Machinery Management as an Environmental Tool - Material Embodiment in Agriculture

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ABSTRACT

The material embodiment in agricultural production systems is important because it determines the convergence of inputs (indirectly, the natural resources) into the crop. Besides this, the material flows are the basis for any environmental (energy analysis, emergy evaluation, life-cycle analysis and carbon inventories) and economical analyses. Since different materials cannot compose a single index, generally these flows are not shown and this fact makes comparisons difficult to be done. Another aspect that makes comparisons more difficult is the establishment of the studied system's boundary. If they differ, results will be different, disguising actual distinctions among systems. This study aimed to apply a methodology in order to determine material flows in agricultural production systems. A secondary goal is to show that machinery management can propitiate less material convergence into the crop. A diagram language to represent the analyzed system was adopted in order to establish the systems' limit. The determination of the material flows of indirectly applied inputs (fuel consumption; the machinery depreciation; and labor) included the determination of the effective field capacity, since the latter aggregates efficiency and is able to make data related to time to be related to area. Data of fuel consumption were compared with the models presented (the most accurate for the surveyed system was presented by Molin and Milan, 2002). The material embodiment of a maize silage production system was determined and compared with regional data, presenting similar data. For this system and a haylage (Tifton 85) production system the embodiment was calculated for different aspects (area, yield and qualitative aspects) in order to show the importance of establishing the limit of study and indicators. A comparison approaching the efficiency was also done, the variables considered were farm size, machinery use and labor requirement, efficiency increased more than the area increase.

Keywords: Sustainability; Material flows; Life cycle assessment; Energy flows; Mechanization; Brazil.

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1. INTRODUCTION

As the requirement for agricultural sector to be environmentally suitable (Jacovine et al., 2009), there is necessity to adopt proper indicators and methodologies approaching sustainability (Esty and Chertow, 1997). Material flow is the basis of cost determination, since every single input multiplied by their price determines cost and also, most of the methodologies used to environmentally assess production systems are based on material flows (DeSimone and Popoff, 1997). Some examples are energy analyses (Chavanne and Frangi, 2008; Pimentel and Patzek, 2005; Pimentel et al., 2005), energy evaluations (Brand-Williams, 2002; Cavalett et al, 2006; Romanelli et al, 2008; Pizzigallo et al, 2008), life-cycle assessment (Halleux et al., 2008; Pizzigallo et al, 2008) and carbon inventories (Van Oost et al, 2007; Wang and Dalal, 2006). All the cited methodologies bring material flow into a unique unit (money, energy, CO2 equivalent etc.), while material flow does not allow since distinct materials are considered and cannot be summed. Unfortunately, most of the reports lack in presenting data of the material flow and, when doing so, either the boundaries of the evaluated system or how the material flow was determined are missing. For instance, in some evaluations, the material impact of mechanization is considered by its cost and a money-resource ratio (Brandt-Williams, 2002), neglecting its actual material content. Therefore, data comparisons on material flows are difficult to be made since each system may not have been evaluated through the same methodology. For field operations there are two kinds of material convergence: direct and indirect. The former considers the agricultural inputs which are directly applied into the field (limestone, fertilizers, pesticides, seeds, seedlings) while the latter regards the goods and services applied indirectly such as fuel, machinery depreciation and labor. This study aimed to apply a methodology in order to determine material flows in agricultural production systems. A secondary goal is to show how machinery efficiency propitiates less material convergence into crop fields.

2. MATERIAL AND METHODS

In this section, it is shown the suggested steps for the material flows to be determined, as follows: 1) Adoption of a diagram language to represent the analyzed system; 2) Determination of the material flows of directly applied inputs; 3) Determination of the material flows of indirectly applied inputs. The latter includes: effective field capacity; fuel consumption; machinery depreciation; and labor.

2.1 Diagram methodology

After the studies on systems theory started with von Bertalanffy and others, some trials in order to make easier for researchers to visualize the studied systems. Among the diagram languages, probably the most known is the Forrester diagram (Haefner, 2005), developed as mathematical tool for modeling. Considering ecology and energy, H.T. Odum developed the Energy Language System (Maud and Cevolatti, 2004; Brown, 2004), which brings the advantage of determining the boundaries of the studied system, i.e., the flows that cross the boundaries and that are quantified are previously shown to the readers.

In this language there are symbols for storage (e.g., soil in agriculture), producers (plants), consumers (animals), transactions (money versus goods/service), interaction (e.g., mechanization is an interaction of labor, machinery depreciation, fuel consumption and the input applied), heat sink which represents entropy generation (only applied when using the language to represent energy flows), constant force source (rain, wind), flow limited source (sunlight due to the refraction in the atmosphere). Producers and consumer may also be represented showing their autocatalytic processes (e.g. biomass accumulation).

