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METHODOLOGY AND CONVERSION FACTORS TO ESTIMATE THE NET PRIMARY PRODUCTIVITY OF HISTORICAL AND CONTEMPORARY AGROECOSYSTEMS (I)

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Resumen

Este manual metodológico contiene información básica para estimar la productividad primaria neta (ppn) de las tierras de cultivo, tanto en el presente como en el pasado, en términos de materia fresca, materia seca y energía bruta. La metodología y los factores de conversión propuestos, basados en la revisión de una amplísima literatura, pueden aplicarse a cualquier región del mundo, salvo alguna excepción que se comenta en el texto. La biomasa producida por los agroecosistemas mediante la conversión de los flujos de energía (solar y hoy, sobre todo, fósil) y la movilización de los nutrientes y el agua constituyen la base operativa de los sistemas agrarios tradicionales y, en alguna medida también, de los sistemas agrarios industrializados. Por ello, la cuantificación de la productividad primaria neta de los agroecosistemas, y de los flujos de biomasa que se configuran a partir ella, es esencial para definir los perfiles metabólicos y evaluar la sostenibilidad tanto de las sociedades tradicionales como de las industriales. La información que proporciona este manual puede ser muy útil para aquellos investigadores que trabajan en el Metabolismo Social del sector agrario, en los balances de gases de efecto invernadero en los agroecosistemas y su impacto en el cambio climático o en el cálculo de los balances energéticos (EROI's), entre otros enfoques metodológicos.

Palabras clave: Índices de reparto de biomasa, índice de cosecha, índice de residuos de cultivo, Ratio raíz:canopea, Energía bruta, Biomasa de cultivos.

Abstract

This methodological manual provides basic information to estimate the net primary productivity (NPP) of historical and contemporary cropland, in terms of fresh and dry matter, and gross energy. The methodology and the proposed conversion factors can be applied to any region of the planet, with some exception to be noted in the text. The biomass produced in agro-ecosystems by transforming energy flows (solar and, currently, fossil) and mobilizing nutrients and water are the operational basis of traditional and, to some extent, industrialised societies. The quantification of NPP of agroecosystems, and biomass flows that are configured from this, is essential to build metabolic profiles and to inquire in agrarian sustainability of traditional agrarian and industrial societies. The provided information herein may be useful for researchers working in Agrarian Social Metabolism, Greenhouse Gas Balances of agroecosystems and Climate Change, and Energy Return on Investment (EROI's) in agro-ecosystems among other methodological approaches.

Keywords: Biomass partitioning coefficients, harvest index, crop residues, root:shoot ratio, gross energy, crop biomass.

JEL Codes: Q10, Q11, Q19, N53

INTRODUCTION

This working paper has been prepared as part of the research project on *Sustainable farm systems: long-term socio-ecological metabolism in western agriculture*, funded by the *Research Council of Canada*.Research groups from Canada, United States, Colombia, Cuba, Austria and Spain are participating in the project. The project applied *Agrarian Social Metabolism* to the study of the transition from traditional to industrialised agriculture in an approach to reconstruct sustainability patterns for the management of the agro-ecosystem and of the agri-food system as a whole in the 21st century. The methodology is applied on different spatial scales, from the farm to the municipality to the nation, and considerable effort has been made toreconstruct the flows of the energy and materials (nutrients and water) which make up the metabolic profiles of traditional agrarian and industrial societies.

The biomass produced in agro-ecosystems through the transformation of flows of energy (solar and, currently, fossil) and the mobilisation of nutrients and water are the basis of the operation of traditional societies and, to a certain extent, of industrialised societies. However, only that biomass which has a use value to society and often only the fraction which has been given a monetary exchange value is quantified. This focus ignored a significant part of the biomass produced, whose recirculation in agro-ecosystems is fundamental to their functioning and to the maintenance of numerous populations of heterotrophic organisms which inhabit the planet. From this point of view, the need to quantify all biomass produced by agro-ecosystems becomes more acute, as a response not only to the flows of imported energy and materials, but also to those which recirculate within the limits of the system. The same can be said of the need to evaluate the magnitude of the human appropriation of biomass which characterises the different metabolic arrangements.

