

# Material Flow Analysis of Sugar Beet Cultivation

GIOVANNI LAGIOIA\*, OTTILIA DE MARCO\*,  
VERA AMICARELLI\*, ANTONELLA SGARAMELLA\*

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## 1. Introduction

In the last fifty years the processing of raw materials in goods and services (manufacturing activity) has grown remarkably alongside the growth in world-wide population. The increase in economic activities has caused a great withdrawal of natural resources, favouring, at the same time, the release of a great amount of substances which are sometimes harmful for the environment. An important consequence is the alteration in the equilibrium of ecosystems which has also caused harm to living creatures. The withdrawal of resources from the environment and the release of waste should be possible in the future if natural ecosystems succeed in supporting the flows of matter from and towards the environment. The "physical" development of the economy should be carefully controlled and should respect the equilibrium between the withdrawal of resources from the environment and the release of waste. In this way man and nature will be able to cohabit.

These problems have stimulated an increasing attention to

## Abstract

The economic growth of the last decades has induced a great withdrawal of raw materials from nature, favouring, at the same time, the release of a great amount of harmful substances. An important consequence has been the alteration in the equilibrium of ecosystems as well as harm to living creatures. These problems have generated an increasing attention to the mass of materials that flows in the whole national economy, in single industries and in the life cycles of commodities. The collection of these kinds of data should be useful to define the environmental burden of a commodity and to prevent the detrimental consequences of human activities on the natural ecosystems. This paper analyses the material and energy flows of sugar beets cultivation. It completes the analysis of the beet sugar industry; a material flow analysis of the sugar production chain has been presented in a previous paper. Environmental aspects will be also studied. Photosynthesis in sugar beets will be considered; CO<sub>2</sub> consumption, sun energy utilization, biomass and oxygen production will be analyzed as inputs and outputs of this process.

**Keywords:** Material Flow Analysis, Sugar beet cultivation.

## Résumé

*La croissance économique des dernières décennies a induit un grand prélèvement des matières premières de la nature, en favorisant, en même temps, le dégagement de quantités énormes de substances nuisibles. Une conséquence importante était l'altération de l'équilibre des écosystèmes, en causant aussi des dégâts sur des êtres vivants.*

*Ces problèmes ont produit une attention croissante à propos des flux des matières que traversent l'économie nationale entière ou un secteur industriel ou un cycle productif unique.*

*La collection de ce type de données ou renseignements pourrait être utile pour définir la pression des marchandises sur l'environnement et prévoir les conséquences des activités humaines sur les écosystèmes naturels.*

*Ce document analyse les flux de matières et d'énergie de la culture (phase agricole) de la betterave sucrière. Il complète l'analyse de ce secteur industriel (phase industrielle) déjà présentée dans un article précédent. Les implications de la pression sur l'environnement seront aussi étudiées. Les flux entrant et sortant de ce processus seront analysés en prenant en compte la photosynthèse de la betteraves sucrière, la consommation de CO<sub>2</sub>, l'utilisation de l'énergie solaire et la production d'oxygène et biomasse.*

**Mots clés:** analyse des flux des matières, culture de la betterave sucrière

the mass of materials that flows in the national economies, in single industries and in the life cycles of commodities. There are several methods for the evaluation of material and energy flows. The collection of these kinds of data should be useful to define the environmental burden of a commodity and to prevent the detrimental consequences of human activities on the natural ecosystems.

This study analyses the material and energy flow of sugar beet cultivation; figure 1 shows the main phases of the process. It completes the analysis of the manufacturing process of sugar beet presented in a previous paper (De Marco et al, 2002). The present note considers also the sugar beet photosynthesis, together with the environmental inputs and outputs involved in the process (CO<sub>2</sub> consumption, sun energy utilization, biomass and oxygen production). Sugar is an important prod-

uct for its high nutritional value but its production determines a remarkable consumption of resources and a considerable environmental burden. The material and energy flow is calculated for the production of one metric ton<sup>1</sup> of clean beet roots<sup>2</sup>.