The diagram (Figure 1) shows the steps taken for the establishment of the material flows through mechanized operations, which depend on the inputs applied indirectly (machinery, irrigation systems, labor, and fuel) and directly (fertilizers, lime, pesticides, seeds, seedlings). The inputs directly applied (named agricultural inputs in this study) have their use rate determined through agricultural prescription made in volume or mass units per area, so that there is no need to have a methodology to obtain these flows.

The flows of machinery (irrigation systems as well) feed the asset stock, since assets are depreciated as the mechanized operations and the irrigation are performed. They have a useful life, i.e., a period when they will provide services and after this period they are replaced. For instance, 4x2 tractors present a useful life around 12,000 hours, which, of course varies according to the maintenance provided and the use intensity. Fuel (or electricity for irrigation) is necessary for the assets to run as well as labor.

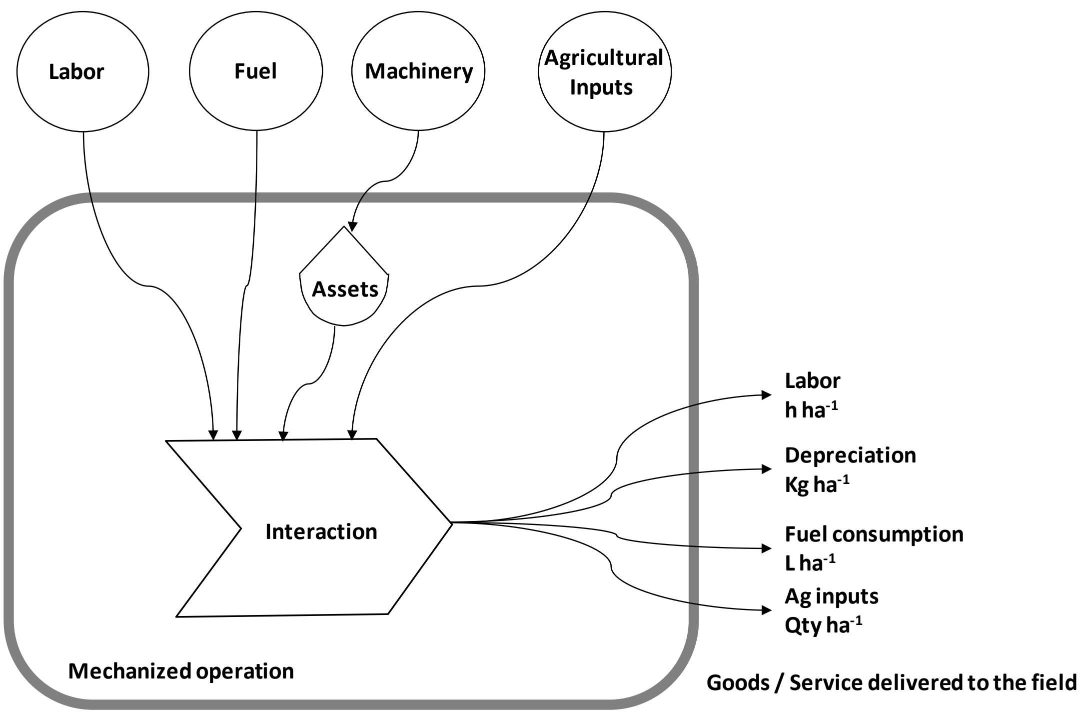

Figure 1. Material flow diagram through a mechanized operation.

2.2 Determination of the material flows of directly applied inputs

The flow of directly applied inputs is determined by technical prescription, the application rate (volume, mass or quantity per area) already is the material flow. Prescription, in this case, is just a simplification of the decision making process, since fertilizer application, for instance, can be determined by soil analyses, by the crop's physiological status or by a sensor (precision farming) that may apply models that are outside the boundaries established (European Fertilizer Manufacturers' Association, 2004).

2.3 Determination of the material flows of indirectly applied inputs

In this item, it will be shown the components that allow the determination of labor, machinery depreciation and fuel consumption in area basis such as the directly applied inputs.

2.3.1 Effective field capacity

Effective field capacity is the amount of area per time that the agricultural machinery actually performs. The theoretical field capacity is the result of work speed multiplied by the work width. The effective field capacity is the theoretical multiplied by the field efficiency (Equation 1). The effective field capacity is important for the flows to be adjusted in area basis, since generally the data (e.g. fuel consumption) generally is obtained in time basis.

$$EFC = (S * W * FE)/10 \qquad (1)$$

where:
EFC = Effective field capacity (ha/h);
S = Work speed (km/h);
W = Work width (m);
FE = field efficiency (decimal).

