Material flow determination through agricultural machinery management

Thiago Libório Romanelli*; Marcos Milan

USP/ESALQ - Depto. de Engenharia de Biossistemas, C.P. 09 - 13418-900 - Piracicaba, SP - Brasil.
**Corresponding author <romanelli@usp.br>*

ABSTRACT: The approach of material embodiment in agricultural production systems is important because it determines the convergence of inputs (indirectly, the natural resources) to the field. Additionally, material flow is the basis for both environmental (energy analysis, emergy synthesis, life-cycle analysis and carbon inventories) and economical analyses. Since different materials cannot compose a single index, generally these flows are not shown, making comparisons among approaches difficult. Another aspect that makes comparisons difficult is the definition of the boundary of the studied system. If these boundaries differ, results will also be different, hiding actual distinctions among systems. The present study aims to suggest an arrangement of existing models to determine material flow in agricultural production systems. The following steps were considered: i) the adoption of a diagram language to represent the analyzed system; ii) determination of the material flow for directly applied inputs; iii) determination of the material flow for indirectly applied inputs, which included: determination of the effective field capacity; fuel consumption; machinery depreciation; and labor. Data on fuel consumption were compared with the models presented. The best model applied was a fixed parameter based on engine power (0.163 L $kW^{-1} h^{-1}$). The determination of the material flow for maize silage production presented similar results as those obtained in regional databases.

Key words: LCA, material embodiment, environmental management, mechanization

Determinação de fluxo de materiais por meio do gerenciamento de máquinas agrícolas

RESUMO: A abordagem da incorporação material em sistemas agrícolas é importante, pois determina a convergência de insumos (indiretamente, de recursos naturais) no campo. Além disso, os fluxos de materiais são a base para quaisquer análises ambientais (análises de energia, síntese de emergia, ciclo de vida e inventários de carbono) e econômicas. Uma vez que diferentes materiais não podem compor um único índice, geralmente esses fluxos não são mostrados. Isso dificulta comparações entre análises. Outro aspecto que contribui para isso é a definição dos limites dos sistemas estudados. Se eles diferirem os resultados serão diferentes, disfarçando as distinções reais entre eles. O presente estudo visa sugerir um arranjo de modelos existentes para a determinação dos fluxos de energia e materiais em sistemas agrícolas. Os seguintes passos foram considerados: i) a adoção de uma linguagem de diagramação para representar o sistema analisado; ii) a determinação do fluxo de materiais dos insumos diretamente aplicados; iii) a determinação do fluxo de materiais dos insumos indiretamente aplicados, que envolve a capacidade de campo operacional dos sistemas mecanizados, o consumo de combustível, a depreciação de maquinário e a mão-de-obra. Dados de consumo de combustível foram comparados com os modelos apresentados. O melhor modelo aplicado foi o fixado em função da potência do motor (0,163 L $kW^{-1} h^{-1}$). A determinação dos fluxos de materiais para a produção de silagem de milho apresentou resultados similares aos dados de abordagem mais ampla.

Palavras-chave: ACV, incorporação material, gestão ambiental, mecanização

Introduction

As the requirements for the agricultural sector to be environmentally sound are increasingly emphasized (Jacovine et al., 2009) it becomes necessary to adopt proper indicators and methodologies for sustainability assessment (Esty and Chertow, 1997). Material flow is the basis for cost determination, since each single input multiplied by its price determines cost and also, most of the methodologies used to environmentally assess production systems are based on material flow (DeSimone and Popoff, 1997). Some examples are energy analyses (Chavanne and Frangi, 2008; Pimentel and Patzek, 2005; Pimentel et al., 2005), emergy synthesis (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 these methodologies represent the material flow in a single unit (money, energy, CO_2 equivalent etc.).

Unfortunately, most of the authors fail in presenting data for the actual material flow and, when doing so, either the boundaries of the evaluated system or how the material flow has been 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 flow 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 convergences: direct and indirect. The former considers the agricultural inputs which are directly applied to the field (limestone, fertilizers, pesticides, seeds, seedlings) while the latter regards the goods and services applied indirectly such as fuel, machinery depreciation and labor. The present study aims to suggest an arrangement of existing models to determine the material flow in agricultural production systems.

