as reference in most statistics and inventories, a weakness of this indicator is that other relevant information like soil type, soil fertility or management history is often not provided.
In short, one hectare of dry, sandy cropland soil is very different from one hectare of pasture on drained peat soils.

Sample Indicators

Indicator values from		Survey	
Experiment or direct measurement		Statistical- or census data	
Expert assessment		Literature values	
Model		Maps or GIS	
Stakeholder participation		Not provided	

Table 1: No Scale

Indicator	**Unit**	**Indicator values from**
[55] Production output/Area of land	$ * ha^{-1}	

Table 2: Field Scale

Indicator	**Unit**	**Indicator values from**
[207] Net income/Area of land	$ * ha^{-1}	

Table 3: Farm Scale

Indicator	Unit	Indicator values from
[26] Operational efficiency (Operational profit/Area of land)	$\$ * ha^{-1}$	
[26] Operational efficiency (including subsidies)(Operational profit + subisidies/Area of land)	$\$ * ha^{-1}$	
[26] Accounting profit/Area of land	$\$ * ha^{-1}$	
[62] Total gross margin/Area of land	$\$ * ha^{-1}$	
[149] Land productivity (Total income generated from farming during a year/Cultivated area of land)	$\$ *$ Not specified^{-1}	
[162] Additional income from fertilization (Additional yields from fertilization*price of products)/Area of land	$\$ * ha^{-1}$	
[162] Additional profit from fertilization/Area of land	$\$ * ha^{-1}$	
[162] Residual effect of fertilization-additional profit/Area of land	$\$ * ha^{-1}$	
[175] Average price (Gross income/Area of land)	$\$ * ha^{-1}$	
[175] Operating margin (Gross margin/Area of land)	$\$ * ha^{-1}$	
[176] Value of gross product/Fodder area	$\$ * ha^{-1}$	,
[176] Net agricultural income (Prices of inputs or sold products)/Fodder area	$\$ * ha^{-1}$	,

Table 4: Regional Scale

Indicator	Unit	Indicator values from
[1] Value of yields (including subsidies)/Agricultural land	$\$ * ha^{-1}$	
[1] Added value/Agricultural land	$\$ * ha^{-1}$	
[100] Agricultural profitability (Profit contribution (revenue - costs)/Area of land)	$\$ * ha^{-1}$	
[133] Land productivity (Value of yields/Area of land)	$\$ * ha^{-1}$	
[182] Gross value of winter wheat/Area of land	$\$ * ha^{-1}$	
[241] Gross profit/Area of land	$\$ * ha^{-1}$	
[248] Net Economic gain [Monetary unit]/Area of land	$\$ * ha^{-1}$	,

References

ID	Citation	[1]Soil type/ texture
1	Adamisin, P., et al. (2015). "Natural climatic conditions as a determinant of productivity and economic efficiency of agricultural entities." Agricultural Economics-Zemedelska Ekonomika 61(6): 265-274.	n/a
26	Brožová, I. and J. Vanek (2013). "Assessment of economic efficiency of conventional and organic agricultural enterprises in a chosen region." Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis **61**(2): 297-307.	n/a
55	Dambaulova, G. K., et al. (2017). "Rural consumer cooperative and efficiency of production systems in agrarian and industrial complex." International Journal of Economic Perspectives **11**(3): 1150-1156.	n/a
62*	Dhehibi, B., et al. (2015). "Impacts of soil salinity on the productivity of Al-Musayyeb small farms in Iraq: An examination of technical, economic and allocative efficiency." Agricultural Economics Review **16**(2): 42-55.	Mainly silty loams or loamy silts
100*	Hagen, Z. (2012). "A basic design for a multicriteria approach to efficient bioenergy production at regional level." Energy, Sustainability and Society **2**(1): 1-17.	n/a
133	Kozhukhivska, R., et al. (2018). "Managing the efficiency of enterprises based on assessment of the land resource potential." Problems and Perspectives in Management **16**(2): 164-178.	Acidic soils (pH < 5.5); -Typical black soils and strongly regraded black soils occupy 53.7% of the region -Dark gray podzolized regraded soils and weakly regraded podzolized black soils occupy 28.9% -Light gray and gray podzolized soils are 7.3%
149*	Li, G., et al. (2013). "Re-examining the inverse relationship between farm size and efficiency: The empirical evidence in China." China Agricultural Economic Review **5**(4): 473-488.	n/a
162	Manolova, V., et al. (2015). "Economic efficiency of fertilization and its residual-effect during conversion period to organic field crop production." Bulgarian Journal of Agricultural Science **21**(5): 1022-1026.	n/a

[1]**Soil type/ texture:** If provided, what are type and texture of the soils studied in the paper?

*The impact area discussed on this factsheet is not a focus of the cited paper

175	Moore, A. D., et al. (2011). "Evaluation of the water use efficiency of alternative farm practices at a range of spatial and temporal scales: A conceptual framework and a modelling approach." Agricultural Systems **104**(2): 162-174.	Black vertosol soil
176	Moreau, P., et al. (2012). "Reconciling technical, economic and environmental efficiency of farming systems in vulnerable areas." Agriculture Ecosystems & Environment **147**: 89-99.	Deep loamy and shallow brown soils
182	Neshchadim, N. N., et al. (2018). "Bioenergetic assessment and economic efficiency of predecessors and fertilizer systems in the cultivation of winter wheat." International Journal of Engineering and Technology(UAE) **7**(4.38 Special Issue 38): 685-689.	Ordinary chernozem with low content of humus (4.5-5.5%)
207	Rehman, A., et al. (2011). "Grain quality, nutrient use efficiency, and bioeconomics of maize under different sowing methods and NPK levels." Chilean Journal of Agricultural Research **71**(4): 586-593.	Sandy clay loam
241	Steyn, J. M., et al. (2016). "Resource use efficiencies as indicators of ecological sustainability in potato production: A South African case study." Field Crops Research **199**: 136-149.	Loam, sandy-loam, sand
248	Talukder, B., et al. (2019). "Energy efficiency of agricultural systems in the southwest coastal zone of Bangladesh." Ecological Indicators **98**: 641-648.	n/a

Impact Area: Biomass per Area

Definition:

$$\frac{Aboveground\ Biomass}{Area\ of\ land}$$

Description:

Benefit: This impact area refers to the total weight of all aboveground, harvestable parts of cultivated plants. It is suitable, where production is to be used for energy and other non-food purposes that can utilize the whole plant. Woody crops and forage crops will show high efficiencies in this impact area.

Resource: Agricultural land is always a limited resource. The type of land can be specified to distinguish between different land qualities. Distinctions are often made, for example, between cropland and pasture, high nature value (HNV) farmland and other farmland, or based on soil fertility and yield potential. For this indicator, the temporal reference must always be specified. However, in case of the standard period of one year, this information is sometimes omitted in scientific publications.

Correlation with soil management:

[157] For sustainable agricultural systems is required to improve the efficiency of crop nitrogen recovery and to reduce gaseous and leaching losses. #Poultry manure, rice hulls and mineral fertilizer combination may represent a good soil amendment to obtain a high yield with a lower environmental impact, at least in the short-term.
[253] Use of mulch helps to retain soil moisture, it can provide room for farmers to reduce the frequency and amount of irrigation.
[268] Nitrogen (N) efficient maize (Zea mays L.) varieties capable of producing higher maize grain yields under conditions of low soil N supply and infertile soils condition.
[274] Result suggests that in the presence of superabsorbent polymer, maize leaf and grain carbon isotope discrimination could be good indicators for evaluating maize water use efficiency during periods of low rainfall.

Strength &weaknesses pertaining to measurement of this impact area:

Biomass: Total amount aboveground biomass (production is generally easy to measure.

However, the informative value is limited where they do not account for qualitative differences between types of biomass and are not accompanied by information on site conditions such as local climate or soil fertility. Therefore, comparisons between efficiencies of different production processes with regard to yields should only be made where products and site conditions are similar. In some cases, it may be advisable to select alternative indicators where the type of benefit is more clearly defined (e.g., energetic value, financial benefit).

Area of Land: While area of land is a standard measure that is used as reference in most statistics and inventories, a weakness of this indicator is that other relevant information like soil type, soil fertility or management history is often not provided.
In short, one hectare of dry, sandy cropland soil is very different from one hectare of pasture on drained peat soils.

Sample Indicators

Indicator values from		Survey	
Experiment or direct measurement		Statistical- or census data	
Expert assessment		Literature values	
Model		Maps or GIS	
Stakeholder participation		Not provided	

Table 1: Field Scale

Indicator	**Unit**	**Indicator values from**
[253] Weed biomass during wet (W) and dry (D) seasons for lowland (IR-841) rice varieties/Area of land	Mg mulch * ha^{-1}	
[253] Weed biomass during wet (W) and dry (D) seasons for upland (Nerica-4) rice varieties/Area of land	Mg mulch * ha^{-1}	
[268] Non-reproductive aboveground biomass accumulated from flowering to harvest/Area of land	Mg * ha^{-1}	
[268] Aboveground biomass at flowering/Area of land	Mg * ha^{-1}	

[274] Above-ground biomass/Area of land	g * ha^{-1}	

Table 2: Farm Scale

Indicator	**Unit**	**Indicator values from**
[157] Total plant biomass/Area of land	kg * m^{-2}	

Reference

ID	**Citation**	**[1]Soil type & texture**
157	Machado, D., et al. (2010). "The use of organic substrates with contrasting C/N ratio in the regulation of nitrogen use efficiency and losses in a potato agroecosystem." Nutrient Cycling in Agroecosystems 88(3): 411-427.	Sandy-loam texture
253	Totin, E., et al. (2013). "Mulching upland rice for efficient water management: A collaborative approach in Benin." Agricultural Water Management 125: 71-80.	n/a
268	Worku, M., et al. (2012). "Nitrogen efficiency as related to dry matter partitioning and root system size in tropical mid-altitude maize hybrids under different levels of nitrogen stress." Field Crops Research 130: 57-67.	Eutric Fluvisol ; Reddish brown clay soil (Nitosol, FAO soil classification)
274	Yang, W. and P. F. Li (2018). "Association of carbon isotope discrimination with leaf gas exchange and water use efficiency in maize following soil amendment with superabsorbent hydrogel." Plant, Soil and Environment **64**(10): 484-490.	Sandy loam

[1]**Soil type/ texture:** If provided, what are type and texture of the soils studied in the paper?

Impact Area: Energy per Area

Definition:

$$\frac{Embodied\ Energy}{Area\ of\ land}$$

Description:

Benefit: Energy content can be used for an integrated evaluation of crops. Generally, the type of energy should be specified to distinguish between use as fuel or use as food and feed. For use as animal feed, further definitions are required to determine if lignocellulosiccrops qualify. Crops with high per hectare yield will show high efficiencies in this impact area.

Resource: Agricultural land is always a limited resource. The type of land can be specified to distinguish between different land qualities. Distinctions are often made, for example, between cropland and pasture, high nature value (HNV) farmland and other farmland, or based on soil fertility and yield potential. For this indicator, the temporal reference must always be specified. However, in case of the standard period of one year, this information is sometimes omitted in scientific publications.

Correlation with soil management:

[58] Systems based on sugarcane, sweet sorghum and oil palm performed best when comparing net energy per area of land.
[182] Improving the conditions of mineral nutrition by introducing balanced doses of fertilizers for all elements contributed to a sufficiently high yield.
[214] In Brazil, biodiesel addition into diesel is mandatory and soybean oil is its main source. Energy balance showed linearity with yield, whereas for EROI, the increases in input and yield were not affected.
[248] Small rice-producing farms ranging from 0.61 to 1.0 ha yielded higher energy ratios (4.14) than larger ones
[270] Energy consumption from irrigation process is converted to electricity, thus the corresponding GHG emission caused by irrigation is included into that of electricity

Strength &weaknesses pertaining to measurement of this impact area

Embodied Energy: Indicators for embodied energy are generally easy to measure and allow integration of or comparison between benefits from very different crops. However, their information value for questions of nutrition is limited because the provision of amino-acids and vitamins is not considered.

Area of land: While area of land is a standard measure that is used as reference in most statistics and inventories, a weakness of this indicator is that other relevant information like soil type, soil fertility or management history is often not provided.
In short, one hectare of dry, sandy cropland soil is very different from one hectare of pasture on drained peat soils.

Sample Indicators

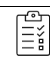
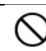
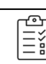
Indicator values from		Survey	
Experiment or direct measurement		Statistical- or census data	
Expert assessment		Literature values	
Model		Maps or GIS	
Stakeholder participation		Not provided	

Table 1: Region Scale

Indicator	**Unit**	**Indicator values from**
[182] Aggregate energy output+ increment of energy (grain tillage crop rotation+ grain grass tillage rotation)/Area of land	GJ * ha^{-1}	
[214] Output energy flow (potential oil in the grains)/Area of land	MJ * ha^{-1}	 , 
[248] Land use efficiency (Output energy/Area of land)	MJ * ha^{-1}	 , 

[248] Net energy gain/Area of land	MJ * ha^{-1}	,
[270] Net energy gain/Area of land	GJ * ha^{-1}	,

Table 2: Global Scale

Indicator	Unit	Indicator values from
[58] Net energy (Net energy yield (Energy content of biofuel and its coproducts − energy used for production, transportation and conversion)/Area of land)	GJ * ha^{-1}	

Table 3: National Scale

Indicator	Unit	Indicator values from
[270] Net energy gain [GJ]/Area of land [ha]	GJ * ha^{-1}	,

References

ID	Citation	[1]Soil type/ texture
58	de Vries, S. C., et al. (2010). "Resource use efficiency and environmental performance of nine major biofuel crops, processed by first-generation conversion techniques." Biomass and Bioenergy **34**(5): 588-601.	n/a
182	Neshchadim, N. N., et al. (2018). "Bioenergetic assessment and economic efficiency of predecessors and fertilizer systems in the cultivation of winter wheat." International Journal of Engineering and Technology(UAE) **7**(4.38 Special Issue 38): 685-689.	Ordinary chernozem with low content of humus (4.5-5.5%)
214	Romanelli, T. L., et al. (2012). "Material embodiment and energy flows as efficiency indicators of soybean (Glycine max) production in Brazil." Engenharia Agricola **32**(2): 261-270.	n/a
248	Talukder, B., et al. (2019). "Energy efficiency of agricultural systems in the southwest coastal zone of Bangladesh." Ecological Indicators **98**: 641-648.	n/a

[1]**Soil type/ texture:** If provided, what are type and texture of the soils studied in the paper?