The status of crop fields affect the efficiency of mechanized operations (e.g.: stand shape since more maneuvers can be required) or the rate of agricultural input application (e.g. more pauses to reload the implement). Data for efficiency can be found in the in the ASAE standard D497.4 (ASAE, 2003a) for three levels (minimum, typical and maximum).
On harvesting operation the relation between area and time, is determined through other means since this kind of machinery present a processing capacity, i.e., mass (grains) per time. The processing capacity (kg/h) and the yield (kg/ha) provide the data in area basis. The processing capacity data can be obtained with the manufacturer, although it also varies with the field condition (slope, weed infestation).

2.3.2 Fuel consumption

For the determination of fuel consumption in a mechanized operation (1) is necessary data about the conditions and characteristics of soil (2), implements (3) and the self-propelled machines (4) (Figure 2).
Although soil (2) is not linked directly to the mechanized operations, its condition and texture (5) affects the traction demand of the tractor-implement set. Of all models presented in this study, soil texture is only used in the model proposed by ASAE (2003a). Since consumption is related to the power supply and demand rate, data about implements (4) and fleet (5) are required. The data about implements (6) and fleet (7) are used either in the power requirement (10) or in the effective field capacity (8) calculation. The power listed in the fleet (7) allows the determination of the available power (9). The ratio (11) between required (10) and available power (9) provides data for the determination of the specific fuel consumption (12) for different load levels. The specific fuel consumption, associated to the required power (10), allows the determination of the

hourly fuel consumption (13), which related to the effective field capacity and provides the operational consumption (L/ha) (14).

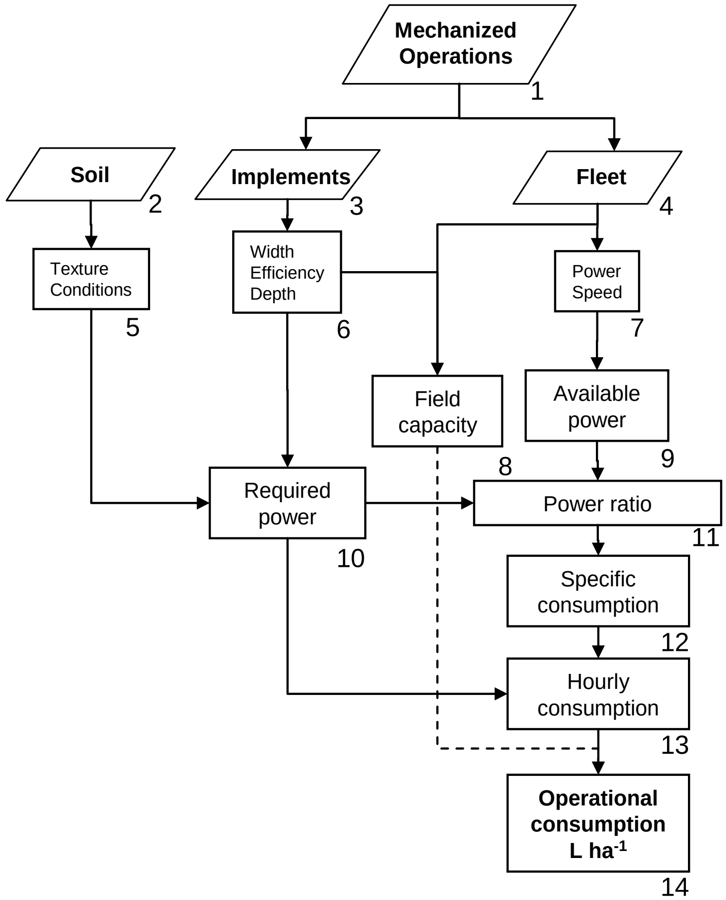

Figure 2. Data flow for fuel consumption.

If the tractor power is known is preferable to use another model for the fuel consumption which applies power as a continuous variable, through the specific consumption and engine power, as adopted by Molin and Milan (2002) (Equation 2).

$$C_{Hour} = GP_{ENG} * SC \qquad (2)$$

where:
C_{Hour}= hourly consumption (L/h);
GP_{ENG} = gross engine power (kW);
SC = specific consumption (0.163L $kW^{-1}h^{-1}$).

The fixed value for the specific consumption does not allow distinguishing operations that require power distinctly, e.g., tillage operations from drilling or spraying. However, when

considering all the operations performed throughout the crop cycle it is an interesting alternative for estimating fuel consumption.
For a more detailed estimation, there is the methodology proposed by ASAE standard D497.4 (ASAE, 2003a). In this model, the specific consumption (L $kW^{-1}h^{-1}$) is given by the ratio of the power required by the implement and the power available at the tractor's PTO (power take-off). For operations in which the implement is attached to the PTO or for those in which self-propelled machinery are used, the determination of the required power is given by work width, the rate of material input and specific parameters of the machinery (ASAE, 2003b). The rate of material input can be either the processing capacity (e.g. harvesting) or the product of yield (t/ha) and field capacity (ha/h).
The power available in the tractor's PTO is directly related to the engine power (ASAE, 2003a), and related to the power required provides the ratio of available power used at the PTO.