To facilitate the calculation of total biomass production, we have compiled this manual, which comprises an explanatory text, a database of 5 Excel spreadsheets with conversion factors and an example applyingthe method to a case study. The conversion factors allow the user: a) to calculate the total biomass produced in the agro-ecosystemon cropland based on information on harvested biomass (e.g. crop production), which is the most commonly available data, in particular for historical sources. A list is included with over 100 crops to calculate the total aerial biomass and more than 30 to calculate underground biomass; b) to convert the fresh biomass into dry biomass and vice versa; c) to convert the biomass into gross energy. The conversion of biomass into gross energy is essential in the study of the energy efficiency of agro-ecosystems (EROI: Energy Return on Investment in agroecosystems), whose methodology has also been fine tuned in this project (Galán *et al*., 2014, Tello *et al.*, 2014).

Here are not included conversion factors to calculate the total biomass produced on grassland or woodlands from the amount of harvested biomass. The main reason is that these conversion factors are highly variable and dependent on circumstances. Typically only a fraction of the aboveground biomass production on pastures is grazed by livestock – depending on stocking density, composition of vegetation and quality of feed. In woodlands, harvested wood can be smaller or much larger than annual aboveground biomass production– it is not straight forward to extrapolate annual biomass produced and annual biomass produced remaining in ecosystems after harvest from wood. However, for calculating the net primary production of agro-ecosystems the biomass produced in these spaces should also be accounted for. To do that, other approaches are possible: for example, experimentally recreating past conditions and carrying out direct measurements that can be extrapolated (experimental history), or using algorithms that take into account variations in vegetation and soil and climatic conditions, etc. The latter option has been used in the example given below.

Most conversion factors includes in this manual (biomass partitioning coefficients, moisture and gross energy content of biomass) has been collected from studies performed and based on so different land use types, crops, technological and climatic conditions. In that sense, they are globally applicable. Nevertheless, these conversion factors are influenced by the genotype of the variety, the hormonal regulation of each plant, the phenological state and the growth conditions (climate, soil, inter- or intra-species competition, cultural practices, etc.). The variability due to the method and moment of the estimate should be added to these. Therefore, the values offered in the database must be considered approximate, being averages taken from data collected from different sources. We include the deviation from the averages in terms of standard deviations.The consulted references for each conversion factor are also available. If more precision is nedeed, the user can select the conversion factors provided by studies that are closer to its environmental conditions.

Only the conversion factor of "weed biomass" is explicitly referred to Mediterranean climate conditions. The application to another specific region requires using data obtained directly from it or from regions with similar environmental conditions.

Regarding to their temporal application, most of the coefficients come from current literature and handbooks. For most coefficients we do not expect large variations over time. For some, like the harvest index, which changes over time, we have provided also information for pre-industrial time periods in some crops.

To learn more of Social Metabolism theory and methodology applied to agricultural activity: Ayres & Simonis (1994), Fischer-Kowalski (1998, 2003); Fischer-Kowlaski & Huttler (1999); Giampietro *et al.* (2012); González de Molina & Toledo (2011, 2014); Haberl *et al.* (2014).

EXPLANATORY TEXT

NET PRIMARY PRODUCTIVITY AND BIOMASS PARTITIONING COEFFICIENTS

In ecology, primary production is the term given to the production of organic material (biomass) or the accumulation of energy by autotrophic organisms through the processes of photosynthesis or chemosynthesis using inorganic material. Chemosynthesis is relevant in certain very specific ecosystems (ocean bed, hydrothermal vents, etc) and, therefore, is not of interest when we consider agrarian metabolism. In terrestrial ecosystems, the main primary producers are plants, with a small contribution from algae. In the oceans, the primary producers are, above all, algae, mainly phytoplankton. Terrestrialprimary production by plants is the basis of agrarian metabolism. However, in flooded agro-ecosystems such as rice fields or in those where marine algae are used as fertiliser, the primary productivity of algae may be relevant.