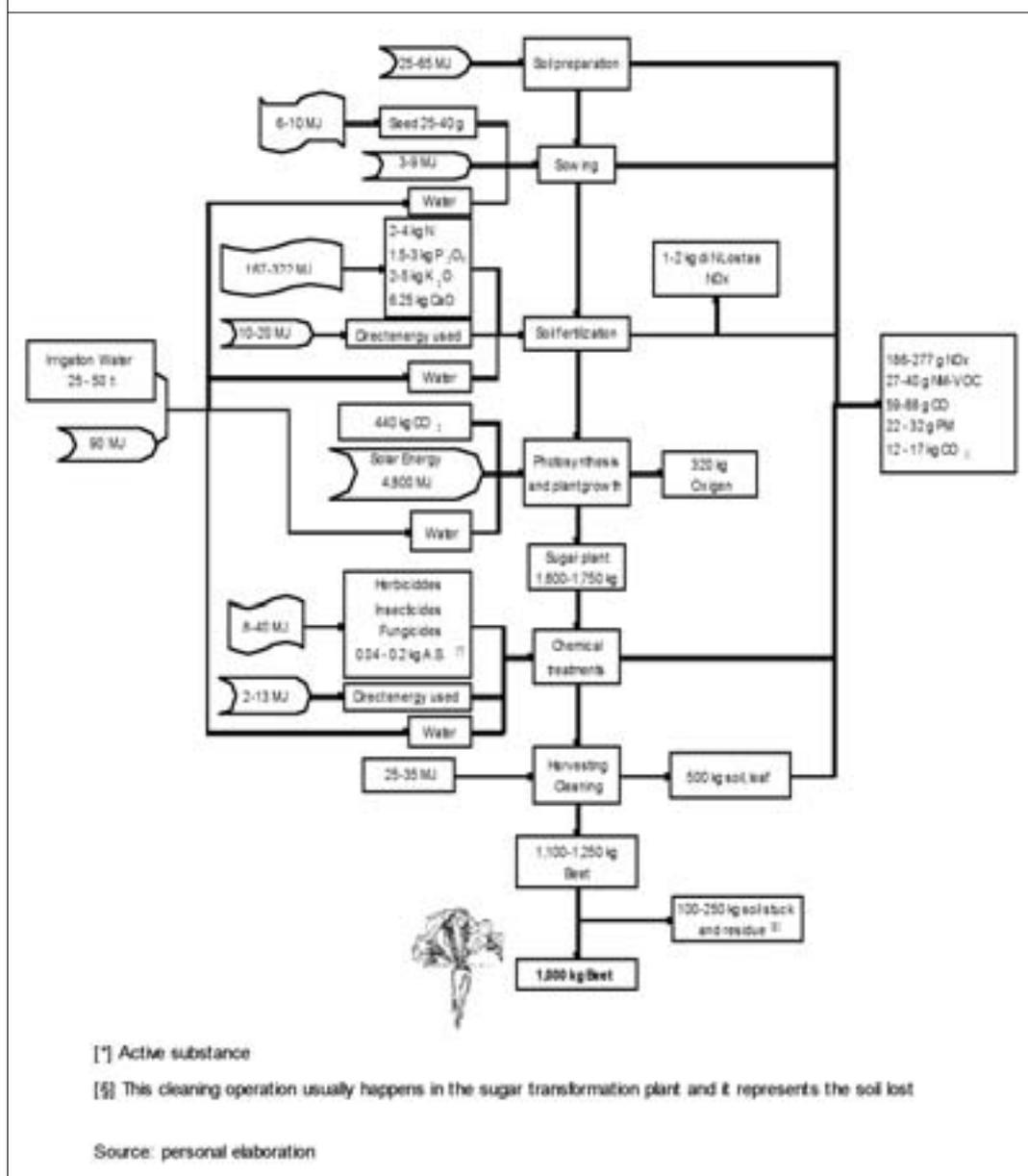
\* This work is the result of the authors' commitment, starting from the idea and ending in its accomplishment. Particularly the introduction, the conclusion and the references collection are the result of the same authors contribution. The sugar beet cultivation analysis can be ascribed to G. Lagioia for 30%, to O. De Marco for 10%, to V. Amicarelli for 30% and to A. Sgaramella for 30%.

\* Dipartimento di Scienze Geografiche e Merceologiche Università degli Studi di Bari (Italy)

<sup>1</sup> All references to ton in this text refer to metric tons and Mt refer to millions of metric tons.

<sup>2</sup> The harvested and loaded beet roots have 0.1-0.25 t of soil and crushed stone stuck. So the real output of cultivated land is 1.1-1.25 t of dirty beet roots: 1 ton of beet roots and 0.1-0.25 t of soil and crushed stone. At the sugar mill the first phase will take away these impurities.