The specific consumption is determined applying the PRUPTO in the model presented by Milan (1992) (Equation 3). ASAE (2003a) also suggests an equation for the specific consumption [$2.64 * RPU_{PTO} + 3.91 - 0.203\sqrt{(738 * RPU_{PTO} + 173)}$].

$$SC = 0.288 + (0.0847/RPU_{PTO}) \qquad (3)$$

where:
SC = specific consumption (L $kW^{-1}h^{-1}$);
RPU_{PTO} = ratio of available power used at the PTO (decimal).

The ASAE model was established based on a wider range of models and it is more recent than Milan's model. However, the comparison of results from Milan (1992) and ASAE (2003a) show that they present a significant correlation (Figure 3). The comparison was performed considering RPU_{PTO} from 0.05 to 1.00 and a tractor of 55.1 kW. Milan (1992) used data tests with tractors at the former National Center of Agricultural Engineering (Brazil), collected during the 1980's.

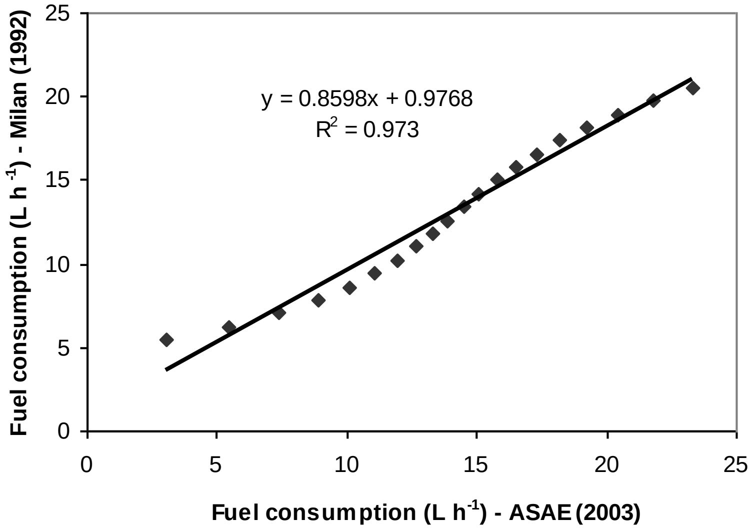

Figure 3. Relation between distinct models for fuel consumption.

The hourly consumption (L/h) is determined multiplying the specific consumption (L $kW^{-1}h^{-1}$); by the required power (kW). Dividing the hourly consumption (L/h) and the effective field capacity (ha/h), the operational consumption is determined (L/ha).

2.3.3 Machinery depreciation

The machinery physical depreciation is based on the useful life and the mass of the machinery, and on effective field capacity they perform in the mechanized operations; it is possible to determine the machinery depreciation (Equation 4). The physical depreciation does not mean that the equipment loses weight, but it means that after its useful life, the same amount of mass will be required to build a new one on order to replace it, i.e., it accounts the convergence of the environment, e.g., steel (iron ores + coal), rubber (oil) etc. that will be applied indirectly into a production system.

$$MD = M/(UL * EFC) \qquad (4)$$

where:
MD = machinery depreciation (kg/ha);
M = machinery mass (kg);
UL = machinery useful life (h);
EFC = effective field capacity of the performed operation (ha/h).

The effective field capacity is the result of a tractor (provides the speed) and the implement (presents the work width). Generally they present distinct mass and useful lives (e.g. 12,000h for a tractor and 2,000h for a fertilizer distributor). For self-propelled sprayer and combine this consideration is unnecessary.

2.3.4 Labor

The labor applied through mechanization (either the driver or the support staff); depend on the number of workers and the effective field capacity of each operation of the evaluated operation (Equation 5). For instance if there is a worker helping two tractor-implement set, its labor flow may be considered as 0.5 man in addition to the labor of the tractor driver. If there is data about how many man-day is necessary it is necessary to know how many hours per day the work is done.

$$Lb = \#Workers / EFC \qquad (5)$$

where:
Lb = labor applied per area (h/ha);
#Workers = number of workers acting in the mechanized operation (unit);
EFC = effective field capacity (ha/h).

For the material flow to be determined, two production systems, maize silage (Table 1) and haylage of Tifton 85 (Table 2) were surveyed. For the maize silage a comparison was also made with regional data. The embodiment from mechanization was evaluated for both scenarios for different aspects of their outputs (Table 3). Data from references were also used in order to analyze the agricultural inputs embodiment (Strieder et al., 2008) and machinery efficiency due to farm sizes (Gimenez, 2006).