270	Wu, H., et al. (2017). "Temporal trends and spatial patterns of energy use efficiency and greenhouse gas emissions in crop production of Anhui Province, China." Energy **133**: 955-968.	n/a

Impact Area: **Nitrogen** per **Area**

Definition:

$$\frac{Embodied\ Nitrogen}{Area\ of\ land}$$

Description:

Benefit: Refers to the total amount of nitrogen in the harvested product. The indicator is relevant for the assessment of food or feed quality as nitrogen content is indicative of the amount of proteins. Furthermore, high protein concentrations are essential for some uses in bio-refineries. Protein rich crops will show high efficiencies in this impact area.

Resource: Agricultural land is always a limited resource. The type of land can be specified to distinguish between different land qualities. Distinctions are often made, for example, between cropland and pasture, high nature value (HNV) farmland and other farmland, or based on soil fertility and yield potential. For this indicator, the temporal reference must always be specified. However, in case of the standard period of one year, this information is sometimes omitted in scientific publications.

Correlation with soil management:

[245] Higher nitrogen fertilizer rates applied to spring wheat results in an increase of grain and aboveground biomass N and in a decrease of the N effectiveness indicators
[261] Paper showed as regards fertilizer treatments, higher yields were obtained in wet years than in dry ones

Strength &weaknesses pertaining to measurement of this impact area

Embodied Nitrogen: can be used to calculate nitrogen use efficiencies (NUE) (e.g., the share of nitrogen recovered by plants relative to the amount of nitrogen fertilizer applied). However, efficiency measures are less suited to assess risks of environmental contamination by nitrogen fertilizer than nitrogen budgets (i.e. amount recovered – amount applied).

Area of land: While area of land is a standard measure that is used as reference in most statistics and inventories, a weakness of this indicator is that other relevant information like soil type, soil fertility or management history is often not provided.
In short, one hectare of dry, sandy cropland soil is very different from one hectare of pasture on drained peat soils.

Sample Indicators

Indicator values from		Survey	
Experiment or direct measurement		Statistical- or census data	
Expert assessment		Literature values	
Model		Maps or GIS	
Stakeholder participation		Not provided	

Table 1: Field Scale

Indicator	**Unit**	**Indicator values from**
[206] Nitrogen content of the shoots/Area of land	kg * ha^{-1}	
[245] N content of grain yield/Area of land	kg * ha^{-1}	
[245] N content of aboveground biomass/Area of land	kg * ha^{-1}	
[246] Content of mineral nitrogen (Nmin)/Area of land	kg * ha^{-1}	
[246, 247] Nitrogen uptake by fertilized plants/Area of land	kg * ha^{-1}	
[246] Nitrogen uptake by control plants (unfertilized)/Area of land	kg * ha^{-1}	

[247] Nitrogen uptake by plants/Control (unfertilized) plot	kg * ha^{-1}	
[261] Amount of N of fertilization on maize yield/Area of land	kg N * ha^{-1}	

Table 2: Farm Scale

Indicator	**Unit**	**Indicator values from**
[176] Nitrogen uptake by crops or fodder grass/ Fodder area	kg N * ha^{-1}	 , 

References

ID	**Citation**	**[1]Soil type/ texture**
176	Moreau, P., et al. (2012). "Reconciling technical, economic and environmental efficiency of farming systems in vulnerable areas." Agriculture Ecosystems & Environment **147**: 89-99.	Deep loamy and shallow brown soils
206	Ratjen, A. M. and H. Kage (2016). "Nitrogen-limited light use efficiency in wheat crop simulators: Comparing three model approaches." Journal of Agricultural Science **154**(6): 1090-1101.	Pseudogleyic luvisol; Sandy loam to clayey loam
245	Szmigiel, A., et al. (2016). "Efficiency of nitrogen fertilization in spring wheat." International Journal of Plant Production **10**(4): 447-456.	Luvic Chernozem
246	Szulc, P., et al. (2018). "The size of the nminsoil pool as a factor impacting nitrogenutilization efficiency in maize (Zea mays L.)." Pakistan Journal of Botany **50**(1): 189-198.	Deer soil; Clay lightweight sand, shallow defaulting on light clay
247	Szulc, P., et al. (2016). "Efficiency of nitrogen fertilization based on the fertilizer application method and type of maize cultivar (Zea mays L.)." Plant Soil and Environment **62**(3): 135-142.	Luvisol; Granulometric composition of shallow, light clay sand on light clay, belonging to the good rye soil class
261	Vig, R., et al. (2012). "The efficiency of natural foliar fertilizers." Idojaras **116**(1): 53-64.	Calcareous chernozem; Mid-heavy adobe

[1]**Soil type/ texture:** If provided, what are type and texture of the soils studied in the paper?

Impact Area: **Yield** per **Area**

Definition:

$$\frac{Grain/Fruit/\,Tuber\ yield}{Area\ of\ land}$$

Description:

Benefit: This impact area refers to the weight of harvested parts of plants that possess economic value. It is suitable, where production is to be used food or feed purposes or as a non-energetic production factor in bio-refineries. Crops with high per hectare yield will show high efficiencies in this impact area.

Resource: Agricultural land is always a limited resource. The type of land can be specified to distinguish between different land qualities. Distinctions are often made, for example, between cropland and pasture, high nature value (HNV) farmland and other farmland, or based on soil fertility and yield potential. For this indicator, the temporal reference must always be specified. However, in case of the standard period of one year, this information is sometimes omitted in scientific publications.

Correlation with soil management:

[38] Controlled traffic system showed lower value in winter wheat production, but higher value in summer maize production

[67] Application of hydrogel, on sandy soils improves water holding capacity, availability of the nutrients, leading to higher productivity. The higher the application rate of the hydrogel, the higher the productivity

[157] For sustainable agricultural systems is required to improve the efficiency of crop nitrogen recovery and to reduce gaseous and leaching losses. Poultry manure, rice hulls and mineral fertilizer combination may represent a good soil amendment to obtain a high yield with a lower environmental impact, at least in the short-term

[162] Studies proved reduction of field crop yields from organic fields in comparison to conventional ones
[177] Extensive farming produces lower yield and requires more land than intensive farming
[182] Improving the conditions of mineral nutrition by introducing balanced doses of fertilizers for all elements contributed to a sufficiently high yield
[207] Nitrogen utilization efficiency played a significant role in determining grain yield, while a negative and poor dependence of grain yield on Nitrogen uptake efficiency was observed
[214] In Brazil, biodiesel addition into diesel is mandatory and soybean oil is its main source. Energy balance showed linearity with yield, whereas for EROI, the increases in input and yield were not affected
[241] Highest land use efficiencies (potato yield per hectare of area) were achieved in regions that produce potatoes under irrigation in summer where solar radiation is high and lowest land use efficiencies were reported for the predominantly dry land and partially dry land regions
[242] Water-saving irrigation and high nitrogen use efficiency are becoming more and more important in rice production aimed at high and stable yield due to the shortage of water resources and the spread of non-point source pollution caused by irrational fertilization
[245] Higher nitrogen fertilizer rates applied to spring wheat results in an increase of grain and aboveground biomass N and in a decrease of the N effectiveness indicators
[248] Small rice-producing farms ranging from 0.61 to 1.0 ha yielded higher energy ratios (4.14) than larger ones
[250] Paper anticipates that the development and implementation of an integrated modeling platform across worlds regions could build capabilities in understanding the agriculture-centered food,
energy and water (FEW) nexus and guiding policy and land management decision making for a sustainable future
[252] In the case of crop rotations, increasing resource-use efficiency while reducing yield gaps can be addressed by suitable agricultural management practices
[260] Inoculation of rice with dark septateendophytic (DSE) fungi represents a strategy to improve green manure-N recovery, grain yield per plant, and grain quality in terms of micronutrients contents in cropping systems with a low N input
[266] Alternate partial root-zone irrigation usually resulted in a higher water use efficiency improvement with no significant difference in yield but 33.3% less irrigation water
[268] Nitrogen (N) efficient maize (Zea mays L.) varieties capable of producing higher maize grain yields under conditions of low soil N supply and infertile soils condition
[274] Result suggests that in the presence of superabsorbent polymer, maize leaf and grain carbon isotope discrimination could be good indicators for evaluating maize water use efficiency during periods of low rainfall
[281] Paper indicates the importance of Arbuscularmycorrhizal fungi (AMF) inoculation in improving P efficiency of rice production
[284] System of rice intensification methods was beneficial for improving soil fertility because of effects on soil microbial biomass. Results also suggest that there is a substantial potential to raise

rice yields by changing field management and cultivation methods rather than depending on genetic modifications or increases in agrochemical inputs

Strength &weaknesses pertaining to measurement of this impact area

Yield: Yield values are generally easy to measure and readily available at farm level or in the form of national inventories.

However, their informative value is limited where they do not account for qualitative differences between types of biomass and are not accompanied by information on site conditions such as local climate or soil fertility. Therefore, comparisons between efficiencies of different production processes with regard to yields should only be made where products and site conditions are similar. In some cases, it may be advisable to select alternative indicators where the type of benefit is more clearly defined (e.g., energetic value, financial benefit).

Area of land: While area of land is a standard measure that is used as reference in most statistics and inventories, a weakness of this indicator is that other relevant information like soil type, soil fertility or management history is often not provided.
In short, one hectare of dry, sandy cropland soil is very different from one hectare of pasture on drained peat soils.

Sample Indicators

Indicator values from		Survey	
Experiment or direct measurement		Statistical- or census data	
Expert assessment		Literature values	
Model		Maps or GIS	
Stakeholder participation		Not provided	

Table 1: No Scale

Indicator	**Unit**	**Indicator values from**
[250] Crop yield/Area of land	ton * ha^{-1}	

Table 2: Field Scale

Indicator	Unit	Indicator values from
[67] Marketable yield(Squash) /Area of land (feddan = arabic unit of area)	mg * feddan^{-1}	
[207]Grain yield/Area of land	ton * ha^{-1}	
[242]Grain yield/Area of land	kg * hm^{-2}	
[245,260,274]Grain yield/Area of land	kg * ha^{-1}	
[246]Grain yield/Plot	kg * ha^{-1}	
[247]Grain yield/Field	ton * ha^{-1}	
[266]Fresh yield /Area of land	g * ha^{-1}	
[266] Dry yield/Area of land	g * ha^{-1}	
[268]Mean grain yield/Area of land	Mg * ha^{-1}	
[281]Biological yield/Area of land	kg * ha^{-1}	
[281]Economic yield/Area of land	kg * ha^{-1}	
[284] Yield/Area of land	ton * ha^{-1}	

Table 3: Farm Scale

Indicator	Unit	Indicator values from
[157] Tuber yield/Area of land	kg * m^{-2}	
[162] Additional yield from fertilization/Area of land	kg * ha^{-1}	
[162] Additional yield from fertilization in the previous year/Area of land	kg * ha^{-1}	
[175, 252]Grain yield/Area of land	kg * ha^{-1}	
[175] Fodder conservation rate (Fodder conserved/Area of land)	kg * ha^{-1}	

[176] Annual Gross Product (Average yield/ Fodder area)	kg * ha^{-1}	,

Table 4: Regional Scale

Indicator	**Unit**	**Indicator values from**
[38] Crop productivity (Yield/Area of land)	kg * ha^{-1}	
[110] Average yield (Yield/Area of land)	ton * ha^{-1}	
[182] Grain yield/Area of land	ton * ha^{-1}	
[185] Extension Yield(Yield of main crop (s)/Area of land)	Not provided* ha^{-1}	,
[190] Grain yield/Area of land	kg * ha^{-1}	,
[202] Gross yield (weight of all harvested fruits) /Area of land	mg * ha^{-1}	
[202] Fresh marketable yield (gross yield minus the fruit discarded as a result of fruit rot or small size, or fruit used for processed products) /Area of land	mg * ha^{-1}	
[214] Yield (obtained product) /Area of land	kg * ha^{-1}	,
[241] Land use efficiency (Potato yield /Area of land)	ton * ha^{-1}	
[248] Rice yield/Area of land	kg * ha^{-1}	,

Table 5: National Scale

Indicator	**Unit**	**Indicator values from**
[177] Marginal yield (yield at the level of fertilization where the curves: "yield per fertilizer unit" and "groundwater nitrate content per fertilizer unit" intersect/Area of land	ton* ha^{-1}	,
[202] Gross yield (weight of all harvested fruits) /Area of land	mg * ha^{-1}	
[202] Fresh marketable yield (gross yield minus the fruit discarded as a result of fruit rot or small size, or fruit used for processed products) /Area of land	mg * ha^{-1}	

References

ID	Citation	[1]Soil type/ texture
38	Chen, H., et al. (2016). "Effect of controlled traffic on energy use efficiency in wheat-maize production in North China Plain." Journal of Computational and Theoretical Nanoscience**13**(4): 2634-2638.	Silt loam; Porous and homogenous
67	"Water and fertilizer use efficiency by squash grown under stress on sandy soil treated with acrylamide hydrogels." Journal of Applied Sciences Research**7**(12): 1828-1833.	Sandy soil
110	Homolka, J. and R. Mydlar (2011). "Efficiency evaluation in intensive growing of winter rape." Agricultural Economics-ZemedelskaEkonomika**57**(5): 247-257.	Pararendzina on terraced broken stones and gravel sands from the acid material
157	Machado, D., et al. (2010). "The use of organic substrates with contrasting C/N ratio in the regulation of nitrogen use efficiency and losses in a potato agroecosystem." Nutrient Cycling in Agroecosystems**88**(3): 411-427.	Sandy-loam texture
162	Manolova, V., et al. (2015). "Economic efficiency of fertilization and its residual-effect during conversion period to organic field crop production." Bulgarian Journal of Agricultural Science**21**(5): 1022-1026.	n/a
175	Moore, A. D., et al. (2011). "Evaluation of the water use efficiency of alternative farm practices at a range of spatial and temporal scales: A conceptual framework and a modelling approach." Agricultural Systems**104**(2): 162-174.	Black vertosol soil
176	Moreau, P., et al. (2012). "Reconciling technical, economic and environmental efficiency of farming systems in vulnerable areas." Agriculture Ecosystems & Environment**147**: 89-99.	Deep loamy and shallow brown soils
177	Mozner, Z., et al. (2012). "Modifying the yield factor based on more efficient use of fertilizer-The environmental impacts of intensive and extensive agricultural practices." Ecological Indicators**16**: 58-66.	n/a
182	Neshchadim, N. N., et al. (2018). "Bioenergetic assessment and economic efficiency of predecessors and fertilizer systems in the cultivation of winter wheat." International Journal of Engineering and Technology(UAE)**7**(4.38 Special Issue 38): 685-689.	Ordinary chernozem with low content of humus (4.5-5.5%)
185	Oladele, O. I. (2013). "Towards Developing a set of Indices to assess the Effectiveness and Efficiency of Agricultural Extension Policy." Life Science Journal-Acta Zhengzhou University Overseas Edition**10**(1): 3309-3314.	n/a
190	Pan, G., et al. (2009). "Using QuickBird imagery and a production efficiency model to improve crop yield estimation in the semi-arid hilly Loess Plateau, China." Environmental Modelling & Software**24**(4): 510-516.	n/a

[1]**Soil type/ texture:** If provided, what aretype and texture of the soils studied in the paper?