Material and Methods

Appropriate steps for material flow determination are proposed, as follows: (i) adoption of a diagram language to represent the analyzed system; (ii) determination of the material flow for directly applied inputs; and (iii) determination of the material flow for indirectly applied inputs: effective field capacity, fuel consumption, machinery depreciation; and labor.

Diagram methodology

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

In this language there are symbols (Figure 1) for storage (e.g., soil in agriculture), producers (plants), consumers (animals), transactions (money versus goods/services), interactions (e.g., mechanization is an interaction of labor, machinery depreciation, fuel consumption and the inputs applied), heat sink which represents entropy generation (only applied when using the language to represent energy flow), constant force sources (rain, wind, etc.), flow-limited sources (sunlight due to the refraction in the atmosphere). Producers and consumer may also be represented showing their autocatalytic processes (e.g., biomass accumulation).

The establishment of the material flow depends on the inputs applied indirectly (machinery, irrigation systems, labor, and fuels) 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 for a specific methodology to obtain these flows.

The flows of machinery (irrigation systems as well) feed the asset stock, since assets are depreciated when mechanization and irrigation operations are performed. They have a useful life, i.e., a period when they provide services and after which they must be replaced. For instance, tractors present a useful life of around 12,000 hours, which of course varies according to the maintenance provided and the types of usage. Fuels (and electricity for irrigation) as well as labor are necessary for the assets to run.

Determination of the material flow of directly applied inputs

The flow of directly applied inputs is determined by technical prescription according to application rates (volume, mass or quantity per area). 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 crop physiological status or by a sensor (precision farming) that may apply models that are outside the established boundaries (EFMA, 2004).

Determination of the material flow of indirectly applied inputs

In this item, we consider the components that allow the determination of labor, machinery depreciation and fuel consumption on an area basis such as the directly applied inputs.

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 area width. The effective field capacity is the theoretical value multiplied by the field efficiency (Equation 1). The effective field capacity is important for the flows to be adjusted on area basis, since generally the data (e.g., fuel consumption) are generally obtained in a time basis.

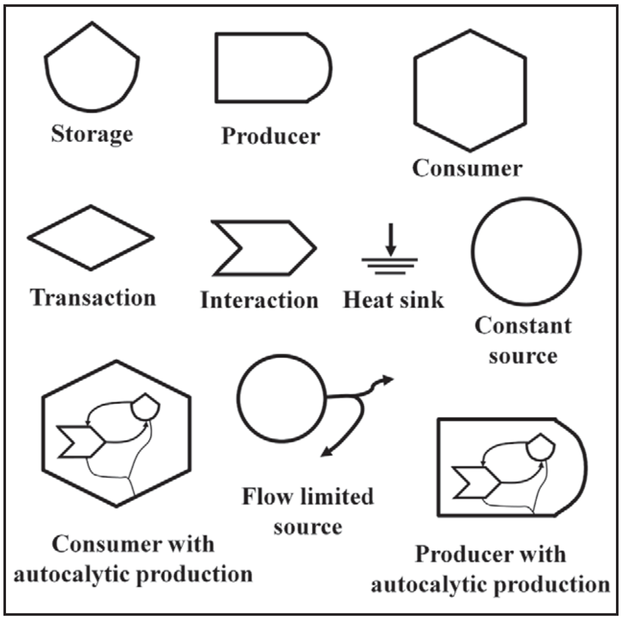

Figure 1 – Symbols of the Energy Language System.

$$FC = S * W * Efc * 0.1 \quad (1)$$

where: FC = Effective field capacity (ha h^{-1}); S = Work speed (km h^{-1}); W = Work width (m); Efc = field efficiency (%); the index 0.1 is necessary to adjust km * m into ha (km * m = 1000 m^2 = 0.1 ha).