Figure 1: Material Flow Analysis of sugar beet cultivation



## 2. Sugar beet cultivation

The sugar beet (*Beta vulgaris*, sort *saccharifera* L.) belongs to the class of Dicotyledons and to the family of Chenopodiaceae. It is a two-year-cycle plant, but it is only cultivated during the first year, when the fleshy root develops. It adapts easily to the different pedoclimatic conditions: the best production results are obtained in areas with a temperate climate, whilst too high temperatures and luminosity – mainly present in the Mediterranean areas – are unfavourable conditions. Medium-mixture, slightly clayey soils are the most suitable for this cultivation because of the abundant supply of water and the good availability of potassium; loose and not irrigated soils are less suitable.

Quadrennial rotation practices should be used and a straw cereal cultivation has to follow the sugar beet cultivation (Casarini et al, 1999).

This reduces the diffusion of specific sugar beet parasites such as rhizomania, nematodes (*Heterodera schachtii*) and fungal affections (*Rhizoctonia*, *Sclerosio*, *Cercospora*). It also assures better soil health and environmental

Our calculations were based on a production of 48 tons of beets per ha (FAO, 2003). All figures illustrated in this paper refer to material and energy flow linked to 1 t of beet roots. Regarding the energy consumption we distinguish between direct energy, the energy directly used in the sugar beet cultivation (for example diesel fuel for harvesting machines), and indirect energy, the energy consumed to produce inputs (for example fertilizers, seeds, etc) of sugar beet cultivation. The electricity figures were converted in primary energy according to the following equation:

$$1 \text{ kWh} = 9 \text{ MJ.}$$

<sup>3</sup> The energy is employed in form of fuel, usually diesel oil, used to run the agricultural machines.

protection and reduces the development of substitution infesting flora.

**Soil preparation.** The sugar beet is a crop which needs a proper soil preparation to allow good seed germination, a rapid growth and a good deep development of the root. The soil preparation begins with a deep ploughing followed by the breaking of the ploughed layer and the preparation of the seed-bed; the latter operation is carried out through sod-breaking and grubbing of the soil. The soil preparation requires an energy consumption of 25-65 MJ/t of beet roots<sup>3</sup>. This wide range is due to the different cultivation techniques adopted and to the varying soil conditions (Beltrami et al, 1993; Bettini, 2003).

**Sowing.** The sowing, a critical phase of the production process, can take place in spring (Northern Italy and Europe)

or in autumn (Southern Italy). This allows optimum utilization of the resources of the area where the sugar beet is cultivated, above all as regards water needs. The seed used, 25-40 g, is in coated units with a size between 3.5 and 4.7 mm. Geoinsecticides, whose aim is to protect the seed and the seedling from attacks of parasites and insects, are introduced into the seed. An optimal investment of the cultivated surface consists in the presence of about 10 plants per square meter<sup>4</sup>. The plant development cycle lasts 70 days; in this period it is important that the sugar beets suffer no stress and have enough water for their growth. In this sense, planned irrigation becomes ever more important. The 3-9 MJ of energy employed in the sowing phase are used as fuel for the seeders whilst 6-10 MJ are associated with the seed production (indirect energy) (Beltrami et al, 1993; Bettini, 2003).

**Soil fertilization.** In order to guarantee a correct and rational dosage of fertilizers, the fertilizing has to be preceded by the chemical-physical analysis of the soil. This is a valid instrument for the quantitative and qualitative evaluation of the nutritive elements of the soil (potassium, phosphorous, nitrogen and calcium). The Italian soils, especially in Southern Italy, usually contain a sufficient amount of potassium, so potassium-based fertilizers should, in most cases, be avoided. However, when there is a lack of potassium in the soil, 2-5 kg of K<sub>2</sub>O, corresponding to 4-10 kg of potassium sulphate, should be distributed at the moment of uprooting.

Phosphorous is an important element for the growth of sugar beet, as it has a positive effect above all in the first phases of the seedling development. Because of the short mobility of phosphorous in the soil, phosphate-fertilizer, 1.5-3 kg of P<sub>2</sub>O<sub>5</sub>, is usually introduced into the soil in the open field, sowed during the ploughing or the uprooting or placed near the seeds during the sowing.

Nitrogen fertilizing is the most difficult to be dosed. This is a very mobile element in the soil and, if exceeded, facilitates a large development of the leaves, reducing the commercial value of the beet. Therefore it is very important to define the nitrogen beet requirements in order to reduce production costs, to improve the quantity and the quality of the final product and to contain the environmental burden. Nitrogen fertilizer distribution, 2-4 kg, is done in pre-seeding and in "covering".