202	Plénet, D., et al. (2009). "Using on-field data to develop the EFI© information system to characterise agronomic productivity and labour efficiency in peach (Prunuspersica L. Batsch) orchards in France." Agricultural Systems**100**(1-3): 1-10.	n/a
207	Rehman, A., et al. (2011). "Grain quality, nutrient use efficiency, and bioeconomics of maize under different sowing methods and NPK levels." Chilean Journal of Agricultural Research**71**(4): 586-593.	Sandy clay loam
214	Romanelli, T. L., et al. (2012). "Material embodiment and energy flows as efficiency indicators of soybean (Glycine max) production in Brazil." Engenharia Agricola**32**(2): 261-270.	n/a
241	Steyn, J. M., et al. (2016). "Resource use efficiencies as indicators of ecological sustainability in potato production: A South African case study." Field Crops Research**199**: 136-149.	Loam, sandy-loam, sand
242	Sun, Y., et al. (2012). "The effects of different water and nitrogen managements on yield and nitrogen use efficiency in hybrid rice of China." Field Crops Research**127**: 85-98.	Sandy loam
245	Szmigiel, A., et al. (2016). "Efficiency of nitrogen fertilization in spring wheat." International Journal of Plant Production**10**(4): 447-456.	LuvicChernozem
246	Szulc, P., et al. (2018). "The size of the nminsoil pool as a factor impacting nitrogenutilization efficiency in maize (Zea mays L.)." Pakistan Journal of Botany**50**(1): 189-198.	Clay lightweight sand, shallow defaulting on light clay; Deer soil
247	Szulc, P., et al. (2016). "Efficiency of nitrogen fertilization based on the fertilizer application method and type of maize cultivar (Zea mays L.)." Plant Soil and Environment**62**(3): 135-142.	Granulometric composition of shallow, light clay sand on light clay, belonging to the good rye soil class;Luvisol
248	Talukder, B., et al. (2019). "Energy efficiency of agricultural systems in the southwest coastal zone of Bangladesh." Ecological Indicators**98**: 641-648.	n/a
250	Tian, H., et al. (2018). "Optimizing resource use efficiencies in the food–energy–water nexus for sustainable agriculture: from conceptual model to decision support system." Current Opinion in Environmental Sustainability**33**: 104-113.	n/a
252	Tomaz, A., et al. (2018). "Efficient use of water and nutrients in irrigated cropping systems in the Alqueva region." Spanish Journal of Soil Science**8**(1): 12-23.	Silt loam; Chromic Cambisols (Bc)
260	Vergara, C., et al. (2018). "Dark SeptateEndophytic Fungi Increase Green Manure-N-15 Recovery Efficiency, N Contents, and Micronutrients in Rice Grains." Frontiers in Plant Science**9**.	Sandy soil (3% clay, 5% silt, and 92% sandy); HaplicPlanosol
266	Wei, Z. H., et al. (2016). "Carbon isotope discrimination shows a higher water use efficiency under alternate partial root-zone irrigation of field-grown tomato." Agricultural Water Management**165**: 33-43.	Sandy loam; Arid
268	Worku, M., et al. (2012). "Nitrogen efficiency as related to dry matter partitioning and root system size in tropical mid-altitude maize hybrids under different levels of nitrogen	Reddish brown clay soil (Nitosol, FAO soil classification); EutricFluvisol

	stress." Field Crops Research **130**: 57-67.	
274	Yang, W. and P. F. Li (2018). "Association of carbon isotope discrimination with leaf gas exchange and water use efficiency in maize following soil amendment with superabsorbent hydrogel." Plant, Soil and Environment **64**(10): 484-490.	Sandy loam
281	Zhang, S., et al. (2016). "Arbuscularmycorrhiza improved phosphorus efficiency in paddy fields." Ecological Engineering **95**: 64-72.	n/a
284	Zhao, L., et al. (2010). "Comparisons of yield, water use efficiency, and soil microbial biomass as affected by the system of rice intensification." Communications in Soil Science and Plant Analysis **41**(1): 1-12.	n/a

Impact Area: **Benefits per Water**

Definition:

$$\frac{Financial\ benefits}{Water}$$

Description:

Benefit: This impact area assesses benefits via their appreciation by markets (Di Maio et al., 2017). It is sensitive to various socio-economic factors because commodity prices reflect demand and are also influenced by value systems and policies through effects of financial incentives and tax regulations.

Resource: Even in rainfed agriculture, water can constitute a stressed resource, impacting for example on farmers' decisions whether or not to plant cover crops. Irrigation water is always a stressed resource. In cases of seasonal water shortages, the use of water can also be specified as use during critical time periods.

Correlation with soil management:

[156] Technology and water management can improve water use efficiency
[249] Result indicates perception of water scarcity, irrigation infrastructure, water price and income increase irrigation water efficiency while time spent on farming and fragmentation decreases it

Strength &weaknesses pertaining to measurement of this impact area

Financial Benefits: Financial indicators are well suited for integrating or comparing agricultural production processes with products for very different end uses. For calculating benefit-cost ratios (BCR), indicators that reflect revenue should be used. In most other cases, indicators that reflect net benefits (after deduction of charges, costs and expenses) provide a more realistic picture of benefits generated. Price volatilities make efficiency calculations valid only for a certain point in time and space.

Sample Indicators

Indicator values from		Survey	
Experiment or direct measurement		Statistical- or census data	
Expert assessment		Literature values	

Model		Maps or GIS	
Stakeholder participation		Not provided	

Table 1: Farm Scale

Indicator	Unit	Indicator values from
[175] Gross margin use efficiency (Total gross margin (Sum of gross income from grain, conserved fodder, and animal products)/Total rainfall)	$ * mm $^{-1}$	
[249] Irrigation water use efficiency (Optimal cost (when all inputs are technically and allocatively efficient)/Amount of irrigation water)	$ * m $^{-3}$	

Table 2: Regional Scale

Indicator	Unit	Indicator values from
[142] Water use efficiency (Economic output of crop yield/Amount of irrigation water)	$ * m $^{-3}$	
[156] Water use efficiency index (Value of agricultural output /Total agricultural water use (irrigation and preciptation))	$ * m $^{-3}$	
[233] Maximum revenue /Unit of Irrigation Water per ton of product	$ * m $^{-3}$	

Table 3: National Scale

Indicator	Unit	Indicator values from
[81] Irrigated agriculture water use efficiency (Gross value added by the portion of the agricultural sector that uses irrigation/Input of irrigation water)	$ * m $^{-3}$	

References

ID	Citation	[1]Soil type/ texture
81	Giupponi, C., et al. (2018). "Spatial assessment of water use efficiency (SDG Indicator 6.4.1) for regional policy support." Frontiers in Environmental Science **6**(NOV).	n/a
142	Latinopoulos, D. (2009). "Multicriteria decision-making for efficient water and land resources allocation in irrigated agriculture." Environment, Development and Sustainability **11**(2): 329-343.	n/a
156	Long, K. S. and B. C. Pijanowski (2017). "Is there a relationship between water scarcity and water use efficiency in China? A national decadal assessment across spatial scales." Land Use Policy **69**: 502-511.	n/a
175	Moore, A. D., et al. (2011). "Evaluation of the water use efficiency of alternative farm practices at a range of spatial and temporal scales: A conceptual framework and a modelling approach." Agricultural Systems **104**(2): 162-174.	Black vertosol soil
233	Solieman, N. Y. and R. M. Barghash (2016). "The economic efficiency of water irrigation usage and restructuring cultivation of agricultural crops." International Journal of ChemTech Research **9**(10): 62-71.	n/a
249	Tang, J. and H. Folmer (2016). "Latent vs. Observed Variables: Analysis of Irrigation Water Efficiency Using SEM and SUR." Journal of Agricultural Economics **67**(1): 173-185.	n/a

[1]**Soil type/ texture:** If provided, what are type and texture of the soils studied in the paper?

Impact Area: **Biomass** per **Water**

Definition:

$$\frac{Aboveground\ Biomass}{Water}$$

Description:

Benefit: This impact area refers to the total weight of all aboveground, harvestable parts of cultivated plants. It is suitable, where production is to be used for energy and other non-food purposes that can utilize the whole plant. Woody crops and forage crops will show high efficiencies in this impact area.

Resource: Even in rainfed agriculture, water can constitute a stressed resource, impacting for example on farmers' decisions whether or not to plant cover crops. Irrigation water is always a stressed resource. In cases of seasonal water shortages, the use of water can also be specified as use during critical time periods.

Correlation with soil management:

[57] Treatment with constant groundwater table showed higher water use efficiency than crops in irrigated field, irrespective of planting density

[195] Results showed a positive and additive effect of water and nitrogen application on Water Use Efficiency, reflected by yield enhancement

Strength &weaknesses pertaining to measurement of this impact area

Biomass: Total amount aboveground biomass (production is generally easy to measure.

However, the informative value is limited where they do not account for qualitative differences between types of biomass and are not accompanied by information on site conditions such as local climate or soil fertility. Therefore, comparisons between efficiencies of different production processes with regard to yields should only be made where products and site conditions are similar. In some cases, it may be advisable to select alternative indicators where the type of benefit is more clearly defined (e.g., energetic value, financial benefit).

Sample Indicators

Indicator values from		Survey	
Experiment or direct measurement		Statistical- or census data	
Expert assessment		Literature values	
Model		Maps or GIS	
Stakeholder participation		Not provided	

Table 1: Field Scale

Indicator	**Unit**	**Indicator values from**
[57] Water use efficiency of total biomass (Total dry matter of bean plants/Amount of evapotranspiration)	$g * mm^{-1}$	
[275] Accumulation of biomass/Soil water content	$g * \%^{-1}$	

Table 2: Farm Scale

Indicator	**Unit**	**Indicator values from**
[175] Shoot biomass transpiration efficiency (Shoot biomass production (Above-ground net primary productivity of plants that contribute to the production of grain, grazed forage or conserved fodder) /Total rainfall)	$kg * mm^{-1}$	

Table 3: Global Scale

Indicator	**Unit**	**Indicator values from**
[195] Normalized Water productivity of biomass (Biomass produced/Irrigation water applied + effective rainfall/evapotranspiration)	$kg * mm^{-1}$	

References

ID	**Citation**	[1]**Soil type/ texture**
57	de Medeiros, G. A., et al. (2014). "Water use efficiency as an indicator of environmental impact of irrigated crops under subtropical conditions." **181**: 455-466.	Red Latosol (Oxisoil); Clay texture (61% clay)

[1]**Soil type/ texture:** If provided, what are type and texture of the soils studied in the paper?

175	Moore, A. D., et al. (2011). "Evaluation of the water use efficiency of alternative farm practices at a range of spatial and temporal scales: A conceptual framework and a modelling approach." Agricultural Systems **104**(2): 162-174.	Black vertosol soil
195	Pascual, M., et al. (2016). "Water use efficiency in peach trees over a four-years experiment on the effects of irrigation and nitrogen application." Agricultural Water Management **164**: 253-266.	Petrocalcic calcixerept (Petrocalcic Calcisol); Loamy textured (20% clay and 40% sand) and pH (1:2.5) is basic(8.3)
275	Yang, Z., et al. (2016). "Leveraging abscisic acid receptors for efficient water use in Arabidopsis." Proceedings of the National Academy of Sciences of the United States of America **113**(24): 6791-6796.	n/a

Impact Area: **Yield** per **Water**

Definition:

$$\frac{Grain/Fruit/\,Tuber\ yield}{Water}$$

Description:

Benefit: This impact area refers to the weight of harvested parts of plants that possess economic value. It is suitable, where production is to be used food or feed purposes or as a non-energetic production factor in bio-refineries. Crops with high per hectare yield will show high efficiencies in this impact area.

Resource: Even in rainfed agriculture, water can constitute a stressed resource, impacting for example on farmers' decisions whether or not to plant cover crops. Irrigation water is always a stressed resource. In cases of seasonal water shortages, the use of water can also be specified as use during critical time periods.

Correlation with soil management:

[57] Treatment with constant groundwater table showed higher water use efficiency than crops in irrigated field, irrespective of planting density
[67] Application of hydrogel, on sandy soils improves water holding capacity and availability of the nutrients. The higher the amount of hydrogel the higher the water use efficiency
[73] Water is clearly a key resource in potato production that affects the use efficiency of other resources

[98] Limiting irrigation or changing irrigation patterns in areas with high water pressure, as well as expanding irrigation in areas with abundant water resources increases water use efficiency. Improving irrigation efficiency and reducing irrigation water per unit area are methods to increase regional water use efficiency. Enhancing crop varieties and crop yield can contribute to increase regional water use efficiency

[130] The treatments with alternate furrow and surge flow irrigation had higher crop yield and water use efficiency of all treatments

[135] Water use efficiency of the treatment with micro irrigation was higher than with check basin irrigation for both crops

[195] Results showed a positive and additive effect of water and nitrogen application on Water Use Efficiency, reflected by yield enhancement

[241] Highest land use efficiencies (potato yield per hectare of area) were achieved in regions that produce potatoes under irrigation in summer where solar radiation is high and lowest land use efficiencies were reported for the predominantly dryland and partially dryland regions
[242] Water-saving irrigation and high nitrogen use efficiency are becoming more and more important in rice production aimed at high and stable yield due to the shortage of water resources and the spread of non-point source pollution caused by irrational fertilization
[252] In the case of crop rotations, increasing resource-use efficiency while reducing yield gaps can be addressed by suitable agricultural management practices

[266] Alternate partial root-zone irrigation usually resulted in a higher water use efficiency improvement with no significant difference in yield but 33.3% less irrigation water

[274] Result suggests that in the presence of superabsorbent polymer, maize leaf and grain carbon isotope discrimination could be good indicators for evaluating maize water use efficiency during periods of low rainfall

[284] System of rice intensification methods were beneficial for improving soil fertility because of effects on soil microbial biomass. Results also suggest that there is a substantial potential to raise rice yields by changing field management and cultivation methods rather than depending on genetic modifications or increases in agrochemical inputs

[286] AquaCrop model has been widely used and calibrated to simulate yield for a number of crops under diverse environments and types of water management

Strength &weaknesses pertaining to measurement of this impact area

Yield: Yield values are generally easy to measure and readily available at farm level or in the form of national inventories.