The status of crop fields affects 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 implements). Data for efficiency can be found in the ASAE standard D497.4 (ASAE, 2003a) for three levels (minimum, typical and maximum). For harvesting operations the relation between area and time is determined through other means since this kind of machinery presents a processing capacity, i.e., mass (grains) per time. The processing capacity and the yield provide the data in area basis (Equation 2). The processing capacity data can be obtained with the manufacturer, although it also varies according to field conditions (slope, weed infestation level).

$$FC = PC_H / Y \quad (2)$$

where: PC_H = processing capacity (Mg h^{-1} or m^3 h^{-1}); Y = yield (Mg ha^{-1} or m^3 ha^{-1}).

Fuel consumption: for the determination of fuel consumption in a mechanized operation (1) data are needed on the conditions and characteristics of soil (2), on implements (3) and on the self propelled machines (4) (Figure 2[1]).

Although soil (2) is not linked directly to the mechanized operations, its condition and texture (5) affect 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) calculations. 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 is related to the effective field capacity and provides the operational consumption (L ha^{-1}) (14).

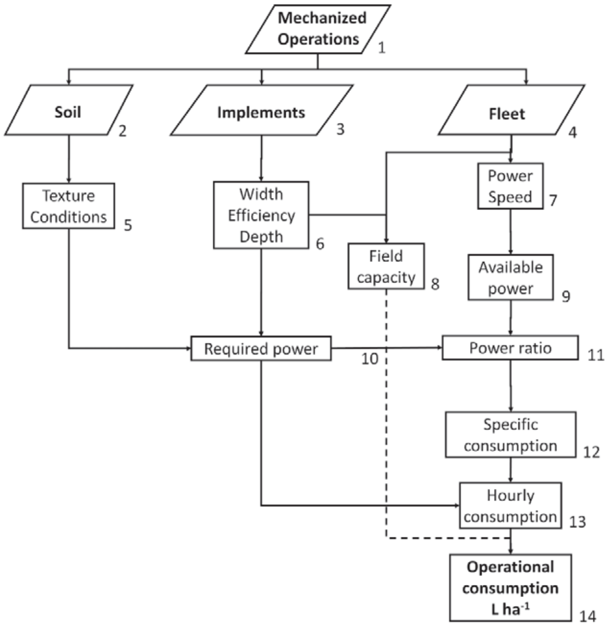

Figure 2 – Data flow for fuel consumption.

There are sources (CONAB[2], 2006) where fuel consumption can be obtained through discrete data (Table 1). The use of power ranges is practical, but this simplification leads to the limitation of using discrete numbers instead of continuous ones. For instance, a difference of 0.8 kW (from 51.4 to 52.2 kW) affects the consumption with an increase of 1.0 L h^{-1}, while a difference of 14.0 kW (from 44.8 to 58.8 kW) will not result in consumption changes. This kind of source may be useful regarding the absence of data such as the exact tractor power.

If the engine power of the tractor is known it 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 3).

$$C_{Hour} = GP_{ENG} * SC \quad (3)$$

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

Table 1 – Hourly diesel consumption (CONAB, 2006).

Machine type	Power	Consumption
	kW	L h^{-1}
Tractor	44.8 - 51.4	8.0
	52.2 - 58.8	9.0
	59.5 - 74.2	10.0
	>74.2	11.0
Combine	>74.2	12.0

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[1] The numbers between brackets indicate the steps on Figure 2.

[2] CONAB stands for National Company of Food Supply, which belongs to the Ministry of Agriculture of Brazil.

For a more detailed estimation, there is the methodology proposed by the 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). The required power is determined according to Equation 4. This model and its parameters A, B and C are related only to tillage and seeding implements.

$$D = Fi\,[A + B\,(S) + C\,(S)^2]\;W\;T \qquad (4)$$

where: D = implement draft (N); F = dimensionless soil texture adjustment; i = 1 for clay (fine), 2 for loamy (medium) and 3 for sand (coarse) texture; A, B and C = parameters specific for implements (ASAE, 2003a); W = Work width, m (ft) or number of rows or tools (ASAE, 2003a); T = tillage depth, cm (in.) for major tools, 1 (dimensionless) for minor tillage tools and seeding implements.