Primary productivity is divided into gross productivity and net productivity. The former includes that part of solar energy that is captured by photosynthesis but which is not accumulated as biomass since it is lost in the process of respiration. **Net primary productivity (NPP)** is the amount of energy really incorporated into plant tissues (increase in accumulated biomass) and is the result of the opposed processes of photosynthesis and respiration. Net primary productivity is expressed in terms of energy accumulated (joules/hectare/year) or in terms of the organic material synthesised (grams/m^2/day, kg/hectare/year). NPP measures an annual flow and is therefore not equal the amount of standing biomass per unit of area which measures a stock at a certain point in time. The stock or perennial plants can therefore be much larger than annual NPP. This needs to be considered when biomass from perennial plants is harvested.

With regard to agrarian metabolism, it is the net primary productivitywhich is of interest, since this is the basis on which the food chain is built. That is to say, the NPP establishes the limits of the capacity for the maintenance of heterotrophic populations: all of the members of the animal kingdom (human population, domesticated animals and wild fauna), fungi, and a large part of the bacteria and the archaeae. From this derives the fact that the appropriation of the NPP by human society affects the maintenance of the rest of the populations of heterotrophic organisms which depend on the same resources (Wright 1990). The approach to assess NPP flows in agrarian ecosystems presented in this paper relates to the socio-ecological concept of human appropriation of net primary production (HANPP) (Vitousek *et al.,* 1986, Haberl *et al*., 2007, Haberl *et al*., 2014) which measures the effects of human-induced changes of productivity and harvest on ecological biomass flows, but focusses on the assessment of the actual NPP in agroecosystems, the amount of NPP harvested and used by humans and the amount of NPP remaining in ecosystems for other species.

The NPP is the basis of agrarian metabolism and, in order to calculate it correctly we must consider the productivity both of cropland and of areas devoted to pasture and forestry. That is, we consider the productivity of all those spaces from which the human society under study extracts biomass to meet the needs of its own metabolism.

The study of the flows of energy and matter between society and nature are the basis of social metabolism methodology.Since not all accumulated biomass is of equal interest or may not be appropriated with equal ease by human populations but still has important ecosystemic functions, we propose to distinguish different fractions of NPP. The first division is the position on or below the soil of the biomass accumulated by plants (belowground NPP, root NPP). With the exception of harvested roots and tubers, belowground NPP is typically not considered in metabolic studies, since most of it is not harvested and since it is difficult to quantify or measure.Its absence from the quantification of material and energy flows also indicates a certain disregard for or ignorance of its ecosystemic functions both in relation to the maintenance of food chains (edaphic biodiversity has only recently attracted interest with respect to the sustainability of agriculture), and also in relation to its role in the storage of nutrients and carbon in the soil. This latter function, which is useful to mitigate climate change, has led to studies which quantify the biomass of the root systems of plants either by direct measurement or through models. The "Basic data on agrarian-biomass metabolism" database has a table which shows the **Root biomass:aerial biomass ratio.** This Excel spreadsheet includes examples of herbaceous and ligneous species which can be used for reference. Normally, this ratio is calculated from dry biomass, but on occasions it refers to fresh matter. In this latter case, a comment has been included in the database. The number of entries on this spreadsheet is small due to the lack of reliable data found in the literature. Undoubtedly, information on this ratio for different crops will increase significantly in the coming years. With regard to the ratio between the root and the aerial part, there are numerous edapho-climatic, hormonal, etc., factors (Linch *et al.,* 2012) which mean that the value given on the spreadsheet should be taken as an approximate value. For example, in areas with a Mediterranean climate, the root biomass:aerial biomass ratio is usually largerthan in areas of higher precipitation due to the need to spread roots over a larger area to capture sufficient water (Hilbert and Canadell, 1995).

Other better known biomass partitioning indices are habitually used in metabolic calculations. The main one of these is the **Harvest Index**, which tells us the biomass of the main product harvested in relation to the sum of that crop plus the rest[1] of the aerial biomass at the time of harvest. The harvest index most usually studied is that for annual grain crops, mainly cereals and legumes. In this case, the harvest index is the % of the biomass harvested (grain) in relation to the total aerial biomass (grain + straw). It is usually calculated from the fresh material (that is with the moisture content at the time of harvest).