However, their informative value is limited where they do not account for qualitative differences between types of biomass and are not accompanied by information on site conditions such as local climate or soil fertility. Therefore, comparisons between efficiencies of different production processes with regard to yields should only be made where products and site conditions are similar. In some cases, it may be advisable to select alternative indicators where the type of benefit is more clearly defined (e.g., energetic value, financial benefit).

Sample Indicators

Indicator values from	Survey	

Experiment or direct measurement		Statistical- or census data	
Expert assessment		Literature values	
Model		Maps or GIS	
Stakeholder participation		Not provided	

Table 1: Field Scale

Indicator	**Unit**	**Indicator values from**
[57] Water use efficiency of seed yield (Yield (bean seeds)/Amount of evapotranspiration)	$g * mm^{-1}$	
[67,130,242] Water use efficiency (Yield/Amount of irrigation water)	$kg * m^{-3}$	
[73] Water use efficiency (Potato yield/Irrigation water)	$g * l^{-1}$	,
[135] Water use efficiency (Grain yield (pea and bean)/ Amount of irrigation water)	$kg * mm^{-1}$	
[266] Water use efficiency at fresh yield scale (Fruit fresh yield/Crop evapotranspiration over the growth period)	$gm^{-2} * mm^{-1}$	
[266] Water use efficiency at dry yield scale (Fruit dry yield/Crop evapotranspiration over the growth period)	$gm^{-2} * mm^{-1}$	
[274] Water use efficiency at the yield level (Grain yield [kg]/Evapotranspiration [mmol m−2 s−1])	$kg * mmol^{-1} * m^2 * s$	
[284] Water use efficiency (Grain yield/Water consumed for system of rice intensification)	$ton\ ha^{-1} * mm^{-1}$	
[284] Irrigation water use efficiency (Grain yield/Irrigation water)	$ton\ ha^{-1} * mm^{-1}$	
[286] Water use efficiency (Crop yield/Evapotranspiration)	$ton * mm^{-1}$	

Table 2: Farm Scale

Indicator	**Unit**	**Indicator values from**
[175] Rainfall use efficiency for grain (Total grain yield/ Total rainfall)	$kg * ha^{-1} * mm^{-1}$	
[252] Water use efficiency (Grain yield/Crop evapotranspiration)	$kg * m^{-3}$	
[252] Irrigation water use efficiency (Grain yield/Seasonal irrigation water applied)	$kg * m^{-3}$	

Table 3: Regional Scale

Indicator	**Unit**	**Indicator values from**
[98] Marginal water productivity (Grain or tuber yield/Amount of irrigation water)	kg * m $^{-3}$	
[233] Yield/Unit of Irrigation Water	ton * m $^{-3}$	
[241] Water use efficiency (Tuber yield/Total amount of rainfall + irrigation water applied)	kg * m $^{-3}$	

Table 4: Global Scale

Indicator	**Unit**	**Indicator values from**
[195] Water productivity of irrigation (Fruit yield/Irrigation water)	kg * mm $^{-1}$	
[195] Normalized Water productivity of yield (Fruit yield/Irrigation water applied + effective rainfall/evapotranspiration)	kg * mm $^{-1}$	

References

ID	**Citation**	[1]**Soil type/ texture**
57	de Medeiros, G. A., et al. (2014). "Water use efficiency as an indicator of environmental impact of irrigated crops under subtropical conditions." **181**: 455-466.	Red Latosol (Oxisoil); Clay texture (61% clay)
67	"Water and fertilizer use efficiency by squash grown under stress on sandy soil treated with acrylamide hydrogels." Journal of Applied Sciences Research **7**(12): 1828-1833.	Sandy soil
73	Franke, A. C., et al. (2018). "Resource use efficiencies in potato production." Water Wheel **17**(2): 18-21.	Sandy soil
98	Guo, X., et al. (2018). "Spatial-temporal distribution and impact factors of irrigation water use efficiency in the grain production of China." International Journal of Agricultural and Biological Engineering **11**(5): 131-138.	n/a
130	Kifle, M., et al. (2017). "Effect of surge flow and alternate irrigation on the irrigation efficiency and water productivity of onion in the semi-arid areas of North Ethiopia." Agricultural Water Management **187**: 69-76.	Clay texture
135	Kumar, M., et al. (2009). "Integrating water harvesting and gravity-fed micro-irrigation system for efficient water management in terraced land for growing vegetables." Biosystems Engineering **102**(1): 106-113.	n/a

[1]**Soil type/ texture:** If provided, what are type and texture of the soils studied in the paper?

175	Moore, A. D., et al. (2011). "Evaluation of the water use efficiency of alternative farm practices at a range of spatial and temporal scales: A conceptual framework and a modelling approach." Agricultural Systems **104**(2): 162-174.	Black vertosol soil
195	Pascual, M., et al. (2016). "Water use efficiency in peach trees over a four-years experiment on the effects of irrigation and nitrogen application." Agricultural Water Management **164**: 253-266.	Petrocalcic calcixerept (Petrocalcic Calcisol); Loamy textured (20% clay and 40% sand) and pH (1:2.5) is basic(8.3)
233	Solieman, N. Y. and R. M. Barghash (2016). "The economic efficiency of water irrigation usage and restructuring cultivation of agricultural crops." International Journal of ChemTech Research **9**(10): 62-71.	n/a
241	Steyn, J. M., et al. (2016). "Resource use efficiencies as indicators of ecological sustainability in potato production: A South African case study." Field Crops Research **199**: 136-149.	Loam, sandy-loam, sand
242	Sun, Y., et al. (2012). "The effects of different water and nitrogen managements on yield and nitrogen use efficiency in hybrid rice of China." Field Crops Research **127**: 85-98.	Sandy loam
252	Tomaz, A., et al. (2018). "Efficient use of water and nutrients in irrigated cropping systems in the Alqueva region." Spanish Journal of Soil Science **8**(1): 12-23.	Chromic Cambisols (Bc); Silt loam
266	Wei, Z. H., et al. (2016). "Carbon isotope discrimination shows a higher water use efficiency under alternate partial root-zone irrigation of field-grown tomato." Agricultural Water Management **165**: 33-43.	Arid; Sandy loam
274	Yang, W. and P. F. Li (2018). "Association of carbon isotope discrimination with leaf gas exchange and water use efficiency in maize following soil amendment with superabsorbent hydrogel." Plant, Soil and Environment **64**(10): 484-490.	Sandy loam
284	Zhao, L., et al. (2010). "Comparisons of yield, water use efficiency, and soil microbial biomass as affected by the system of rice intensification." Communications in Soil Science and Plant Analysis **41**(1): 1-12.	n/a
286	Zhuo, L. and A. Y. Hoekstra (2017). "The effect of different agricultural management practices on irrigation efficiency, water use efficiency and green and blue water footprint." Frontiers of Agricultural Science and Engineering **4**(2): 185-194.	n/a

Impact Area: **Biomass** per **Nitrogen fertilizer**

Definition:

$$\frac{Aboveground\ Biomass}{Nitrogen\ fertilizer}$$

Description:

Benefit: This impact area refers to the total weight of all aboveground, harvestable parts of cultivated plants. It is suitable, where production is to be used for energy and other non-food purposes that can utilize the whole plant. Woody crops and forage crops will show high efficiencies in this impact area.

Resource: Nitrogen fertilizer is considered a stressed resource for several reasons. While the supply of nitrogen is effectively unlimited, its production is highly energy intensive and its application results in emissions of ammonium and nitrous oxide, creating a conflict between nitrogen fertilizer application and climate change mitigation targets.
Depending on the application rate and type of nitrogen fertilizer (in combination with site specific conditions), diffuse pollution and contamination of water resources is also relevant. Diffuse nitrogen pollution may also strongly affect nutrient poor natural ecosystems and alter species composition.
Finally, fertilizer application is a relevant factor in farmers' cost calculations.

Correlation with soil management:

[260] Inoculation of rice with dark septate endophytic (DSE) fungi represents a strategy to improve green manure-N recovery, grain yield per plant, and grain quality in terms of micronutrients contents in cropping systems with a low N input

Strength &weaknesses pertaining to measurement of this impact area:

Biomass: Total amount aboveground biomass (production is generally easy to measure.

However, the informative value is limited where they do not account for qualitative differences between types of biomass and are not accompanied by information on site conditions such as local climate or soil fertility. Therefore, comparisons between efficiencies of different production processes with regard to yields should only be made where products and site conditions are similar. In some cases, it may be advisable to select alternative indicators where the type of benefit is more clearly defined (e.g., energetic value, financial benefit).

Can be measured as:

Biomass:
- yield, fresh weight [t]
- yield, dry matter weight [t]

Nitrogen fertilizer:
- total nitrogen fertilizer application [kg N]

Sample Indicators

Indicator values from		Survey	
Experiment or direct measurement		Statistical- or census data	
Expert assessment		Literature values	
Model		Maps or GIS	
Stakeholder participation		Not provided	

Table 1: Field Scale

Indicator	**Unit**	**Indicator values from**
[260] Nutrient concentration (%) (Dry matter/N content)	mg $plant^{-1}$ * (mg $plant^{-1}$ $)^{-1}$	

References

ID	Citation	[1]Soil type & texture
260	Vergara, C., et al. (2018). "Dark Septate Endophytic Fungi Increase Green Manure-N-15 Recovery Efficiency, N	Haplic Planosol;

[1]**Soil type & texture:** If provided, what are type and texture of the soils studied in the paper?

	Contents, and Micronutrients in Rice Grains." Frontiers in Plant Science **9**.	Sandy soil (3% clay, 5% silt, and 92% sandy)

Impact Area: Energy per Nitrogen fertilizer

Definition:

$$\frac{Embodied\ Energy}{Nitrogen\ fertilizer}$$

Description:

Benefit: Energy content can be used for an integrated evaluation of crops. Generally, the type of energy should be specified to distinguish between use as fuel or use as food and feed. For use as animal feed, further definitions are required to determine if lignocellulosic crops qualify. Crops with high per hectare yield will show high efficiencies in this impact area.

Resource: Nitrogen fertilizer is considered a stressed resource for several reasons. While the supply of nitrogen is effectively unlimited, its production is highly energy intensive and its application results in emissions of ammonium and nitrous oxide, creating a conflict between nitrogen fertilizer application and climate change mitigation targets.
Depending on the application rate and type of nitrogen fertilizer (in combination with site specific conditions), diffuse pollution and contamination of water resources is also relevant. Diffuse nitrogen pollution may also strongly affect nutrient poor natural ecosystems and alter species composition.
Finally, fertilizer application is a relevant factor in farmers‘ cost calculations.

Correlation with soil management:

[45] Precision farming (applying nutrients and pesticides match temporally and spatially crop requirements) increases fertilizer use efficiency. Locating food production in areas with the suitable climate and soil conditions for a crop can increase agricultural input efficiency (the amount of food produced per input of fertilizer or feed)
[58] Soybean performed well on nitrogen use efficiency (ability to fix nitrogen)

Strength &weaknesses pertaining to measurement of this impact area:

Embodied Energy: Indicators for embodied energy are generally easy to measure and allow integration of or comparison between benefits from very different crops. However, their information value for questions of nutrition is limited because the provision of amino-acids and vitamins is not considered.

Can be measured as:

Embodied Energy:
- nutritional value (humans) [J]
- nutritional value (non-grazing livestock) [J]
- nutritional value (grazing livestock) [J]
- heating value [J]

Nitrogen fertilizer:
- total nitrogen fertilizer application [kg N]

Sample Indicators

Indicator values from		Survey	
Experiment or direct measurement		Statistical- or census data	
Expert assessment		Literature values	
Model		Maps or GIS	
Stakeholder participation		Not provided	

Table 1: No Scale

Indicator	**Unit**	**Indicator values from**
[58] Nitrogen use efficiency (Net energy yield (Energy content of biofuel and its coproducts – energy used for production, transportation and conversion)/Nitrogen input)	GJ * kg^{-1}	

Table 2: Farm Scale

Indicator	**Unit**	**Indicator values from**
[45] Nitrogen use efficiency (Digestable calories in grain yield/Nitrogen fertilizer)	Kcal * g^{-1}	

References

ID	**Citation**	**[1]Soil type/ texture**
45*	Clark, M. and D. Tilman (2017). "Comparative analysis of environmental impacts of agricultural production systems, agricultural input efficiency, and food choice." Environmental Research Letters **12**(6).	n/a
58	de Vries, S. C., et al. (2010). "Resource use efficiency and environmental performance of nine major biofuel crops, processed by first-generation conversion techniques." Biomass and Bioenergy **34**(5): 588-601.	n/a

[1]**Soil type/ texture:** If provided, what are type and texture of the soils studied in the paper?
*The impact area discussed on this factsheet is not a focus of the cited paper

Impact Area: **Nitrogen** per **Nitrogen fertilizer**

Definition:

$$\frac{Embodied\ Nitrogen}{Nitrogen\ fertilizer}$$

Description:

Benefit: Refers to the total amount of nitrogen in the harvested product. The indicator is relevant for the assessment of food or feed quality as nitrogen content is indicative of the amount of proteins. Furthermore, high protein concentrations are essential for some uses in bio-refineries.
Protein rich crops will show high efficiencies in this impact area.

Resource: Nitrogen fertilizer is considered a stressed resource for several reasons. While the supply of nitrogen is effectively unlimited, its production is highly energy intensive and its application results in emissions of ammonium and nitrous oxide, creating a conflict between nitrogen fertilizer application and climate change mitigation targets.
Depending on the application rate and type of nitrogen fertilizer (in combination with site specific conditions), diffuse pollution and contamination of water resources is also relevant. Diffuse nitrogen pollution may also strongly affect nutrient poor natural ecosystems and alter species composition.
Finally, fertilizer application is a relevant factor in farmers‘ cost calculations.