The power available at the drawbar depends on the soil condition and the kind of traction of the tractor (Figure 3).

The implement draft at the PTO (Equation 5) is related to the factor of power transmission to the tractor wheel drive. These factors are presented in Figure 3.

$$RP_{PTO} = D\,S\,/\,(3{,}600\;CTr) \qquad (5)$$

where: RP_{PTO} = power required by the implement at the PTO (kW); CTr = factor of power transmission (%), 3600 sec h^{-1} is to adjust time units.

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 according to Equation 6 (ASAE, 2003b)

$$RP_{PTO} = a + b\,W + c\,RM \qquad (6)$$

where: RP_{PTO} = power required by the implement at the PTO (kW); RM = rate of material input (t h^{-1}), a, b and c = 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^{-1}) and field capacity (ha h^{-1}).

The power available at the tractor's PTO is directly related to the engine power (Figure 3), and a fixed index can be obtained (Equation 7).

$$AP_{PTO} = GP_{ENG} * 0.83 \qquad (7)$$

where: AP_{PTO} = power available in the PTO (kW).

The ratio of power demand and supply at the PTO establishes the ratio of the used available power (Equation 8).

$$RPU_{PTO} = RP_{PTO}\,/\,AP_{PTO} \qquad (8)$$

where: RPU_{PTO} = ratio of available power used at the PTO (decimal).

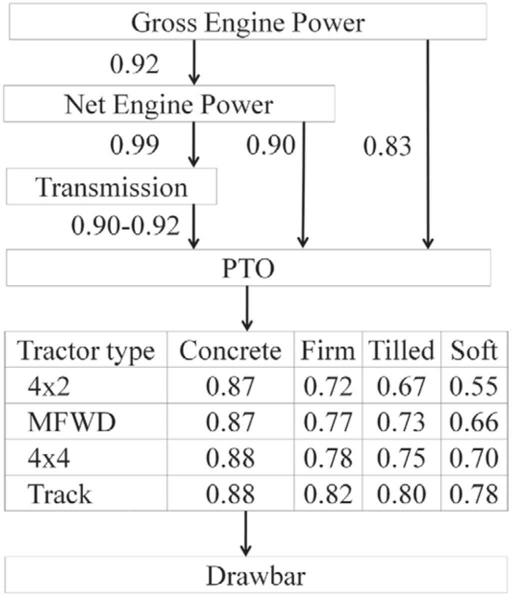
The specific consumption is determined applying the RPU_{PTO} in the model presented by Milan (1998) (Equation 9). ASAE (2003a) also suggests an equation for the specific consumption (Equation 10).

$$SC = 0.288 + (0.0847\,/\,RPU_{PTO}) \qquad (9)$$

$$SC = 2.64*RPU_{PTO} + 3.91 - 0.203((SQRT)(738*RPU_{PTO} + 173)) \qquad (10)$$

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 (1998) and ASAE (2003a) show that they present a significant correlation (Figure 4). The comparison was performed considering RPU_{PTO} from 0.05 to 1.00 and a tractor of 55.1 kW.

The hourly consumption is determined multiplying the specific consumption by the required power (Equation 11).



Tractor type	Concrete	Firm	Tilled	Soft
4x2	0.87	0.72	0.67	0.55
MFWD	0.87	0.77	0.73	0.66
4x4	0.88	0.78	0.75	0.70
Track	0.88	0.82	0.80	0.78

Figure 3 – Expected mechanical power performance (ASAE, 2003a).

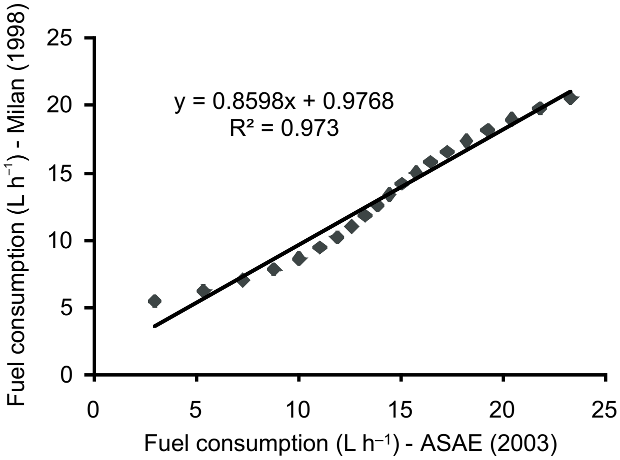


Figure 4 – Relation between distinct models for fuel consumption.