Table 1. Data of the maize silage production system

Operations	Efficiency	Width	Speed	EFC	Fuel	Tractor		Implement		Workers
	%	m	km/h	ha/h	L/h	kg	h	kg	h	unit
Subsoiling	73.1	1.9	5.5	0.76	14.7	4560	12000	580	2000	1
Harrowing	54.3	2.7	11.8	1.75	17.5	3960	12000	690	2000	1
Drilling	69.1	3.1	5.4	1.15	7.8	3800	12000	2052	1500	4
Herbicide	65.6	10.7	5.4	3.83	8.2	3800	12000	632	2000	2
Fertilizer appl.	69.5	3.0	5.5	1.13	7.7	3800	12000	404	1500	4
Insecticide	47.9	14.1	4.8	3.24	6.3	3620	12000	632	1500	2
Harvesting	54.2	0.8	3.0	0.13	9.3	3745	12000	583	1500	2

Table 2. Data of the haylage (Tifton 85) production system

Operations	Efficiency	Width	Speed	EFC	Fuel	Tractor		Implement		Workers
	%	m	km/h	ha/h	L/h	kg	h	kg	h	unit
Fertilizer appl.	81.2	14.66	2.43	10.41	10.1	4150	12000	1320	2000	2
Windrower	78.1	4.2	1.78	2.1	19.9	5071	12000	620	1500	1
Mower	100	7.45	1.97	5.28	8.4	3780	12000	910	1500	1
Raking	79.3	6.53	2.36	4.4	9.6	3780	12000	670	1500	1
Baling	76.1	6.53	1.43	2.52	18.9	5470	12000	6800	1500	1
Packaging	75			5.19	15.7	7130	12000	6500	1500	1

Table 3. Characteristics of the output of supplementary cattle feeding production systems.

Data	Unit	Maize silage	Haylage (Tifton 85)
Yield	kg/ha	47025	3467
DM	%	33.31	26.26
Protein	%	5.21	15.14
TDN	%	67.13	61.19

3. RESULTS AND DISCUSSION

The suggested arrangement of the methodologies cited was applied in the diagram design (two cases: a mechanized operation and a maize silage production system)

3.1 Adoption of a diagram language to represent the analyzed system

The Energy Language System was applied to represent a single operation – spraying (Figure 5) and also the whole field process for a maize silage production (Figure 6). The spraying on maize requires the pesticide (directly applied), fuel, machinery and labor (indirectly applied). The machinery flow feeds a stock since this equipment will be depreciated. These four inputs interact resulting in the spraying, whose goal is the soil where the crop (systemic ingredients) is or the own crop. Weather conditions will affect spraying allowance and its effectiveness. The goal of this diagram is not quantify, but identify relationships and to set the analysis boundary. The flows that cross the boundary are those able to be further quantified.

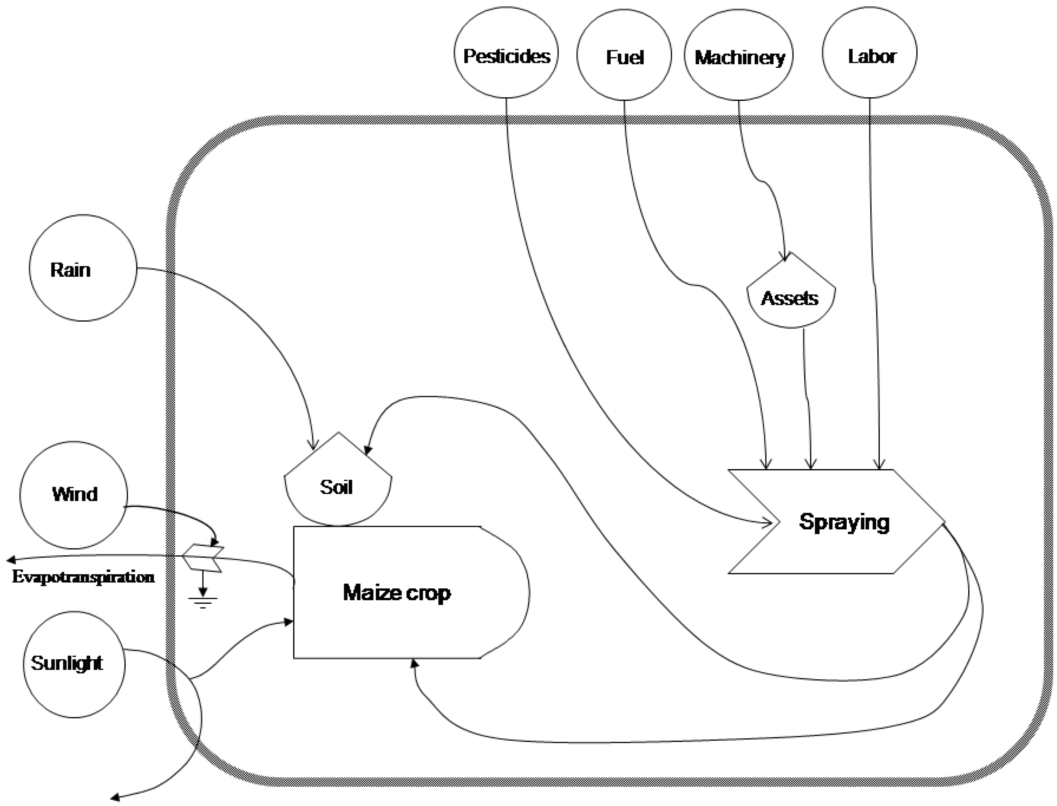

Figure 5. Diagram of spraying.