In the case of ligneous species, such as fruit trees, the harvest index contemplates in the numerator the fruit harvested annually and, in the denominator, the sum of fruit harvested plus the wood extracted in pruning. This is not strictly the harvest index, since the denominator should also include the part of biomass produced annually but which does not leave the system. For example, most of the leaves and some of the branches. As an illustration, in the case of the holm oak (*Quercus ilex*), the acorn represents 15% of the total aerial biomass produced annually, with wood from pruning representing 50% and the rest (35%) corresponding to the leaves (Almoguera, 2007). Strictly speaking, the harvest index would be 15%. However, since the denominator does not

[1] In the case of sugar beet and other root crops, it refers to the ratio between the root harvested and the sum of the harvest plus aerial biomass.

include recirculated biomass, the harvest index rises to 23%. In the case of orange trees, the fruit is 42% of the annual dry aerial biomass. Pruned firewood is 22% and the rest (34% of dry material) is the leaves and branches which remain on the ground (Roccuzzo *et al*., 2012). In kiwis, 46% of dry aerial biomass corresponds to the fruit, 24% to leaves and 30% to branches (Smith *et al.,* 1988). Likewise, in these two cases, the biomass generated annually which is recirculated on the same plot has not been used to calculate the harvest index. We would draw attention to the ecosystemic functions of the recirculating biomass and the need to take it into account in metabolic studies. However, due to a lack of data, we have included the crop and residue indicesin the same way as they are usually reported in the literature and we have used the example of the holm oak, orange and kiwi to illustrate the magnitude of the biomass which is excluded.

The partitioning of the biomass in the plants between their different parts (vegetative part versus reproductive part, root biomass versus aerial biomass, etc.) is influenced by the genotype of the variety, the hormonal regulation of each plant, the phenological state (including the age in the case of fruit trees) and the growth conditions (climate, soil, inter- or intra-species competition, cultural practices, etc.). These sources of variation, which can be either intrinsic or extrinsic to the plants, mean that the values of the crop and residue indices can vary within a certain range. To these must be added the variability due to the method and moment of the estimate (Unkovich *et al*. 2010). Therefore, the values offered in the database must be considered approximate, being averages taken from data collected from different sources. We included the deviation from the average in terms of standard deviations.

Only in the case of the cereals which are most affected by scientific varietal improvements do we offer harvest index values for old varieties (prior to the 1940s) differentiated from current values. In these crops, genetic selection focused on the increase of grain production to the detriment of straw and, clearly, current varieties have an average harvest index which is greater than that of the older varieties.

The “Crop and residue indices” table in the “Basic data on agrarian-biomass metabolism” database shows the harvest index of numerous crops. It also gives other indices such as “kg of residue/kg of aerial biomass”. This index complements the harvest index. The sum of both is 1. The third index is “kg of residue/kg of product”. All of these indices are expressed in terms of fresh biomass, although in some cases they have been recalculated if they appeared as dry biomass in the original document. In these cases, it has taken into account the specific moisture content of the product and residuesat the time of harvest, since they are usually significantly different. In the case of trees, they refer to adult specimens at peak production.

Weed biomass

Part of the net primary productivity of agro-ecosystems is not cultivated. It is the adventitious flora which escapes the control strategies of the farmer. In modern agriculture, with the continuous use of herbicides, this biomass may be minimal but, in traditional agriculture and in today's ecological agriculture, its biomass is relevant.

Again, we underline the importance of including it in the energy and material flows of agrarian metabolism due to its ecosystemic functions. The "Weed biomass" tab in the "Basic data on agrarian-biomass metabolism" database gives examples of the magnitude of this biomass expressed as dry weight for different crops and different managements methods in Mediterranean agro-climatic conditions.

Moisture content of the biomass

When studying the hydro-metabolism, it is essential to ascertain the moisture content of the biomass. It is, furthermore, necessary as a conversion factorin any metabolic calculation in order to refer the data always to the same units. In the previous section, we presented some indices which usually refer to fresh material and others to dry material but, within the indices, there is also variation in the way these are expressed, depending on the authors. Three different values can be found in the literature: fresh weight typicaly refers to the moisture content of living biomass or biomass at the time of harvest; airdry weight refers to biomass at a standardized water content of typically 15% and dry matter refers to moisture free biomass (moisture content 0%). Care must therefore be taken with the databases and the precise method of calculation must be verified.