$$C_{Hour} = SC * RP_{PTO} \tag{11}$$

The operational consumption is determined by relating the hourly consumption and the effective field capacity (Equation 12).

$$C_{OP} = C_{Hour} / FC \tag{12}$$

where: C_{OP} = operational consumption (L ha^{-1}).

Machinery depreciation: is based on the useful life and the mass of the equipments, and on the effective field capacity they perform in the mechanized operations (Equation 13). The physical depreciation does not mean that the equipment loses weight, but it means that after its useful life, around the same amount of mass will be required to build a new one in 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 its production.

$$MD = M / (UL\ FC) \tag{13}$$

where: MD = machinery depreciation (kg ha^{-1}); M = machinery mass (kg); UL = machinery useful life (h).

Generally, tractors and implements present distinct mass and useful lives (e.g. 12,000 h for a tractor and 2,000 h for a fertilizer distributor). So, their mass depreciation should be determined individually and summed, since field efficiency is common to both.

Labor: the labor applied through mechanization (either the driver or the support staff), depends on the number of workers and the effective field capacity for each operation (Equation 14). For instance, if there is a worker helping two tractor-implement sets, the labor flow may be considered as 0.5 man in addition to the labor of the tractor driver.

$$Lb = \#Workers / FC \tag{14}$$

where: Lb = labor applied per area (h ha^{-1}); #Workers = number of workers acting in the mechanized operation (unit).

A production system of maize silage was surveyed as an example for the presently proposed material flow calculations (Table 2). The operations considered were from soil tillage to harvest. Data from a regional survey (southeastern region of Brazil) were gathered from secondary sources (EMBRAPA, 2009) for carrying out comparisons.

Results and Discussion

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

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 maize silage production (Figure 6). The spraying on maize requires pesticides (directly applied), fuels, machinery and labor (indirectly applied). The machinery flow feeds a stock since this equipment will be depreciated. These four

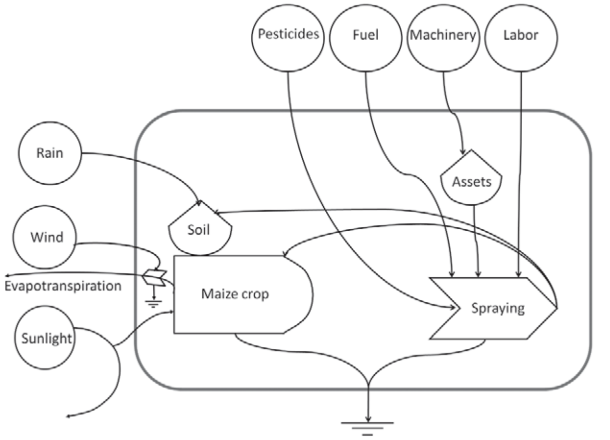


Figure 5 – An example of a diagram of a mechanized operation (spraying).

Table 2 – Primary data for a maize silage production system.

Mechanized	FC	Worker	Tractor*			Implement		Agricultural inputs		
			Power	Fuel	mass	mass	useful life			
	ha h^{-1}	h ha^{-1}	kW	L h^{-1}	kg	kg	h	Qty.	Unit	Type
Subsoiling	0.76	1.3	89	14.7	4560	580	2000			
Harrowing	1.76	0.6	88	17.5	3960	690	2000			
Sowing	1.16	3.5	55	7.8	3800	2052	1500	28.0	kg	seeds
								414.7	kg	08-28-16
Fertilizer application	1.14	3.5	55	7.7	3800	404	2000	630.5	kg	20-0-20
Herbicide spraying	3.83	0.5	55	8.2	3800	632	1500	11.0	L	Atrazine
Insecticide spraying	3.24	0.6	48	6.3	3620	632	1500	0.4	L	Lufenuron
Harvest	0.13	7.7	55	9.3	3745	583	1500			

*The considered useful life for tractor was 12,000h.

inputs interact resulting in the spraying, with target on the soil (systemic ingredients) or the crop itself. Weather conditions affect spraying both in terms of mechanism and effectiveness. The goal of this diagram is not to quantify, but to identify relationships and to set the analysis boundaries. The flows that cross the main boundary are those to be quantified.