The maize silage production system (Figure 6) depends on a resource basis which includes renewable environmental inputs (rainfall, wind and sunlight, represented by the evapotranspiration), natural stocks (soil), material stocks (machinery) and flows acquired in the market (fuels, pH management materials, seedlings, fertilizer, pesticides, new machinery and labor). Although the scenario surveyed did not correct soil acidity, it was design in order to be useful for general production systems. There are interactions in mechanized operations aiming the crop establishment and maintenance and also in harvesting, where the product is obtained allowing the transaction with money that pays all the inputs from market, if the silage was not produced for the farm inner production. The mechanization aims the crop or the soil, where the inputs are applied or the harvesting residues (straw) are left. One must emphasize that the diagram shows no payment for the natural resources. The energy sink represents the inefficiency of transformation process, such as heat generation in the engines or fertilizer that does not reach the roots, for instance.

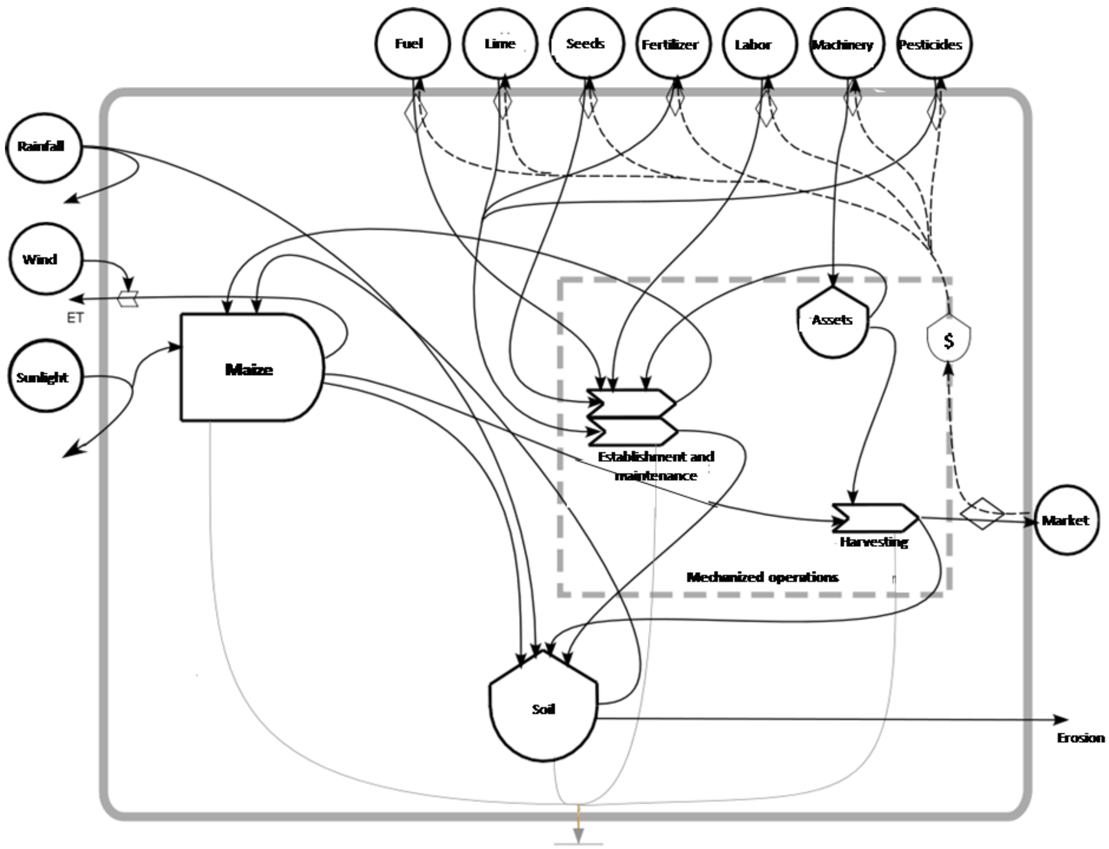

Figure 6. Representation of a maize silage production system.