The moisture content of wood is the proportion of free and hygroscopic water expressed as a percentage with respect to the dry weight (Ruiz & Vega, 2007). The wood is not usually totally dry, but contains humidity which may vary between 15% and 60%, depending on the open-air drying time. Wood is a porous, hygroscopic material and, given its chemical-histological structure, it has two types of porosity: macroporosity, created by the cavities in the conducting vessels and theparenchymal cells which contain free water (or imbibition water), and the microporosityof the ligneous substance itself (fundamentally, cellulose, hemicellulose and lignin), which always contains a certain amount of bound water. The wood begins to lose water from the moment at which the tree is felled. Firstly, imbibition water evaporates from the outer part (sapwood) and, subsequently, from the internal parts (heartwood) of the trunk. At a certain point, all of the free water of the dry wood evaporates, while the bound water reaches a point of dynamic equilibrium with external humidity, falling to a value of less than 20% (Francescato *et al*., 2008). Tay (2007) reports that newly cut biomass may have 80-90% moisture content and, on drying, this figure could fall to 10-26%. The **Dry matter conversion factor** table of the "Basic data on agrarian-biomass metabolism" database gives the average percentage moisture content of the wood of different fruit trees after a variable period of open-air drying, together with the standard deviation of the data.

The dry matter of green fodder varies with the phenological state of the plant. Mainly, the dry matter given in the database refers to when the fodder is at 50% of floration.

The dry matter of the main fruit and vegetable products refers mainly to the whole fruit or vegetable. Normally, the dry material data for fruit and vegetables which appears in the literature refers to the edible part. In the case of some products (e.g. lettuce, spinach, etc.) the water content of the edible part is the same as that of the residue (peel, outer leaves, etc.), but in other cases (peel of cucurbitaceae, stones of drupe fruit, shells of nuts, etc.), the moisture content is significantly different. Given that the production data which appears in agricultural statistics refers to complete fruit or vegetables, we have attempted to compile dry material data for complete fruit, which in some cases we have calculated from the dry material of the parts and of the proportion of each one in the product.

In cereals, legumes, fruit and vegetables, we give not only the dry material of the main product, but also the dry material of the rest of the plant (straw, prunings, plant remains) which, while it is not the main product, can also be sold, buried, burned, left on the land, etc. Depending on the treatment given to it, this biomass is considered in different ways in agrarian metabolism.

As an example, we have included data on the dry material of livestock products, some processed industrial products and large volume by-products of agri-industry.

GROSS ENERGY OF BIOMASS

The **gross energy** (GE) is the energy liberated as heat when an organic substance is completely oxidised to carbon dioxide and water. In the International System, it is expressed in Joules per gram of substance. It is also common, however, to find GE expressed in calories per gram. We must take care to note whether the GE value refers to humid or dry matter in order to multiply it by the amount of biomass, whether humid or dry, as the case may be, whose GE is being calculated.

The GE contentof an organic substance (human foodstuffs, fodder, wood, etc.) can be obtained directly by measuring the energy content of a given mass of the substance, as combustion heat in a calorimeter (bomb calorimeter), or indirectly by estimating from the chemical-bromatological composition of the substance.

It is essential to ascertain the GE of organic substances in order to calculate the EROIS. However, a calorimeter is only available in a few cases to make direct measurements of the GE of different products and residues from agricultural and forestry activities. In practice, we shall make a comprehensive review of the literature to obtain published GE data, such as the calculation based on chemical-bromatological composition tables of biomass. By means of this indirect calculation, we can also verify data found in the literature on GE which appears to lack credibility.

We should warn that the energy which usually appears in the tables relating to human and livestock nutrition is not gross energy, but metabolisable energy. Metabolisable energy is the result of deducting the energy of faeces, urine and gases from the gross energy. It is, therefore, useful when preparing diets but not to calculate the EROIS.

The database presented here to facilitate the calculation of the EROIS uses both sources: literature and indirect calculation, which was performed as described below. The database specifies, in each case, the source of the information.

The IS energy unit used in the database is the Joule. We have used a conversion factor to calories (thermochemical calorie) of 4.184 cal/J (FAO, 1971).