Correlation with soil management:

[27] Strategies to improve N use efficiency on Irish dairy farms: Optimization of application of N fertilizers and organic manures (timing, rate, form, method of application). Incorporation of N fixing forage legumes into grass swards. Improved grazing management and grass utilization (offsetting concentrate feed import) and better soiled water management

[68] Agricultural systems can reduce fertilizer use and can achieve higher nitrogen use efficiency by facilitating biological nitrogen fixation

[91] Increasing farm size and new technologies for fertilizer application could increase nitrogen use efficiency in Chinese cropland

[157] For sustainable agricultural systems is required to improve the efficiency of crop nitrozen recovery and to reduce gaseous and leaching losses. Poultry manure, rice hulls and mineral fertilizer combination may represent a good soil amendment to obtain a high yield with a lower environmental impact, at least in the short-term

[259] Effectiveness of fertilization strategies using bio-digestion waste derivatives as compared to conventional practices using animal manure and chemical fertilizer
[260] Inoculation of rice with dark septate endophytic (DSE) fungi represents a strategy to improve green manure-N recovery, grain yield per plant, and grain quality in terms of micronutrients contents in cropping systems with a low N input

Correlation with soil functions:

[27] Land with more free draining soils was related to higher nitrogen use efficiency
[82] Change in soil N stock influences system N efficiency

Strength &weaknesses pertaining to measurement of this impact area

Embodied Nitrogen: can be used to calculate nitrogen use efficiencies (NUE) (e.g., the share of nitrogen recovered by plants relative to the amount of nitrogen fertilizer applied). However, efficiency measures are less suited to assess risks of environmental contamination by nitrogen fertilizer than nitrogen budgets (i.e. amount recovered – amount applied).

Sample Indicators

Indicator values from		Survey	
Experiment or direct measurement		Statistical- or census data	
Expert assessment		Literature values	
Model		Maps or GIS	
Stakeholder participation		Not provided	

Table 1: Field Scale

Indicator	Unit	Indicator values from
[259] Nitrogen use efficiency (Plant N uptake/Amount of N applied in fertilization)	kg ha^{-1} * (kg ha^{-1})$^{-1}$	
[260] N recovery efficiency (10%) (Amount of N in the plants derived from C. ensiformis-15 N/Amount of applied N as 15N-labeled green manure (NGM))	mg plant^{-1} * (mg plant^{-1})$^{-1}$	

[260] Fraction of N in the plant derived from finely ground C. ensiformis N (N in excess in rice plant/N in excess in green manure)	mg $plant^{-1}$ * (mg $plant^{-1})^{-1}$	

Table 2: Farm Scale

Indicator	**Unit**	**Indicator values from**
[27] Nitrogen use efficiency (Total nitrogen output (N milk + N crop + N livestock)/Total N input (fertilizer + concentrates + forage feeds + livestock imports))	kg * kg^{-1}	
[82] System nitrogen efficiency (Net N output (Animals + milk + high protein crops + low protein crops + manure)/Net N input (Fertilizer + biological N fixation + seed input + high protein feed + low protein feed + manure) + net indirect losses (occurring during production and transport of inputs) + change in soil N))	kg * kg^{-1}	 , 
[82] Nitrogen use efficiency (N output (Animals + milk + high protein crops + low protein crops + manure)/N input (Fertilizer + biological N fixation + seed input + high protein feed + low protein feed + manure))	kg * kg^{-1}	
[157] Nitrogen use efficiency (Nitrogen measured in plant biomass at harvest – amount of Nitrogen coming from the initial soil/Total amount of applied Nitrogen (MF: mineral fertilizer; P + F: poultry manure and mineral fertilizer; R + F: rice hulls and mineral fertilizer and P + R + F: poultry manure, rice hulls and mineral fertilizer))	g * g^{-1}	

Table 3: National Scale

Indicator	**Unit**	**Indicator values from**
[68] Full-Chain nitrogen use efficiency (Embodied Nitrogen in Food/Total nitrogen input (fertilizer + biological nitrogen fixation + atmospheric deposition + net N import of food and feed) + changes in N stock (annual net balance of national imports and exports of food and feed))	Kton * $Kton^{-1}$	
[83] System nitrogen efficiency (Net N output (Animal products + crops + manure)/Net N input (fertilizer + biological N fixation + atmospheric N depostiton + manure + crops + animals) + net N indirect losses (occurring during production and transport of inputs) + change in soil N))	kg * kg^{-1}	
[83] Nitrogen use efficiency (N output (Animal products + crops + manure)/Net N input (Fertilizer + biological N fixation + atmospheric N depostiton + manure + crops + animals))	kg * kg^{-1}	

[91] Nitrogen use efficiency in the cropland (Total N in the crop (including seed and straw)/Total N input (fertilizer, manure, biological nitrogen fixation, atmospheric deposition, straw recycled, irrigation))	Tg * Tg $^{-1}$	 , 

References

ID	Citation	[1]Soil type/ texture
27	Buckley, C., et al. (2016). "Farm gate level nitrogen balance and use efficiency changes post implementation of the EU Nitrates Directive." Nutrient Cycling in Agroecosystems **104**(1): 1-13.	n/a
68	Erisman, J. W., et al. (2018). "An Integrated Approach to a Nitrogen Use Efficiency (NUE) Indicator for the Food Production-Consumption Chain." Sustainability **10**(4).	n/a
82	Godinot, O., et al. (2014). "SyNE: An improved indicator to assess nitrogen efficiency of farming systems." Agricultural Systems **127**: 41-52.	n/a
83*	Godinot, O., et al. (2016). "Indicators to evaluate agricultural nitrogen efficiency of the 27 member states of the European Union." Ecological Indicators **66**: 612-622.	n/a
91	Gu, B., et al. (2017). "Nitrogen use efficiencies in Chinese agricultural systems and implications for food security and environmental protection." Regional Environmental Change **17**(4): 1217-1227.	n/a
157	Machado, D., et al. (2010). "The use of organic substrates with contrasting C/N ratio in the regulation of nitrogen use efficiency and losses in a potato agroecosystem." Nutrient Cycling in Agroecosystems **88**(3): 411-427.	Sandy-loam texture
259	Vaneeckhaute, C., et al. (2014). Assessing nutrient use efficiency and environmental pressure of macronutrients in biobased mineral fertilizers: A review of recent advances and best practices at field scale. Advances in Agronomy. **128:** 137-180.	Sandy loam
260	Vergara, C., et al. (2018). "Dark Septate Endophytic Fungi Increase Green Manure-N-15 Recovery Efficiency, N Contents, and Micronutrients in Rice Grains." Frontiers in Plant Science **9**.	Haplic Planosol; Sandy soil (3% clay, 5% silt, and 92% sandy)

[1]**Soil type/ texture:** If provided, what are type and texture of the soils studied in the paper?

*The impact area discussed on this factsheet is not a focus of the cited paper

Impact Area: **Yield** per **Nitrogen fertilizer**

Definition:

$$\frac{Grain/Fruit/\,Tuber\ yield}{Nitrogen\ fertilizer}$$

Description:

Benefit: This impact area refers to the weight of harvested parts of plants that possess economic value. It is suitable, where production is to be used food or feed purposes or as a non-energetic production factor in bio-refineries. Crops with high per hectare yield will show high efficiencies in this impact area.

Resource: Nitrogen fertilizer is considered a stressed resource for several reasons. While the supply of nitrogen is effectively unlimited, its production is highly energy intensive and its application results in emissions of ammonium and nitrous oxide, creating a conflict between nitrogen fertilizer application and climate change mitigation targets.
Depending on the application rate and type of nitrogen fertilizer (in combination with site specific conditions), diffuse pollution and contamination of water resources is also relevant. Diffuse nitrogen pollution may also strongly affect nutrient poor natural ecosystems and alter species composition.
Finally, fertilizer application is a relevant factor in farmers‘ cost calculations.

Correlation with soil management:

[67] Application of hydrogel, on sandy soils improves water holding capacity and availability of the nutrients. Higher amount of hydrogel improves fertilizer use efficiency
[92] Integrated management could increase grain yield and nitrogen use efficiency: increasing planting density and tillage depth, improving water management and applying organic fertilizer
[252] In the case of crop rotations, increasing resource-use efficiency while reducing yield gaps can be addressed by suitable agricultural management practices

Strength &weaknesses pertaining to measurement of this impact area

Yield: Yield values are generally easy to measure and readily available at farm level or in the form of national inventories.

However, their informative value is limited where they do not account for qualitative differences between types of biomass and are not accompanied by information on site conditions such as local climate or soil fertility. Therefore, comparisons between efficiencies of different production processes with regard to yields should only be made where products and site conditions are similar. In some cases, it may be advisable to select alternative indicators where the type of benefit is more clearly defined (e.g., energetic value, financial benefit).

Sample Indicators

Indicator values from		Survey	
Experiment or direct measurement		Statistical- or census data	
Expert assessment		Literature values	
Model		Maps or GIS	
Stakeholder participation		Not provided	

Table 1: Field Scale

Indicator	Unit	Indicator values from
[67] Fertilizer use efficiency (Squash yield/Amount of N fertilizer)	kg * kg^{-1}	
[92] Nitrogen partial factor productivity (Grain yield/Total N input (fertilizer + manure + biological N2 fixation + atmospheric deposition + straw recycled + irrigation))	kg * kg $^{-1}$	

Table 2: Farm Scale

Indicator	Unit	Indicator values from
[252] Nitrogen use efficiency (Grain yield/Available N)	kg * kg^{-1}	

References

ID	Citation	[1]Soil type/ texture
67	"Water and fertilizer use efficiency by squash grown under stress on sandy soil treated with acrylamide hydrogels." Journal of Applied Sciences Research **7**(12): 1828-1833.	Sandy soil

[1]**Soil type/ texture:** If provided, what are type and texture of the soils studied in the paper?

92	Gu, J., et al. (2017). "Canopy light and nitrogen distributions are related to grain yield and nitrogen use efficiency in rice." Field Crops Research **206**: 74-85.	Typic Fluvaquent; Sandy loam
252	Tomaz, A., et al. (2018). "Efficient use of water and nutrients in irrigated cropping systems in the Alqueva region." Spanish Journal of Soil Science **8**(1): 12-23.	Chromic Cambisols (Bc); Silt loam

Impact Area: **Benefits** per **Energy**

Definition:

$$\frac{Financial\ benefits}{Energy}$$

Description:

Benefit: This impact area assesses benefits via their appreciation by markets (Di Maio et al., 2017). It is sensitive to various socio-economic factors because commodity prices reflect demand and are also influenced by value systems and policies through effects of financial incentives and tax regulations.

Resource: The use of energy usually refers to inputs of fuel or electricity. Solar irradiation is not considered because it is not a stressed resource, but also because the amount of this natural input would dwarf out all other energy inputs. Furthermore, energy from human or animal labour is usually not considered, although some studies explicitly include it (Arodudu et al., 2017).

Correlation with soil management:

[255] Paper anticipated that in long-term agricultural activity would gradually contract in currently better developed countries and energy intensity in agricultural sector should gradually diminish

Strength &weaknesses pertaining to measurement of this impact area

Financial Benefits: Financial indicators are well suited for integrating or comparing agricultural production processes with products for very different end uses. For calculating benefit-cost ratios (BCR), indicators that reflect revenue should be used. In most other cases, indicators that reflect net benefits (after deduction of charges, costs and expenses) provide a more realistic picture of benefits generated. Price volatilities make efficiency calculations valid only for a certain point in time and space.

Energy: For this indicator, a number of standard values for agricultural management are readily available. LCA inventories even provide standard values for energy used in precursory processes.
If the (fossil) energy input is used as a proxy for greenhouse gas emission, it is necessary to also consider the share of non-energy related GHG emission sources like drained soils or nitrous oxide from fertilizers.

Can be measured as:

Financial Benefits:

- revenue [$]
- gross profit [$]
- farmers' net income [$]

Energy:

- total energy use [J]
- energy use from non-renewable sources [J]

Sample Indicators

Indicator values from		Survey	
Experiment or direct measurement		Statistical- or census data	
Expert assessment		Literature values	
Model		Maps or GIS	
Stakeholder participation		Not provided	

Table 1: Global Scale

Indicator	**Unit**	**Indicator values from**
[255] Energy intensity (One European Euro/Amount of energy used)	$\$ * ton^{-1}$	

References

ID	**Citation**	**[1]Soil type/ texture**

[1]**Soil type/ texture:** If provided, what are type and texture of the soils studied in the paper?

255	Tvaronavičiene, M., et al. (2017). "Energy ecurity and long-term energy efficiency: Case of selected counties." Journal of Security and Sustainability Issues **7**(2): 349-357.	n/a

Impact Area: **Biomass** per **Energy**

Definition:

$$\frac{Aboveground\ Biomass}{Energy}$$

Description:

Benefit: This impact area refers to the total weight of all aboveground, harvestable parts of cultivated plants. It is suitable, where production is to be used for energy and other non-food purposes that can utilize the whole plant. Woody crops and forage crops will show high efficiencies in this impact area.

Resource: The use of energy usually refers to inputs of fuel or electricity. Solar irradiation is not considered because it is not a stressed resource, but also because the amount of this natural input would dwarf out all other energy inputs. Furthermore, energy from human or animal labour is usually not considered, although some studies explicitly include it (Arodudu et al., 2017).

Strength &weaknesses pertaining to measurement of this impact area

Biomass: Total amount aboveground biomass (production is generally easy to measure.

However, the informative value is limited where they do not account for qualitative differences between types of biomass and are not accompanied by information on site conditions such as local climate or soil fertility. Therefore, comparisons between efficiencies of different production processes with regard to yields should only be made where products and site conditions are similar. In some cases, it may be advisable to select alternative indicators where the type of benefit is more clearly defined (e.g., energetic value, financial benefit).

Energy: For this indicator, a number of standard values for agricultural management are readily available. LCA inventories even provide standard values for energy used in precursory processes.

If the (fossil) energy input is used as a proxy for greenhouse gas emission, it is necessary to also consider the share of non-energy related GHG emission sources like drained soils or nitrous oxide from fertilizers.