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

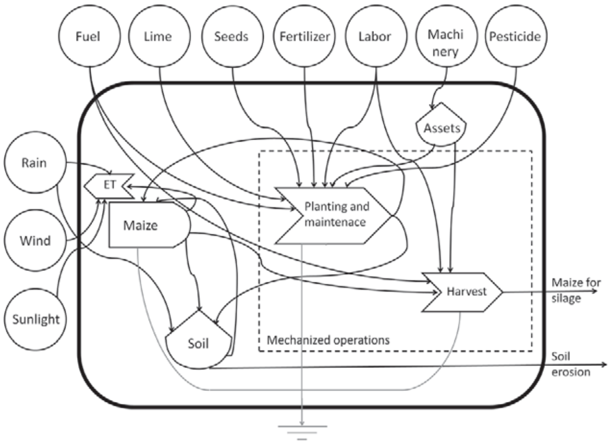


Figure 6 – Diagram of a production system of maize silage, presenting mechanization as a tool for input management.

Determination of the material flows of directly applied inputs

The directly applied input flows of maize silage are shown with the other kinds of flows (Table 3). Here, in order to provide an example of material embodiment analysis, the methodology was applied on data on a comparison among hybrid corn seeds and plant density (Strieder et al, 2008), studies which were carried out under different crop management (Table 3). One observes that although the most intensified management (Very High) provided the highest yields, it demanded about twice N-P-K inputs 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 intense one (17.0 mm Mg^{-1} of corn against 14.3 mm Mg^{-1}). 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.

Determination of the material flows of indirectly applied inputs

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 the operation for the consumed volume to be checked. For these operations, estimates of fuel consumption were performed using all the models here presented (Tables 4 and 5). ASAE models were not used for spraying, since their 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). Hourly consumption (Table 4) has presented considerable differences (-81.9% for harrowing Actual vs. ASAE). Differences on the operational fuel consumption were not determined because they keep the tendency shown on Table 4. On the other hand, for the whole production system (excluding spraying) the differences reached 11.7%. Spraying operations 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

Table 3 – Fertilizer embodiment in distinct management for maize (Strieder et al., 2008).

Crop management system	Yield	N	P_2O_5	K_2O	H_2O
	$Mg\ ha^{-1}$	------------------------------------ $kg\ Mg^{-1}$ ------------------------------------			$mm\ Mg^{-1}$
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

Table 4 – Comparison of hourly fuel consumption determined by the models presented in this study (Variation from the actual value in italic).

Operation	Power	Model			
		Actual*	CONAB£	Molin and Milan¥	ASAEΨ
	kW	Hourly consumption (L h^{-1})			
Subsoiling	88.9	14.7	11.0 *-25.2%*	14.5 *-1.8%*	5.6 *-62.8%*
Harrowing	88.2	17.5	11.0 *-37.1%*	14.4 *-28.2%*	5.7 *-81.9%*
Drilling + Fertilizer	55.1	7.8	9.0 *+15.4%*	9.0 *+13.3%*	4.0 *-42.2%*
Cultivator	55.1	7.7	9.0 *+16.9%*	9.0 *+14.4%*	3.5 *-46.7%*
Herbicide spraying	55.1	8.2	9.0 *+9.8%*	9.0 *+8.9%*	-
Insecticide spraying	47.8	6.3	8.0 *+27.0%*	7.8 *+18.8%*	-
Harvesting	55.1	9.3	9.0 *-3.2%*	9.0 *-3.3%*	10.9 *+17.8%*

*Measured in field conditions, £CONAB (2006), ¥Molin and Milan (2002); ΨASAE (2003b) for harvesting and ASAE (2003a) for the other operations.