3.2 Determination of the material flows of directly applied inputs

The directly applied inputs flows of the maize silage are shown together the other kinds of flow (Table 6). Here, in order to provide an example of material embodiment analysis, the methodology was applied on data of a comparison among hybrid corn seeds and plant density (Strieder et al, 2008), which was carried out studies under different crop management (Table 4). One observes that although the most intensified management (Very high), provided the highest yield, it demanded about the double N-P-K than the lower yield (Medium), which was the only one produced without irrigation. The intermediary management presented worse performance for water use than the most intensified one (17.0 mm/t of corn against 14.3 mm/t). This kind of data provides the idea of material convergence from ecosystems, since nitrogen demands mainly natural gas (non-renewable fossil source) to be synthesized, and phosphorus and potassium come from ores (non-renewable sources) that would be interesting for multi-criteria decision making to approach environmental issues.

Table 4. Fertilizer embodiment in distinct management for maize (Strieder et al., 2008).

Crop management system	Yield t/ha	N kg/t	P_2O_5 kg/t	K_2O kg/t	H_2O mm/t
Medium	8.1	8.6	4.9	4.9	0.0
High	11.8	11.9	8.1	8.1	17.0
Very high	14.0	16.1	9.3	9.3	14.3

3.3 Determination of the material flows of indirectly applied inputs

3.3.1 Fuel consumption

A production system of maize silage was evaluated for the material flow to be determined. Fuel consumption was evaluated for every mechanized operation by filling the tank on a plain surface before and after performing them. For these operations, estimates of fuel consumption were performed using all the models here presented (Table 5). ASAE models were not used for hourly determination for the spraying operation, since its models concern tillage, sowing and harvesting operations. For the sake of operational consumption of the whole system, in the ASAE scenario, spraying operations used the same data from the model presented by Molin and Milan (2002). For the whole production system (excluding sprayings) the differences reached 11.7%. Sprayings were excluded since the standards of ASAE applied are focused on soil tillage, sowing and harvesting. Herbicide and insecticide sprayings presented distinct consumption since tractors with different power were used for each of them and the methodology applied (Molin and Milan, 2002) uses a fixed parameter regarding power.

Table 5. Comparison of operational fuel consumption determined by the models presented in this study.

Operation	FC ha/h	Actual*	Molin and Milan[¥]	ASAE[ψ]
		Operational consumption (L/ha)		
Subsoiling	0.76	19.4	19.1	7.4
Harrowing	1.76	10.0	8.2	3.2
Drilling + Fertilizer	1.16	6.7	7.8	3.5
Cultivator	1.14	6.8	7.9	3.1
Herbicide spraying	3.83	2.1	2.3	2.3
Insecticide spraying	3.24	1.9	2.4	2.4
Harvesting	0.13	71.6	69.3	84.2
Total		114.5	112.3	101.4
Variation (%)			-2.1	-11.7

* Measured in field conditions, ¥ = Molin and Milan (2002); ψ = ASAE (2003b) for harvesting and ASAE (2003a) for the other operations.

The fixed index (0.163 L kW^{-1} h^{-1}) presented by Molin and Milan (2002) was the best for the scenario surveyed, although ASABE's models are more detailed. It is necessary to highlight that the best index was determined approaching mechanized operation in general and the ASABE´s model present more specific data for tillage, sowing and harvesting. The intention of the present study was not to validate the presented models; this had already been made in the cited references, but to present models that can be applied for farm-level planning. One cannot assure that the actual data reflect the consumption of a region, since the data were collected experimentally at farm level. One must emphasize that consumption is also affected by the machinery maintenance and fuel quality, for instance. So, it is recommended that the decision-maker monitor the consumption in the mechanized operations for the producer to record his or her own data for better further planning. The model of Molin and Milan (2002) is more practical to be applied since it depends only on the machinery power, on the other hand, the ASABE's models are more specific for tillage, sowing and harvesting operations.

3.3.2 Material flow

Considering the material flows applied for the maize silage production (47 t/ha) in the production surveyed, the quantity of each material used for producing 1 t of maize silage was obtained (Table 6). The general data (50 t/ha) represents the maize silage production in the Brazilian southeastern region.

Table 6. Embodied material on maize silage (1 t) from tillage to harvesting.

Material	Unit	Production Surveyed	EMBRAPA (2009)
Diesel	L	2.5	3.0
Labor	h	0.5	0.5
Machinery	g	191.5	244.8
N	kg	3.4	1.6
P_2O_5	kg	2.5	1.5
K_2O	kg	4.1	0.9
Limestone	kg	0.0	46.3
Seed	kg	0.60	0.49
Herbicide	L	0.23	0.08
Insecticide	mL	7.5	10.1

Some differences were found between both scenarios. The surveyed production did not correct soil acidity applying limestone, while the larger scenario did it (once on every three-year period). For both, all the internal transportation was neglected since there was no data for the surveyed scenario (2.3-hectare plot). There were differences on the nutrient embodiment, because besides applying less fertilizer the EMBRAPA scenario presented a yield 25% higher. The tillage operations and the lower field capacity increased fuel embodiment in the maize silage produced in the surveyed system. On the other hand it required less labor, since they sprayed and used machinery less than the reference.