Indirect calculation of the gross energy of biomass

Calculation of the GE of human foodstuffs

Each pure substance which makes up organic material has its own GE (e.g. 4.23 kcal GE/g for starch, 3.75 kcal GE/g for glucose, 3.82 kcal/g for hemicellulose, etc.), and so if we know the composition, we can calculate the GE of the substance. To simplify the calculation, average GE values are used for proteins, lipids and carbohydrates, since these are the compositional data of human foodstuffs which are easiest to find, being available in many tables.

To calculate gross energy in our database, we have used figures of 23.5 kJ/g for proteins, 39.5 kJ/g for lipids and 17.5 kJ/g for carbohydrates (Flores Mengual & Rodríguez Ventura, 2013). These values are similar to those used by other authors. For example, Masson (1997) proposes values of 5.4 kcal or 23 kJ/g for protein, 4.1 kcal or 17 kJ/g for carbohydratesand 9.3 kcal or 39 kJ/g for lipids. Maynard *et al*. (1979) uses 4.15 kcal/g for carbohydrates, 9.4 kcal/g for fatand 5.65 kcal/g for proteins. Merrill and Watt (1973) also offer GE for fat, carbohydrates and proteins from different sources.

The composition of foodstuffs has been obtained mainly from Moreiras *et al*., (2011). In the few cases in which the foodstuffs did not appear in this publication, we have used Mataix & Mañas (1998). These authors give the percentage of food consumed by the person (e.g., 84% of an apple) and the composition of the part consumed. Given that many foodstuffs have a part which is not consumed, we would be underestimating the gross energy of the agricultural product if we did not also consider the combustion energy of the waste. To avoid this underestimation, we have also calculated the GE of the waste, as explained in the section *Calculation of the GEof green fodder, crop residue, food waste and fibre,* which appears below.

Therefore, the database includes the GE of the consumable foodstuff, the GE of the waste and total GE, which is the sum of both. We must, then, simply multiply the total GE of the foodstuff by the total crop obtained (kg of wheat, kg of wheat/ha, litres of milk, litres of milk/farm, etc.) to obtain the GE of the part extracted from the agro-ecosystemin the form of human foodstuffs. If the residue is partially or totally returned, database users can also estimate the GE returned to the agro-ecosystem.

Calculation of the GE of livestock feed

In order to calculate the GE of processed livestock feed such as silage, oil cake or composite feedstuff different formulae are available from the literatue which use information of the chemical composition of feedstuff and statistical relations between material characteristics and energy content.In the literature, the following formulae to calculate the GE can be found:

- For concentrates (Nehring & Haenlein, 1973, in Meineri & Peiretti, 2005):

GE (kcal/kg dry matter) = 5.72* raw protein + 9.5 * ether extract + 4.79* raw fibre + 4.03 * N-free extract ± 0.9 (in g/100g dry matter)

- For silage (Andrieu & Demarquilly, 1987, in Meineri & Peiretti, 2005):

GE (kcal/kg organic matter) = 3,910 + 2.45 * protein + 169 pH ± 84 (in g/kg organic matter, R^2=0.59)

- For alfalfa silage (Valente *et al.*, 1991, in Meineri & Peiretti, 2005):

GE (MJ/kg dry matter) = 21.54 – 0.011 * Total N – 0.011 * dry matter + 1,030 pH – 0.073 * acetic acid + 0.018 * lactic acid– 0.056* ethanol ± 0.22 (g/kg dry matter, R^2=0.91)

- Forcrimson cloversilage (Peiretti *et al.*, 1994, in Meineri & Peiretti, 2005):

GE (MJ/kg dry matter) = 14.74 + 0.319 * methanol– 0.008* lactic acid + 0.082 * Total N + 0.012* acetic acid ± 0.21 (g/kg dry matter, R^2=0.91)

- Ewan Formula, 1989 (in NRC, 1998):

GE (kcal/kg fresh matter) = 4,143 + (56 * % ether extract) + (15 * % raw protein) - (44 * % ashes) (R^2=0.98). (% of fresh matter).

In our database, the GE of livestock foodstuffs (grain, feed, cake) is calculated using the Ewan formula (1989, in NRC, 1998), unless otherwise indicated. The composition of the foodstuff (ether extract, raw protein and ashes) comes from the tables of "Ingredients for animal feed" of the Spanish Foundation for the Development of Animal Nutrition (FEDNA, 2010).