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

Operation	Power	Actual*	CONAB£	Molin and Milan¥	ASAEΨ
	ha h^{-1}	Hourly consumption (L ha^{-1})			
Subsoiling	0.76	19.4	14.5	19.1	7.4
Harrowing	1.76	10.0	6.3	8.2	3.2
Drilling + Fertilizer	1.16	6.7	7.8	7.8	3.5
Cultivator	1.14	6.8	7.9	7.9	3.1
Herbicide spraying	3.83	2.1	2.3	2.3	2.3
Insecticide spraying	3.24	1.9	2.5	2.4	2.4
Harvesting	0.13	71.6	69.3	69.3	84.2
	Total	114.5	105.8	112.3	101.4
	Variation (%)		-7.6	-2.1	-11.7

*Measured in field conditions, £CONAB (2006), ¥Molin and Milan (2002); ΨASAE (2003b) for harvesting and ASAE (2003a) for the other operations.

the methodology applied (Molin and Milan, 2002) uses a fixed parameter regarding power.

The fixed index (0.163 L kW^{-1} h^{-1}) presented by Molin and Milan (2002) was the best for the scenario surveyed, although ASAE's models are more detailed. The best index was determined approaching mechanized operation in general and the ASAE'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 the farm level. One must emphasize that consumption is also affected by the machinery maintenance and fuel quality, for instance. 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 ASAE's models are specific for tillage, sowing and harvesting operations.

Material flow: Considering the material flow applied for the maize silage production (43 Mg ha^{-1}) in the production surveyed, the quantity of each material used for producing 1 Mg of maize silage was obtained (Table 6). The general data for maize silage had a yield of 50 Mg ha^{-1}; its flows are also presented in Table 6. The latter scenario represents the maize silage production in the Southeastern region of Brazil.

Some differences were found between the two scenarios. The surveyed production did not correct soil acidity applying limestone, while the scenario with larger production did (once every three years). For both, all internal transportation was neglected since there was no data for the surveyed scenario (2.3-hectare plot). There were differences on the nutrient embodiment, be-

Table 6 – Embodied material in 1 Mg of maize silage from tillage to harvesting.

Material	Unit	Production Surveyed	EMBRAPA (2009)
Diesel	L	2.5	3.0
Labor	h	0.3	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

cause besides applying less fertilizer the EMBRAPA scenario presented a 25% higher yield. The EMBRAPA scenario used 80 kg ha^{-1} of N, 77 kg ha^{-1} of P_2O_5 and 44 kg ha^{-1} K_2O, its yield was 50 Mg ha^{-1}, while the surveyed production system used 120 kg ha^{-1} of N, 112 kg ha^{-1} of P_2O_5 and 106 kg ha^{-1} K_2O, producing 40 Mg ha^{-1}. The tillage operations and the lower field capacity increased fuel embodiment in the maize silage produced by the surveyed system. On the other hand it required less labor, since this scenario used less machinery and spraying than the reference.

The analysis of material flow brings multi-criteria for decision makers, since distinct indicators are brought together. For instance, if soil acidity correction brings the same impact on yield as a certain amount of applied nitrogen, the cost will be the most profitable. Energy flow will show the most efficient energy option, but the material flow will bring the environmental aspect and it also will make possible to check within the surrounding natural resources and good availability which is the best option. Additionally, this kind of data is vital for environmental analyses (emergy synthesis, life-cycle analysis or energy flow) 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.

Conclusions

The adoption of a diagram establishing the system's limit is interesting to allow comparisons among studies. The fixed index was the best for the surveyed scenario, although ASAE's models are more detailed for tillage, sowing and harvesting operations. The proposed arrangement of existing models to determine material flow is applicable for general as well as for local or specific scenarios, since it is based on the physical demand on agricultural mechanized operations. The proposed arrangement may favor consideration of material flow more clearly for researches that intrinsically have needed them to evaluate environmentally and economically agricultural production systems without giving to material convergence the emphasis they should have given.

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