Can be measured as:

Biomass:

- yield, fresh weight [t]
- yield, dry matter weight [t]

Energy:

- total energy use [J]
- energy use from non-renewable sources [J]

Sample Indicators

Indicator values from		Survey	
Experiment or direct measurement		Statistical- or census data	
Expert assessment		Literature values	
Model		Maps or GIS	
Stakeholder participation		Not provided	

Table 1: Field Scale

Indicator	Unit	Indicator values from
[275] Biomass/Energy	g * MJ $^{-1}$	

Table 2: Regional Scale

Indicator	Unit	Indicator values from
[190] Aboveground biomass/Absorbed photosynthetic active radiation	g * MJ $^{-1}$	,

References

ID	Citation	[1]Soil type/ texture
190	Pan, G., et al. (2009). "Using QuickBird imagery and a production efficiency model to improve crop yield estimation in the semi-arid hilly Loess Plateau, China." Environmental Modelling & Software **24**(4): 510-516.	n/a
275	Yang, Z., et al. (2016). "Leveraging abscisic acid receptors for efficient water use in Arabidopsis." Proceedings of the National Academy of Sciences of the United States of America **113**(24): 6791-6796.	n/a

[1]**Soil type/ texture:** If provided, what are type and texture of the soils studied in the paper?

Impact Area: **Energy in (harvested) Biomass** per **Energy**

Definition:

$$\frac{Energy\ in\ (harvested)\ Biomass}{Energy}$$

Description:

Benefit:

Resource: The use of energy usually refers to inputs of fuel or electricity. Solar irradiation is not considered because it is not a stressed resource, but also because the amount of this natural input would dwarf out all other energy inputs. Furthermore, energy from human or animal labour is usually not considered, although some studies explicitly include it (Arodudu et al., 2017).

Correlation with soil management:

[5] Integrated farming techniques (balancing N fertilization and adopting minimum tillage) improves energy use efficiency of a maize based rotation system compared to conventional farming

[10] Lower tractor implementation, as well as human and animal labor, surface irrigation and reduced tillage improve the energy efficiency of biofuel production systems

[17] Reduced tillage improves energy use efficiency

[38] Controlled traffic system showed lower value in winter wheat production, but higher value in summer maize production

[58] Biofuel production from sugarcane, sweet sorghum and oil palm is efficient (highest energy yield per hectare). Reduced tillage could reduce energy use and increase energy efficiency. For cereals, planting legumes in rotation, may increase energy efficiency. Energy ratios can be improved by using crop residues as fuel

[125] Conservation management (including the use of organic compost, cover crops, and reduced level of tillage) are more energy efficient than conventional systems
[152] Mixed organic farming produce food with high energy-use efficiency. Improved farm management and technologies can increase resource-use efficiency and maintain high yield performance. Energy use efficiency of agro-forestry systems was higher than for arable farming in both the organic and conventional systems
[186] to improve energy efficiency, several technological and organizational procedures may be applied, e.g. reducing distances between fields, reducing the amounts of transported goods by preliminary treatment, efficient machinery for tillage operations

[199] Results showed a positive and additive effect of water and nitrogen application on Water Use Efficiency, reflected by yield enhancement

[214] In Brazil, biodiesel addition into diesel is mandatory and soybean oil is its main source. Energy balance showed linearity with yield, whereas for EROI, the increases in input and yield were not affected
[248] Small rice-producing farms ranging from 0.61 to 1.0 ha yielded higher energy ratios (4.14) than larger ones
[270] Energy consumption from irrigation process is converted to electricity, thus the corresponding GHG emission caused by irrigation is included into that of electricity

Correlation with soil functions:

[152] Organic mixed farming improved soil fertility and soil structure. Grass cover alfalfa of organic arable farming and organic agro-forestry systems is used to increase soil structure, soil fertility, and humus content

Strength &weaknesses pertaining to measurement of this impact area

Energy: For this indicator, a number of standard values for agricultural management are readily available. LCA inventories even provide standard values for energy used in precursory processes.
If the (fissile) energy input is used as a proxy for greenhouse gas emission, it is necessary to also consider the share of non-energy related GHG emission sources like drained soils or nitrous oxide from fertilizers.

Sample Indicators

Indicator values from		Survey	
Experiment or direct measurement		Statistical- or census data	
Expert assessment		Literature values	

Model		Maps or GIS	
Stakeholder participation		Not provided	

Table 1: No Scale

Indicator	**Unit**	**Indicator values from**
[58] Energy ratio (Bioenergy output (including co-products)/Fossil energy (used in agriculture, transport and processing))	MJ * MJ $^{-1}$	
[85] Energy in harvested fruits/Energy input (farmyard manure energy + chemical fertilizers + machinery and diesel fuel energy)	MJ * MJ $^{-1}$	

Table 2: Field Scale

Indicator	**Unit**	**Indicator values from**
[5] Energy use efficiency (EUE) (Energy in harvested grains/Total energy inputs until field gate (Mechanization + fertilization + irrigation + crop propagation + herbicides))	GJ * GJ $^{-1}$	
[5] Environmental Efficiency of Support Energy (EESE) (Energy in harvested grains + soil organic matter/Total energy inputs (Mechanization + fertilization + irrigation + crop propagation + herbicides))	GJ * GJ $^{-1}$	
[17] Energy use efficiency (Energy content of sunflower grain yield/Total energy input (human labor, machinery, chemical fertilizers, diesel fuel, irrigation, seeds))	MJ * MJ $^{-1}$	
[125] Energy use efficiency (Energy in harvested potato/Total Energy input (direct energy (diesel fuel, lubricants) + indirect energy (manufacturing of machinery, fertilizer, pesticides)))	GJ * GJ $^{-1}$	
[152] Energy use efficiency (Energy in harvested biomass – energy in the seed/Total energy input (Direct energy (diesel) + indirect energy (Seed + mineral and organic fertilizers + pesticides + machines))	GJ * GJ $^{-1}$	

Table 3: Farm Scale

Indicator	**Unit**	**Indicator values from**
[152] Energy use efficiency (Energy in harvested biomass – energy in the seed/Total energy input (Direct energy (diesel) + indirect energy (Seed + mineral and organic fertilizers + pesticides + machines))	GJ * GJ $^{-1}$	

[186] Partial energetic efficiency (Energy content of biofuel after processing/Energy used for transportations of products, machines or tools)	$MJ * MJ^{-1}$	,
[186] Partial energetic efficiency (Energy content of biofuel after processing/Energy used after tillage operations)	$MJ * MJ^{-1}$	,
[276] Energy use efficiency (Output energy/Input energy)	$MJha^{-1} * (MJha^{-1})^{-1}$	

Table 4: Regional Scale

Indicator	**Unit**	**Indicator values from**
[38] Energy use efficiency (Energy output (wheat grain + maize grain + straw)/Energy input (machine + diesel fuel + labor + seed + nitrogen + P2O5 + K2O + herbicides + electricity))	$MJ * MJ^{-1}$	
[199] Energy Return on Investment (EROI) (Energy output/Energy input)	$MJ * MJ^{-1}$	,
[214] Energy return over investment (EROI) (Energy output flow - energy input flow/Energy input flow (grain yield))	$MJ * MJ^{-1}$	,
[248] Energy efficiency (Output energy/Input energy	$MJha^{-1} * (MJha^{-1})^{-1}$	,
[248] Non-renewable energy ratio (Output energy/Non-renewable energy input)	$MJha^{-1} * (MJha^{-1})^{-1}$	,
[270] Energy output/Energy input	$GJha^{-1} * (GJha^{-1})^{-1}$	,
[271] Energy output/Energy input	$J * J^{-1}$	
[283] Thermal efficiency (Released energy (energy released by the fuel and ignition material)/Useful energy (energy used by the water temperature rising + water evaporating + energy absorbed by the pot))	$kJ * kJ^{-1}$	

Table 5: National Scale

Indicator	**Unit**	**Indicator values from**
[270] Energy output/Energy input	$GJha^{-1} * (GJha^{-1})^{-1}$	,

Table 6: Global Scale

Indicator	**Unit**	**Indicator values from**
[10] Energy return on energy invested (EROI) (Bio energy output (including co-products)/Energy input (direct energy	$MJ * MJ^{-1}$	

(farm operation + energy for conversion of biomass to energy) + indirect energy (production of chemicals)))		

References

ID	Citation	[1]Soil type/ texture
5	Alluvione, F., et al. (2011). "EUE (energy use efficiency) of cropping systems for a sustainable agriculture." Energy **36**(7): 4468-4481.	Coarse-loamy mixed non-acid mesic Typic Hapludalf; Loamy sand
10	Arodudu, O. T., et al. (2017). "Integrating agronomic factors into energy efficiency assessment of agro-bioenergy production – A case study of ethanol and biogas production from maize feedstock." Applied Energy 198: 426-439.	n/a
17	Baran, M. F. and O. Gokdogan (2016). "COMPARISON OF ENERGY USE EFFICIENCY OF DIFFERENT TILLAGE METHODS ON THE SECONDARY CROP CORN SILAGE PRODUCTION." Fresenius Environmental Bulletin **25**(9): 3808-3814.	Clayey and loamy soil
38	Chen, H., et al. (2016). "Effect of controlled traffic on energy use efficiency in wheat-maize production in North China Plain." Journal of Computational and Theoretical Nanoscience **13**(4): 2634-2638.	Porous and homogenous; Silt loam
58	de Vries, S. C., et al. (2010). "Resource use efficiency and environmental performance of nine major biofuel crops, processed by first-generation conversion techniques." Biomass and Bioenergy **34**(5): 588-601.	n/a
85	Gökdoğan, O., et al. (2018). "Studies of Energy Use Efficiency on Fruit Production." Erwerbs-Obstbau: 1-5.	n/a
125	Khakbazan, M., et al. (2017). "Energy Use Efficiency of Conventional versus Conservation Management Practices for Irrigated Potato Production in Southern Alberta." American Journal of Potato Research **94**(2): 105-119.	Mainly orthic brown Chernozemic soils
152	Lin, H. C., et al. (2017). "Effects of changing farm management and farm structure on energy balance and energy-use efficiency-A case study of organic and conventional farming systems in southern Germany." European Journal of Agronomy **82**: 242-253.	Cambisol; Loamy to sandy soil
186	Orynycz, O. and A. Swic (2018). "The Effects of Material's Transport on Various Steps of Production System on Energetic Efficiency of Biodiesel Production." Sustainability **10**(8).	n/a
199	Peter, C., et al. (2017). "Impact of Energy Crop Rotation Design on Multiple Aspects of Resource Efficiency." Chemical Engineering and Technology **40**(2): 323-332.	Stagnic Cambisol, Chernosem, Luvisol, Regosol, Planosol, Albeluvisol, Gleyic Cambisol, Stagnic Cambisol;

[1]**Soil type/ texture:** If provided, what are type and texture of the soils studied in the paper?

		Fine, medium and coarse
214	Romanelli, T. L., et al. (2012). "Material embodiment and energy flows as efficiency indicators of soybean (Glycine max) production in Brazil." Engenharia Agricola **32**(2): 261-270.	n/a
248	Talukder, B., et al. (2019). "Energy efficiency of agricultural systems in the southwest coastal zone of Bangladesh." Ecological Indicators **98**: 641-648.	n/a
270	Wu, H., et al. (2017). "Temporal trends and spatial patterns of energy use efficiency and greenhouse gas emissions in crop production of Anhui Province, China." Energy **133**: 955-968.	n/a
271	Wu, Z. N., et al. (2017). "Water efficiency evaluation of a regional water scheme - Zhengzhou, China, using a water ecological-economic system (WEES) and based on emergy theory." Water Science and Technology-Water Supply 17(3): 674-687.	n/a
276	Yousefi, M. and A. Mohammadi (2011). "Economical analysis and energy use efficiency in alfalfa production systems in Iran." Scientific Research and Essays **6**(11): 2332-2336.	n/a
283	Zhang, Y., et al. (2018). "Assessment of pollutant emissions and energy efficiency of four commercialized charcoal stoves with modified Chinese cooking stove protocol." International Journal of Agricultural and Biological Engineering **11**(2): 202-207.	n/a

Impact Area: **Yield** per **Energy**

Definition:

$$\frac{Grain/Fruit/Tuber\ yield}{Energy}$$

Description:

Benefit: This impact area refers to the weight of harvested parts of plants that possess economic value. It is suitable, where production is to be used food or feed purposes or as a non-
energetic production factor in bio-refineries. Crops with high per hectare yield will show high efficiencies in this impact area.

Resource: The use of energy usually refers to inputs of fuel or electricity. Solar irradiation is not considered because it is not a stressed resource, but also because the amount of this natural input would dwarf out all other energy inputs. Furthermore, energy from human or animal labour is usually not considered, although some studies explicitly include it (Arodudu et al., 2017).

Correlation with soil management:

[5] Maize had the most efficient biomass production per fossil energy. Low-input cropping and integrated farming were more efficient in biomass production than conventional management

[17] Reduced tillage improves energy use efficiency

[125] Conservation management (including the use of organic compost, cover crops, and reduced level of tillage) increased potato yield per unit of energy input

[248] Small rice-producing farms ranging from 0.61 to 1.0 ha yielded higher energy ratios (4.14) than larger ones

Strength &weaknesses pertaining to measurement of this impact area

Yield: Yield values are generally easy to measure and readily available at farm level or in the form of national inventories.
However, their informative value is limited where they do not account for qualitative differences between types of biomass and are not accompanied by information on site conditions such as local climate or soil fertility. Therefore, comparisons between efficiencies of different production processes with regard to yields should only be made where products and site conditions are similar. In some cases, it may be advisable to select alternative indicators where the type of benefit is more clearly defined (e.g., energetic value, financial benefit).

Energy: For this indicator, a number of standard values for agricultural management are readily available. LCA inventories even provide standard values for energy used in precursory processes.
If the (fossil) energy input is used as a proxy for greenhouse gas emission, it is necessary to also consider the share of non-energy related GHG emission sources like drained soils or nitrous oxide from fertilizers.