Sometimes calcium-based fertilizers are useful to correct soil pH, 6.25 kg CaO. This can be substituted by filter cakes, a by-product of the sugar mill (24.26 kg). Fertilizing requires direct energy employment of 10-20 MJ. In this note an indirect energy use of about 165-320 MJ/t is associated to the production of estimated fertilizer quantities (2-5 kg di K<sub>2</sub>O, 1.5-3 kg P<sub>2</sub>O<sub>5</sub>, 2-4 kg N) (Biancardi et al, 2001; Venturi et al. 2002).

**Photosynthesis and plant growth.** Photosynthesis process starts after seed germination, in the first emitted

cotyledons, starting from absorption of CO<sub>2</sub>, H<sub>2</sub>O, and solar energy. This allows O<sub>2</sub> and biomass production as follows:



Photosynthesis allows beet growing, amassing sugar substances in the pulpy root.

The process is strictly linked to the availability of nourishment in the soil and of solar energy; in the north of Europe, in fact, product quality is very high thanks to the availability of solar energy. It has been evaluated that, during the whole cultivation cycle, sugar beet plants absorb about 440 kg of CO<sub>2</sub>, 4.8 GJ of solar energy and release 320 kg of oxygen, to produce 1 ton roots (Burcky, 1989; Hülsergen et al, 2002).

**Chemical treatments.** Beet defence from insects start with the seeding, when coated seeds or micro-granular insecticides are distributed by seeders near the seeds. After seeding, plant protection from pathogenic agents with proper chemical products, does not take place systematically, but only if there is a big infection. This is the reason why has been noticed very variable use of herbicides, fungicides, insecticides (0.04-0.2 kg/t).

Nowadays chemical substance application has been reduced for a cost production containment and growing attention toward environment problems. A useful tool to reduce specific plant diseases

is the use of resistant plant; the use of such experimental seeds has to be done in precise way, due to the fact that lower beet productivity is associated to resistance.

Chemical products application requires an energy employment of 2-13 MJ/t; for their production 8-40 MJ/t of indirect energy is needed (Ribaud, 1997; Tits et al, 2002).

**Harvesting.** Harvesting is an important phase in sugar beet cultivation since the commercial value of the final product depends on this; it is important that it takes place in the period with the highest concentration of sucrose in the roots. Techniques should be used that limit, as much as possible erosion, caused by soil removal during harvesting, as well as root damage. Nowadays mechanical means (up leavers, beet toppers, grubbers and diggers) seem more efficacious and cost-effective. For a further reduction of the soil stuck to the roots ("soil tare"), during beet truck loading, special conveyer belts are used which permit loaded roots impurities to slide. Through this operation soil stuck to roots is less than 10% (0.1 t/t of roots). This will be removed in the sugar mill and is called "return soil". Without this phase the return soil can reach 0.25 t/t of roots. Harvesting requires an energy use of 28-36 MJ/t of roots.

**Irrigation.** Sugar beet cultivation requires a great absorption of irrigation water 25-52 m<sup>3</sup>/t of roots; this is normally given by micro irrigation, a system that allows a considerable water saving. About 90 MJ/t of energy are employed to run the irrigation devices (water raising pumps, nozzle movement etc.) (Biavati, et al, 2001; Cavazza et al, 1983).

<sup>4</sup> The sowing is carried out with precision seeders. The technological development and the genetic improvements have allowed a remarkable reduction in the amount of seeds used. Moreover, the seed is monogermic with high germinability. This made it possible to eliminate expensive agricultural activities such as the thinning out.

### 3. Conclusions

The study concerning material and energy flow of beet cultivation allowed us to calculate that for the production, harvesting and transport of 1 sugar beet ton, 5,400-5,700 MJ of energy are needed, 4,800 MJ of which is solar energy. Direct energy, 420-530 MJ, is mainly from fuels used for agricultural machines (tractors, pickers, etc.) and means of transport, while indirect energy, 180-370 MJ, goes into fertilizer production. Further inputs are 25-50 m<sup>3</sup> of water, 440 kg of CO<sub>2</sub>, 12-18 kg of fertilizers, some seeds and few grams of pesticides. It is observed that energy and materials mass is basically represented by solar energy, water and CO<sub>2</sub>. The main by-products are 320 kg of O<sub>2</sub> and 0.5 t of leaves and epicotyls, which remain in the same cultivation field. Therefore the environmental burden is mainly due to fertilizer and pesticide use and to atmospheric emissions associated to combustibles. Once studies<sup>5</sup> began into agricultural practice and pollution, it was soon realised that sugar beet production had a great environmental impact<sup>6</sup>. Sugar beet requires, in fact, deep ploughings<sup>7</sup>, and a high application of fertilizers, herbicides, insecticides and fungicides. Recent studies by IRBAB (Institut Royal Belge pour l'amélioration de la betterave) show that modern beet cultivation techniques, always in progress, have allowed a notable reduction of environmental problems (Misonne, 2002). Rational fertilizing systems (located and fractionized fertilization) allowed proper dosaging of nutrients and a reduction in the use of chemical fertilizers and their dispersion in the environment. As concerning fertilizer losses it has been evaluated that the most potassium and phosphorous are absorbed by sugar beet and only a marginal amount is lost by leaching. On the contrary, approximately 50 to 60% of nitrogenous fertilizers utilized (1-2 kg/t of sugar beet) are wasted in the form of NO<sub>x</sub> emission (Beltrami et al., 1993; Bettini 2003).