When one compares different agricultural management, crops, scenarios one must determine the main objective of this comparison. For instance, the material embodiment comparison approaching mechanization in two production system (maize silage and haylage of Tifton 85) for supplementary cattle feeding production (Table 7). The area point-of-view will provide that maize silage when compared to haylage embodies less fuel and machinery depreciation (45.9%

and 22.9% respectively) but more labor (+45.5%). But since yield differs one could analyze these systems by the mass produced (second row of data). Additionally if one wants to analyze the qualitative aspects of these productions (Table 7), one can compare the material embodiment by dry matter (DM), by protein content or by the total digestible nutrient (TDN).

Table 7. Material embodiment under distinct output boundaries.

Embodiment	Maize silage			Haylage Tifton 85			Variation (maize/haylage)		
measure	Diesel	Labor	Machinery	Diesel	Labor	Machinery.	Diesel	Labor	Machinery.
unit	L/unit	h/unit	kg/unit	L/unit	h/unit	kg/unit	%	%	%
ha	118.56	25.43	9.03	258.25	17.48	39.36	45.9	145.5	22.9
t	2.52	0.54	0.19	7.14	0.48	1.09	35.3	112.0	17.7
t Dry matter	7.57	1.62	0.58	27.18	1.84	4.14	27.9	88.3	13.9
t Protein	145.36	31.18	11.07	179.51	12.15	27.36	81.0	256.6	40.5
t TDN	11.28	2.42	0.86	44.42	3.01	6.77	25.4	80.5	12.7

For instance, soybean crops with the same yield can be compared in area basis. If yield differs, so the comparison per mass is more appropriated. For comparison among oil crop the material embodiment per mass of oil is more interesting and it would allow even comparisons of production systems of other oil sources (animal fat). So, the system's limit presents vital role in choice of the indicator.

The analysis of material flow brings multi-criteria for decision makers, since distinct indicators are put together. For instance if soil acidity correction brings the same impact on yield as certain amount of nitrogen applied, cost will show the most profitable and energy flows will show the most energy efficient option, but the material flow will bring the environmental aspect and also it will be possible to check within the surrounding natural resources and good availability which is the best option.

Besides this, this kind of data is vital for environmental analyses (emergy evaluation, life-cycle analysis or energy flows) and economical analysis to be performed since these methodologies use their own indices regarding the demanded mass used of each material in order to obtain a unique indicator (cost, energy input etc.) for a whole system to be evaluated.

3.4 Efficiency on agricultural machinery use due to the farm size

During a survey on Parana state, Brazil, Gimenez (2006) collected data from 139 producers, referring to 645 tractors and 199 combines. The data were divided due to the farm arable area. Considering the power sources and human resources (Table 8), one can notice that the larger the farm, the lesser the requirement. The area covered per length of sprayers' boom was also considered. When the extremes situations are compared, one can observe that the smallest efficiency increase is 49.5% (labor) while the machinery availability, either in units or in power, reached efficiency increases from 115.2% to 242.6%.

Table 8. Efficiency on agricultural machinery use (Gimenez, 2006).

Area	Labor	Tractor		Combine		Sprayer
	ha/man	kW/ha	ha/unit	kW/ha	ha/unit	ha/m bar
100-300	78.9	0.99	79.5	0.80	183	10.6
300-600	96.9	0.69	117.3	0.43	371	19.3
600-900	102.8	0.60	138.5	0.42	414	22.9
>900	117.8	0.46	176.8	0.33	627	30.2
+efficiency (%)	49.5	115.2	122.4	142.4	242.6	184.9

4. CONCLUSIONS

There is lack of methodologies for material flow determination, even though these flows are considered in economical and environmental analyses. The adoption of a diagram establishing the system´s limit is interesting for the sake of comparison among studies. This is vital for comparisons to be made and indicators to be selected. There are two kinds of material flows: directly and indirectly applied. The former represent the agricultural inputs and the latter the inputs required for operation (labor, fuel, machinery) to be performed. Within the methodologies presented for consumption the fixed index presented by Molin and Milan (2002) was the best for the scenario surveyed, although ASABE’s models are more detailed. It is necessary to highlight that the best index was determined approaching mechanized operation in general and the ASABE´s model present more specific data for tillage, sowing and harvesting. The proposed arrangement of existing models to determine the material flow is applicable for general and punctual scenarios, since it is based on the physical demand on agricultural mechanized operations. The larger the farm size the lesser the machinery and labor stock either in unit or power terms.

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