Sample Indicators

Indicator values from		Survey	
Experiment or direct measurement		Statistical- or census data	
Expert assessment		Literature values	
Model		Maps or GIS	
Stakeholder participation		Not provided	

Table 1: No Scale

Indicator	**Unit**	**Indicator values from**
[85] Energy productivity (Fruit yield/Energy input (farmyard manure energy + chemical fertilizers + machinery and diesel fuel energy))	kg * MJ $^{-1}$	

Table 2: Field Scale

Indicator	**Unit**	**Indicator values from**
[5] Energy Intensity (EI) (Grain yield/Fossil energy used in farm operations and production of inputs and machinery)	kg * MJ $^{-1}$	

[17] Energy productivity(Sunflower grain yield/Total energy input (human labor, machinery, chemical fertilizers, diesel fuel, irrigation, seeds))	kg * MJ $^{-1}$	
[125] Potato yield/Total Energy input (direct energy (diesel fuel, lubricants) + indirect energy (manufacturing of machinery, fertilizer, pesticides))	kg * GJ $^{-1}$	

Table 3: Farm Scale

Indicator	**Unit**	**Indicator values from**
[276] Energy productivity (Forage yield/Input energy)	kg * MJ $^{-1}$	

Table 4: Regional Scale

Indicator	**Unit**	**Indicator values from**
[190] Light use efficiency (Net primary production (crop yield depending on the fraction of plant biomass that is harvested)/Absorbed photosynthetic active radiation)	g * MJ $^{-1}$	,
[248] Energy productivity (Crop yield/Input energy)	kg * MJ	,

References

ID	Citation	[1]Soil type/ texture
5	Alluvione, F., et al. (2011). "EUE (energy use efficiency) of cropping systems for a sustainable agriculture." Energy **36**(7): 4468-4481.	Coarse-loamy mixed non-acid mesic Typic Hapludalf; Loamy sand
17	Baran, M. F. and O. Gokdogan (2016). "COMPARISON OF ENERGY USE EFFICIENCY OF DIFFERENT TILLAGE METHODS ON THE SECONDARY CROP CORN SILAGE PRODUCTION." Fresenius Environmental Bulletin **25**(9): 3808-3814.	Clayey and loamy soil
85	Gökdoğan, O., et al. (2018). "Studies of Energy Use Efficiency on Fruit Production." Erwerbs-Obstbau: 1-5.	n/a
125	Khakbazan, M., et al. (2017). "Energy Use Efficiency of Conventional versus Conservation Management Practices for Irrigated Potato Production in Southern Alberta." American Journal of Potato Research **94**(2): 105-119.	Mainly orthic brown Chernozemic soils
190	Pan, G., et al. (2009). "Using QuickBird imagery and a production efficiency model to improve crop yield estimation in the semi-arid hilly Loess Plateau, China." Environmental Modelling & Software **24**(4): 510-516.	n/a
248	Talukder, B., et al. (2019). "Energy efficiency of agricultural systems in the southwest coastal zone of Bangladesh." Ecological Indicators **98**: 641-648.	n/a
276	Yousefi, M. and A. Mohammadi (2011). "Economical analysis and energy use efficiency in alfalfa production systems in Iran." Scientific Research and Essays **6**(11): 2332-2336.	n/a

[1]**Soil type/ texture:** If provided, what are type and texture of the soils studied in the paper?

Impact Area: **Energy** per **GHG emissions**

Definition:

$$\frac{Embodied\ Energy}{GHG\ emissions}$$

Description:

Benefit: Energy content can be used for an integrated evaluation of crops. Generally, the type of energy should be specified to distinguish between use as fuel or use as food and feed. For use as animal feed, further definitions are required to determine if lignocellulosiccrops qualify. Crops with high per hectare yield will show high efficiencies in this impact area.

Resource: Under current policy targets such as the 2015 Paris Agreement or the United Nations' Sustainable Development Goals (SDG), the total amount of greenhouse gases that can safely be emitted into the atmosphere is limited. Greenhouse gas emissions can therefore be treated as a limited resource.
For this indicator, emissions of different greenhouse gases are combined by calculating carbon dioxide equivalent emissions (CO2 eq.), based on the 100-year global warming potential (GWP) of each gas. It is necessary to define both the spatial reference (e.g. emissions per hectare) and the temporal reference (e.g. emissions per year).

Correlation with soil management:

[58] Biofuel from sweet sorghum, sugarcane, soybean and oil palm show highest reduction in GHG emission per unit of energy produced compared to fossil fuel

Strength & Weaknesses (pertaining to measurement of this impact area)

Embodied Energy: Indicators for embodied energy are generally easy to measure and allow integration of or comparison between benefits from very different crops. However, their information value for questions of nutrition is limited because the provision of amino-acids and vitamins is not considered.

GHG Emissions: For this indicator, a number of standard values and national inventories exist. The use of the 100-year GWP enables comparability between studies and between emissions of different greenhouse gasses. However, for short lived gasses such as methane, this standard underestimates the contribution to global warming in the short term and overestimates their contribution in the long term.

Can be measured as:

Embodied Energy:

- nutritional value (humans) [J]
- nutritional value (non-grazing livestock) [J]
- nutritional value (grazing livestock) [J]
- heating value [J]

GHG Emissions:

- total emissions [Mg CO2 eq. ha^{-1} yr^{-1}]

Sample Indicators

Indicator values from		Survey	
Experiment or direct measurement		Statistical- or census data	
Expert assessment		Literature values	
Model		Maps or GIS	
Stakeholder participation		Not provided	

Table 1: No Scale

Indicator	**Unit**	**Indicator values from**
[58] GHG emission indicator (Produced Energy in the biofuel and its coproducts/CO2 emission)	MJ * g^{-1}	

References

ID	**Citation**	**[1]Soil type/ texture**
58	de Vries, S. C., et al. (2010). "Resource use efficiency and environmental performance of nine major biofuel crops, processed by first-generation conversion techniques." Biomass and Bioenergy **34**(5): 588-601.	n/a

[1]**Soil type/ texture:** If provided, what are type and texture of the soils studied in the paper?

Impact Area: **Yield** per **GHG emissions**

Definition:

$$\frac{Grain/Fruit/\,Tuber\ yield}{GHG\ emissions}$$

Description:

Benefit: Yield refers to the weight of harvested parts of plants that possess economic value. It is suitable, where production is to be used food or feed purposes or as a non-energetic production factor in bio-refineries. Crops with high per hectare yield will show high efficiencies in this impact area.

Resource: Under current policy targets such as the 2015 Paris Agreement or the United Nations' Sustainable Development Goals (SDG), the total amount of greenhouse gases that can safely be emitted into the atmosphere is limited. Greenhouse gas emissions can therefore be treated as a limited resource.
For this indicator, emissions of different greenhouse gases are combined by calculating carbon dioxide equivalent emissions (CO2 eq.), based on the 100-year global warming potential (GWP) of each gas. It is necessary to define both the spatial reference (e.g. emissions per hectare) and the temporal reference (e.g. emissions per year).

Correlation with soil management:

[125] Conservation management (including the use of organic compost, cover crops, and reduced level of tillage) management was more efficient in terms of yield per GHG emissions than conventional management
[241] Highest land use efficiencies (potato yield per hectare of area) were achieved in regions that produce potatoes under irrigation in summer where solar radiation is high and lowest land use efficiencies were reported for the predominantly dryland and partially dryland regions.

Strength &weaknesses pertaining to measurement of this impact area

Yield: Yield values are generally easy to measure and readily available at farm level or in the form of national inventories.

However, their informative value is limited where they do not account for qualitative differences between types of biomass and are not accompanied by information on site conditions such as local climate or soil fertility. Therefore, comparisons between efficiencies of different production processes with regard to yields should only be made where products and site conditions are similar. In some cases, it may be advisable to select alternative indicators where the type of benefit is more clearly defined (e.g., energetic value, financial benefit).

GHG Emissions: For this indicator, a number of standard values and national inventories exist. The use of the 100-year GWP enables comparability between studies and between emissions of different greenhouse gasses. However, for short lived gasses such as methane, this standard underestimates the contribution to global warming in the short term and overestimates their contribution in the long term.

Can be measuredas:

Yield:

- yield, fresh weight [t]
- yield, dry matter weight [t]

GHG Emissions:

- total emissions [Mg CO2 eq. ha^{-1} yr^{-1}]

Sample Indicators

Indicator values from		Survey	
Experiment or direct measurement		Statistical- or census data	
Expert assessment		Literature values	
Model		Maps or GIS	
Stakeholder participation		Not provided	

Table 1: Field Scale

Indicator	Unit	Indicator values from
[125] Potato yield/GHG emission	kg * kg^{-1}	Experiment or direct measurement

Table 2: Regional Scale

Indicator	Unit	Indicator values from
[241] Energy use efficiency (Potato yield/Energy use (CO2 emissions) associated with irrigation, fertilizer and seed production)	ton * kg^{-1}	Survey

References

ID	Citation	[1]Soil type/ texture
125	Khakbazan, M., et al. (2017). "Energy Use Efficiency of Conventional versus Conservation Management Practices for Irrigated Potato Production in Southern Alberta." American Journal of Potato Research **94**(2): 105-119.	Mainly orthic brown Chernozemic soils
241	Steyn, J. M., et al. (2016). "Resource use efficiencies as indicators of ecological sustainability in potato production: A South African case study." Field Crops Research **199**: 136-149.	Loam, sandy-loam, sand

[1]**Soil type/ texture:** If provided, what are type and texture of the soils studied in the paper?

Impact Area: **Benefits per Labour**

Definition:

$$\frac{Financial\ benefits}{Human\ labour}$$

Description:

Benefit: This impact area assesses benefits via their appreciation by markets (Di Maio et al., 2017). It is sensitive to various socio-economic factors because commodity prices reflect demand and are also influenced by value systems and policies through effects of financial incentives and tax regulations.

Resource: The use of labour is closely connected with the provision of employment and therefore a reduction is not always positive. If the main benefit of a reduction in the use of labour is reducing factor costs, it is recommended to use monetary indicators instead. However, where reductions serve the purpose of reducing hard physical labour and thereby increasing human health, labour should be used as indicator.

Correlation with soil management:

[149] Labor productivity of larger farms is higher than of small farms

[288] Formation of a mixed economy in the agrarian sector

Strength &weaknesses pertaining to measurement of this impact area

Financial Benefits: Financial indicators are well suited for integrating or comparing agricultural production processes with products for very different end uses. For calculating benefit-cost ratios (BCR), indicators that reflect revenue should be used. In most other cases, indicators that reflect net benefits (after deduction of charges, costs and expenses) provide a more realistic picture of benefits generated. Price volatilities make efficiency calculations valid only for a certain point in time and space.

Sample Indicators

Indicator values from		Survey	
Experiment or direct measurement		Statistical- or census data	
Expert assessment		Literature values	
Model		Maps or GIS	

Stakeholder participation		Not provided	

Table 1: No Scale

Indicator	Unit	Indicator values from
[288] Specific labor productivity (Gross output/Man-hour)	$ * h^{-1}	
[288] Specific labor productivity (Gross output/Employee)	$ * No^{-1}	

Table 2: Farm Scale

Indicator	Unit	Indicator values from
[149] Labor productivity (Total income generated from farming during a year/Total work days during a year)	$ * day^{-1}	
[149] Labor productivity (Total income generated from farming during a year/Farm labor)	$ * No^{-1}	
[176] Net agricultural income (Prices of inputs or sold products)/Family worker	$ * No^{-1}	,

Table 3: Regional Scale

Indicator	Unit	Indicator values from
[1] Value of yields (including subsidies)/Number of employees	$ * No^{-1}	
[1] Added value/Number of employees	$ * No^{-1}	
[142] Labor efficiency (Economic output of crop yield/Farming activities of labor)	$ * labor time^{-1}	

References

ID	Citation	[1]Soil type/ texture
1	Adamisin, P., et al. (2015). "Natural climatic conditions as a determinant of productivity and economic efficiency of agricultural entities." Agricultural Economics-Zemedelska Ekonomika 61(6): 265-274.	n/a
142*	Latinopoulos, D. (2009). "Multicriteria decision-making for efficient water and land resources allocation in irrigated	n/a

[1]**Soil type/ texture:** If provided, what are type and texture of the soils studied in the paper?
*The impact area discussed on this factsheet is not a focus of the cited paper

	agriculture." Environment, Development and Sustainability **11**(2): 329-343.	
149*	Li, G., et al. (2013). "Re-examining the inverse relationship between farm size and efficiency: The empirical evidence in China." China Agricultural Economic Review **5**(4): 473-488.	n/a
176	Moreau, P., et al. (2012). "Reconciling technical, economic and environmental efficiency of farming systems in vulnerable areas." Agriculture Ecosystems & Environment **147**: 89-99.	Deep loamy and shallow brown soils
288	Zotov, V. P., et al. (2014). "The main labor-forming factors and the assessment of labor efficiency in agriculture (by the example of kemerovo oblast)." Foods and Raw Materials **2**(1): 91-97.	n/a

Impact Area: **Yield** per **Labour**

Definition:

$$\frac{Grain/Fruit/\,Tuber\ yield}{Human\ labour}$$

Description:

Benefit: This impact area refers to the weight of harvested parts of plants that possess economic value. It is suitable, where production is to be used food or feed purposes or as a non-energetic production factor in bio-refineries. Crops with high per hectare yield will show high efficiencies in this impact area.

Resource: The use of labour is closely connected with the provision of employment and therefore a reduction is not always positive. If the main benefit of a reduction in the use of labour is reducing factor costs, it is recommended to use monetary indicators instead. However, where reductions serve the purpose of reducing hard physical labour and thereby increasing human health, labour should be used as indicator.

Correlation with soil management:

[182] Improving the conditions of mineral nutrition by introducing balanced doses of fertilizers for all elements contributed to a sufficiently high yield

Strength &weaknesses pertaining to measurement of this impact area

Yield: Yield values are generally easy to measure and readily available at farm level or in the form of national inventories.

However, their informative value is limited where they do not account for qualitative differences between types of biomass and are not accompanied by information on site conditions such as local climate or soil fertility. Therefore, comparisons between efficiencies of different production processes with regard to yields should only be made where products and site conditions are similar. In some cases, it may be advisable to select alternative indicators where the type of benefit is more clearly defined (e.g., energetic value, financial benefit).