The chemical quantity, employed for beet protection, has been reduced. This has happened thanks to the use of cultivars genetically selected for disease resistance and an integrated control of parasites with small doses of pesticides and fungicide in the coated seeds. Environmental problems due to soil erosion phenomena have been reduced thanks to the introduction of mechanized harvesting; the soil quantity withdrawn for each production cycle, has sensitively lowered because the taproots pre-cleaning is carried out in

the field, with an immediate return of the soil on the production ground. Also the micro-irrigation, in addition to guarantying a rational employment of water resources, has given a contribution to the reduction of ground removal by leaching. It has been evaluated that the soil eroded in the sugar beet cultivation cycle, in a three year plan of agricultural rotation, is 0.15 mm per year, considering a pluviometer regimen of 800 mm per year. It is possible to calculate that depending on the kind of soil used for the sugar beet cultivation (2.6 kg/L density) and removed thickness, the soil loss is about 80 kg/t of beets.

Another interesting datum is the great amount of CO<sub>2</sub>, for the evaluation of the environmental impact, absorbed from sugar beet cultivation (equal to 440 kg). Our previous paper noted that the sugar productive chain – from seed to sugar sacs – has a CO<sub>2</sub> balance (-95; -110 kg for 110 kg of packed sugar<sup>8</sup>) that is profitable for the environment (De Marco et al. 2004). CO<sub>2</sub> emissions of transformation of sugar beet, ranging approximately from 310 to 320 kg per 110 kg of packed sugar, are balanced by CO<sub>2</sub> absorbed during the agriculture phase (440 kg). According to the analyses presented in this paper, it seems that the main input influencing sugar beet cultivation is water. The literature and data available show that even though this crop is able to adapt to different environmental and climatic conditions, it is characterized by high water demand during all its cultivation. As a consequence the sugar beet yield depends mostly on water supply.

The analyses herein and in our other papers (De Marco et al. 2002 and 2004) describe the utility of Material Flow Analysis (MFA) above all considering the new Common Agriculture Policy (CAP)<sup>9</sup> which has reformed the sugar industry and market within the Union. Member States of the European Union are obliged to convert old sugar industrial and distribution system. Based on the results of MFA and on the possibility to transform sugar beet into something different from saccharose, into ethanol for example (Lagioia et al., 2005), decision makers can reorganize the sugar sector. In this way, an environment-friendly cultivation is conserved, a part of the industrial know-how is saved and another product – bioethanol – can be produced. The main limit remains the poor profitability of bioethanol which however could be overcome by government help at the pre-competitive stage.

<sup>5</sup> In 1993, during the development of "Project for Agricultural Production for environment Protection" (PANDA), three main strategies for an agriculture compatible with the environment were summarised: 1) agriculture has to guarantee a satisfactory productivity for the human community and a profit for agriculture itself; 2) it has to promote the saving of the ground and water resources (this means the principle of indefinite lasting of productivity); 3) it has to guarantee safety conditions for health operators and for customers.

<sup>6</sup> Ever since 1989 when IIRB (International Institute for Beet Research) dedicated a complete session in the winter Congress to the subject, the problem of pollution linked to sugar beet cultivation has strongly been felt throughout Europe.

<sup>7</sup> Deep ploughing facilitates chemical product infiltration into underground water.

<sup>8</sup> This figure, 110 kg of sugar, is the average amount of sucrose obtainable from one ton of sugar beet.

<sup>9</sup> Council Regulation on the common organisation of the markets in the sugar sector-COM(2005) 263 final [http://www.europarl.eu.int/registre/docs\\_autres\\_institutions/commission\\_europeenne/com/2005/0263/COM\\_COM\(2005\)0263\\_EN.pdf](http://www.europarl.eu.int/registre/docs_autres_institutions/commission_europeenne/com/2005/0263/COM_COM(2005)0263_EN.pdf), last accessed January 2007.

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