Sample Indicators

Indicator values from		Survey	
Experiment or direct measurement		Statistical- or census data	
Expert assessment		Literature values	
Model		Maps or GIS	
Stakeholder participation		Not provided	

Table 1: Regional Scale

Indicator	**Unit**	**Indicator values from**
[182] Yield of grain/Labor	kg * No^{-1}	
[202] Gross yield (weight of all harvested fruits)/Working hours	Mg * h^{-1}	
[202] Fresh marketable yield (gross yield minus the fruit discarded as a result of fruit rot or small size, or fruit used for processed products)/Working hours	Mg * h^{-1}	

Table 2: National Scale

Indicator	**Unit**	**Indicator values from**
[202] Gross yield (weight of all harvested fruits)/Working hours	Mg * h^{-1}	
[202] Fresh marketable yield (gross yield minus the fruit discarded as a result of fruit rot or small size, or fruit used for processed products)/Working hours	Mg * h^{-1}	

References

ID	**Citation**	**[1]Soil type/ texture**
182	Neshchadim, N. N., et al. (2018). "Bioenergetic assessment and economic efficiency of predecessors and fertilizer systems in the cultivation of winter wheat." International Journal of Engineering and Technology(UAE) **7**(4.38 Special Issue 38): 685-689.	Ordinary chernozem with low content of humus (4.5-5.5%)
202	Plénet, D., et al. (2009). "Using on-field data to develop the EFI© information system to characterise agronomic productivity and labour efficiency in peach (Prunus persica L.	n/a

[1]**Soil type/ texture:** If provided, what are type and texture of the soils studied in the paper?

	Batsch) orchards in France." Agricultural Systems **100**(1-3): 1-10.	

Impact Area: **Yield** per **Phosphorus fertilizer**

Definition:

$$\frac{Grain/Fruit/\,Tuber\ yield}{Phosphorus\ fertilizer}$$

Description:

Benefit: This impact area refers to the weight of harvested parts of plants that possess economic value. It is suitable, where production is to be used food or feed purposes or as a non-energetic production factor in bio-refineries. Crops with high per hectare yield will show high efficiencies in this impact area.

Resource: The primary source of inorganic phosphorous used in fertilizers is phosphate rock. As global reserves are limited and risk of contamination with heavy metals like uranium and costs of processing are expected to increase, there is a strong motivation to reduce the dependence on mineral phosphorous inputs.
Furthermore, phosphorous availability is a key limiting factor for aquatic ecosystems. High application rates of phosphorous fertilizer in agricultural management, in combination with runoff and erosion, can lead to phosphorous entering into waterways and thereby damaging aquatic ecosystems through eutrophication. Finally, fertilizer application is a relevant factor in farmers' cost calculations. It is therefore considered a stressed resource.

Correlation with soil management:

[252] In the case of crop rotations, increasing resource-use efficiency while reducing yield gaps can be addressed by suitable agricultural management practices

Strength &weaknesses pertaining to measurement of this impact area

Yield: Yield values are generally easy to measure and readily available at farm level or in the form of national inventories.

However, their informative value is limited where they do not account for qualitative differences between types of biomass and are not accompanied by information on site conditions such as local climate or soil fertility. Therefore, comparisons between efficiencies of different production processes with regard to yields should only be made where products and site conditions are similar. In some cases, it may be advisable to select alternative indicators where the type of benefit is more clearly defined (e.g., energetic value, financial benefit).

Can be measured as:

Yield:

- yield, fresh weight [t]
- yield, dry matter weight [t]

Phosphorus fertilizer:

- total phosphorous fertilizer application [kg P]

Sample Indicators

Indicator values from		Survey	
Experiment or direct measurement		Statistical- or census data	
Expert assessment		Literature values	
Model		Maps or GIS	
Stakeholder participation		Not provided	

Table 1: Farm Scale

Indicator	**Unit**	**Indicator values from**
[252] Phosphorus use efficiency (Grain yield/Available phosphorus)	kg * kg^{-1}	

References

ID	**Citation**	[1]**Soil type/ texture**
252	Tomaz, A., et al. (2018). "Efficient use of water and nutrients in irrigated cropping systems in the Alqueva region." Spanish Journal of Soil Science **8**(1): 12-23.	Chromic Cambisols (Bc); Silt loam

[1]**Soil type/ texture:** If provided, what are type and texture of the soils studied in the paper?

Impact Area: Energy per Pesticides

Definition:

$$\frac{Embodied\ Energy}{Pesticides}$$

Description:

Benefit: Energy content can be used for an integrated evaluation of crops. Generally, the type of energy should be specified to distinguish between use as fuel or use as food and feed. For use as animal feed, further definitions are required to determine if lignocellulosiccrops qualify. Crops with high per hectare yield will show high efficiencies in this impact area.

Resource: Pesticide application negatively affects biodiversity and is partly responsible for the continuing biodiversity decline of Europe's agricultural landscapes. For this reason, it conflicts with policy targets such as those included in the EU 2020 biodiversity strategy and can therefore be considered a stressed resource.
Production processes that provide the same benefits with lower use of pesticides are more efficient. For this indicator, the total amount of pesticides brought into the system should be considered, irrelevant of whether pesticides are applied externally, or produced by genetically modified plants themselves, as in the case of BT-maize.

Correlation with soil management:

[58] Pesticide use efficiency was highest for sugarcane, sweet sorghum and oil palm

Strength &weaknesses pertaining to measurement of this impact area

Embodied Energy: Indicators for embodied energy are generally easy to measure and allow integration of or comparison between benefits from very different crops. However, their information value for questions of nutrition is limited because the provision of amino-acids and vitamins is not considered.

Pesticides: A weakness of this indicator is that the quantity of pesticides applied is insufficient to determine the associated environment problems. Effects on biodiversity will strongly depend on site characteristics and pesticide specific properties.

Can be measured as:

Embodied Energy:

- nutritional value (humans) [J]
- nutritional value (non-grazing livestock) [J]
- nutritional value (grazing livestock) [J]
- heating value [J]

Pesticides:

- total pesticide application [kg]
- total application of a specific pesticide (e.g. glyphosate) [kg]

Sample Indicators

Indicator values from		Survey	
Experiment or direct measurement		Statistical- or census data	
Expert assessment		Literature values	
Model		Maps or GIS	
Stakeholder participation		Not provided	

Table 1: No Scale

Indicator	**Unit**	**Indicator values from**
[58] Pesticide use efficiency (Net energy yield (Energy content of biofuel and its coproducts – energy used for production, transportation and conversion)/Pesticide input)	$GJ * kg^{-1}$	

References

ID	Citation	[1]Soil type/ texture
58	de Vries, S. C., et al. (2010). "Resource use efficiency and environmental performance of nine major biofuel crops, processed by first-generation conversion techniques." Biomass and Bioenergy **34**(5): 588-601.	n/a

[1]**Soil type/ texture:** If provided, what are type and texture of the soils studied in the paper?

Impact Area: **Benefits per Money**

Definition: $$\frac{Financial\ benefits}{Money}$$

Description:

Benefit: This impact area assesses benefits via their appreciation by markets (Di Maio et al., 2017). It is sensitive to various socio-economic factors because commodity prices reflect demand and are also influenced by value systems and policies through effects of financial incentives and tax regulations.

Resource: Evaluation of costs is imperative for all agronomic planning and central to management decisions made by farmers. For this indicator, it is necessary to define whether investment costs are considered and what interest rates are applied.

Correlation with soil management:

[135] Micro irrigation treatment had higher benefit cost ratio than check basin irrigation

[149] including labor cost, profit ratio of smaller farms is much lower than of bigger farms

[162] Studies proved reduction of field crop yields from organic fields in comparison to conventional ones

[288] Formation of a mixed economy in the agrarian sector

Strength &weaknesses pertaining to measurement of this impact area

Financial Benefits: Financial indicators are well suited for integrating or comparing agricultural production processes with products for very different end uses. For calculating benefit-cost ratios (BCR), indicators that reflect revenue should be used. In most other cases, indicators that reflect net benefits (after deduction of charges, costs and expenses) provide a more realistic picture of benefits generated. Price volatilities make efficiency calculations valid only for a certain point in time and space.

Sample Indicators

Indicator values from		Survey	
Experiment or direct measurement		Statistical- or census data	
Expert assessment		Literature values	
Model		Maps or GIS	
Stakeholder participation		Not provided	

Table 1: No Scale

Indicator	Unit	Indicator values from
[288] Overall labor productivity (Gross output/Current costs)	$ * -	

Table 2: Field Scale

Indicator	Unit	Indicator values from
[135] Benefit cost ratio (Annual return of crops/Total costs (initial investment for irrigation system+ present worth value of annual cost))	$ * $^{-1}$	

Table 3: Farm Scale

Indicator	Unit	Indicator values from
[149] Profit ratio (Economic benefit (total income – material costs – labor input costs) [Chinese yuan]/Total costs (Material costs (costs for machinery/animal operations + seed + chemical fertilizer + manure + agricultural plastic film + farm chemicals + irrigation + fuels and energy + small farm tools + total depreciation on the fixed asset) + labor input costs) [Chinese yuan])	$ * $^{-1}$	
[149] Profit ratio (Economic benefit (total income – material costs)/Material costs)	$ * $^{-1}$	
[162] Cost effectiveness of fertilization (Additional profit earned as a result of fertilization/Expenses on fertilization)	$ * $^{-1}$	

Table 4: Regional Scale

Indicator	Unit	Indicator values from

[1] Value of yields (including subsidies)/Wage costs	$\$ * \$^{-1}$	
[1] Added value/Wage costs	$\$ * \$^{-1}$	

References

ID	Citation	[1]Soil type & texture
1	Adamisin, P., et al. (2015). "Natural climatic conditions as a determinant of productivity and economic efficiency of agricultural entities." Agricultural Economics-Zemedelska Ekonomika 61(6): 265-274.	n/a
135	Kumar, M., et al. (2009). "Integrating water harvesting and gravity-fed micro-irrigation system for efficient water management in terraced land for growing vegetables." Biosystems Engineering **102**(1): 106-113.	n/a
149*	Li, G., et al. (2013). "Re-examining the inverse relationship between farm size and efficiency: The empirical evidence in China." China Agricultural Economic Review **5**(4): 473-488.	n/a
162	Manolova, V., et al. (2015). "Economic efficiency of fertilization and its residual-effect during conversion period to organic field crop production." Bulgarian Journal of Agricultural Science **21**(5): 1022-1026.	n/a
288	Zotov, V. P., et al. (2014). "The main labor-forming factors and the assessment of labor efficiency in agriculture (by the example of kemerovo oblast)." Foods and Raw Materials **2**(1): 91-97.	n/a

[1]**Soil type & texture:** If provided, what are type and texture of the soils studied in the paper?

*The impact area discussed on this factsheet is not a focus of the cited paper

Impact Area: **Carbon** per **Money**

Definition:

$$\frac{Sequestered\ Carbon}{Money}$$

Description:

Benefit: Carbon sequestered in soils or in long life products helps to achieve global climate change mitigation targets.

Resource: Evaluation of costs is imperative for all agronomic planning and central to management decisions made by farmers. For this indicator, it is necessary to define whether investment costs are considered and what interest rates are applied.

Correlation with soil management:

[125]Conservation management (including the use of organic compost, cover crops, and reduced level of tillage) was more cost-effective (Mg of carbon retained/ cost) than conventional management

[285]Analytical results provided evidence to guide agribusiness in improving their current performance toward sustainability under the BRI

Strength &weaknesses pertaining to measurement of this impact area:

Sequestered Carbon: For carbon sequestration, additionally and stability over time are usually relevant. Unfortunately, stability over time is very difficult to estimate. Depending on system boundaries and context, it may be appropriate to consider only a share of the sequestered carbon if external factors (like climate change, management change) are likely to result in emissions of previously sequestered carbon at a later point in time.

Can be measured as:

Sequestered Carbon:

- carbon sequestered [t C]

- carbon sequestered until 2050 [t C]

Money:

- variable costs [$]
- total costs [$]

Sample Indicators

Indicator values from		Survey	
Experiment or direct measurement		Statistical- or census data	
Expert assessment		Literature values	
Model		Maps or GIS	
Stakeholder participation		Not provided	

Table 1: Field Scale

Indicator	Unit	Indicator values from
[125]Carbon retained in potatos and aboveground residue/Production cost of potatos	Mg * $^{-1}$	
[285]Carbon Emissions Per Product (Total Carbon Emissions (CO2+diesel+recycled waste)/Total Amount of Products)	kg * $^{-1}$	,

References

ID	Citation	[1]Soil type & texture
125	Khakbazan, M., et al. (2017). "Energy Use Efficiency of Conventional versus Conservation Management Practices for Irrigated Potato Production in Southern Alberta." American Journal of Potato Research**94**(2): 105-119.	Mainly orthic brown Chernozemic soils
285	Zhao, R., et al. (2018). "Enhancing eco-efficiency of agro-products' closed-loop supply chain under the belt and road initiatives: A system dynamics approach." Sustainability (Switzerland)**10**(3).	n/a

[1]**Soil type/ texture:** If provided, what aretype and texture of the soils studied in the paper?

Impact Area: **Yield** per **Money**

Definition:

$$\frac{Grain/Fruit/\ Tuber\ yield}{Money}$$

Description:

Benefit: This impact area refers to the weight of harvested parts of plants that possess economic value. It is suitable, where production is to be used food or feed purposes or as a non-energetic production factor in bio-refineries. Crops with high per hectare yield will show high efficiencies in this impact area.

Resource: Evaluation of costs is imperative for all agronomic planning and central to management decisions made by farmers. For this indicator, it is necessary to define whether investment costs are considered and what interest rates are applied.

Strength &weaknesses pertaining to measurement of this impact area:

Yield: Yield values are generally easy to measure and readily available at farm level or in the form of national inventories.

However, their informative value is limited where they do not account for qualitative differences between types of biomass and are not accompanied by information on site conditions such as local climate or soil fertility. Therefore, comparisons between efficiencies of different production processes with regard to yields should only be made where products and site conditions are similar. In some cases, it may be advisable to select alternative indicators where the type of benefit is more clearly defined (e.g., energetic value, financial benefit).

Can be measured as:

Yield:

- yield, fresh weight [t]
- yield, dry matter weight [t]

Money:

- variable costs [$]

- total costs [$]

Sample Indicators

Indicator values from		Survey	
Experiment or direct measurement		Statistical- or census data	
Expert assessment		Literature values	
Model		Maps or GIS	
Stakeholder participation		Not provided	

Table 1: Farm Scale

Indicator	**Unit**	**Indicator values from**
[276] Yield/Total production cost	kg * $^{-1}$	

References

ID	Citation	[1]Soil type & texture
276	Yousefi, M. and A. Mohammadi (2011). "Economical analysis and energy use efficiency in alfalfa production systems in Iran." Scientific Research and Essays **6**(11): 2332-2336.	clay lightweight sand, shallow defaulting on light clay

[1]**Soil type & texture:** If provided, what is the type & texture of the soil studied in the paper?