In the case of green fodder and humid fibrous by-products, for which this formula is not appropriate, the calculation has been performed as indicated in the following section.

Calculation of the GE of crop residues, food waste, green fodder and fibre

The term "crop residue" refers here to the aerial biomass of herbaceous plants which are not harvested as the main crop product. It may or may not be used by society. Crop residue is the straw and stubble of cereals and legumes whose main product is the grain, although this residue is frequently used as animal feed. Crop residue also includes other herbaceous crops (sugar beet, sugar cane, horticultural, industrial crops, etc.) some of which can be used as feed or energy carrier.

Food waste is the inedible part of foodstuffs as contained in the section *Calculation of the GE of human foodstuffs*.

Green fodder refers to the aerial parts of these crops at the moment in which they are harvested as fodder for livestock. They have not, therefore, undergone the process of haymaking or silage.

Fibre refers to the product of fibre-producing crops (cotton, flax…).

In these four cases, the calculation is based on the assumption that the plant biomass composed basically of carbohydrates has, on average, 4,200 kcal/kg of dry matter (17.57 Mj/kg dry matter)(Merrill & Watt, 1973, González González, 1993). In this regard, there is a certain variation between authors, between 4,000-4,400 kcal/kg dry matter(Campos & Naredo, 1980, NRC, 2001).In fact, since there is a slight variation in the proportion of the different carbohydrates contained in the different plant species, as well as the presence of other substances in small quantities (resins, lignin, etc.), a certain amount of variation is to be expected.

Therefore, the GE of 1 kg of fresh matter of these products is obtained by multiplying by the percentage of dry matter and by 17.57 Mj/kg dry matter. The percentage of dry matter of each product is contained in the database (Tab: "Dry matter conversion factors"). We would calculate the GE of the biomass of weeds (adventitious flora) in the same way.

<u>Gross energy of the wood in forest species and pruning residue of fruit trees</u>

According to the FAO (1991), the gross energy of wood depends very much on the species and the part of the tree that is used, varying between 17-23 MJ/kg dry matter of wood. Generally, conifers have higher values than broadleaf trees, with an average value of 21 MJ/kg of dry matter for resinous wood and 19.8 MJ/kg dry matterfor other woods. There is very little variation in the GE of the substance of the wood, which is 19 MJ/kg of dry matter, with the difference between species depending on the proportion of resin. Resin has a GE of 40 MJ/kg dry matter (FAO, 1991). Likewise, Francescato *et al.* (2008) says that the GE of different species of wood varies within a very reduced interval, of 18.5 to 19 MJ/Kg dry matter. In conifers, it is 2% higher than in broadleafs. This difference is due fundamentally to the higher lignin content of conifers but also in part to their higher resin, wax and oil content. In comparison with cellulose (17.2-17.5 MJ/kg dry matter) and hemicellulose (16 MJ/kg dry matter), lignin has a higher GE (26-27 MJ/kg dry matter) (Francescato *et al*., 2008).

To calculate the GE of different types of wood, we have reviewed the literature (see the *Gross energy of biomass* table in the database). Since this biomass is habitually used to generate energy, it is possible to find information for each species or group of species. The data is normally given for dry matter, and so we have also considered the percentage of dry matter per kilogram of fresh wood in order to calculate the GE per kilogram of fresh wood.

Since, as we have seen, the percentage of dry matter of the wood varies with the time that has elapsed since it was cut, the storage conditions, etc.,we have standardised the moisture content for all wood on a 25%.

This decision is arbitrary and would correspond to wood that has been aired for a certain period of time, without being exposed to rain. In our case, we have considered that the wood production data which appears in historical sources refers to wood in this condition and not to newly cut wood. In other cases, if there is a suspicion that the production data refers to other conditions, the GE value may be adjusted, dividing by 0.75 and multiplying by the decimal representing the percentageof dry matter considered most appropriate in each case.

In the case of pruning residue, the dry matter content is taken from a review of the literature (see *Dry matter conversion factors*).

EXAMPLE OF THE APPLICATION OF THE CONVERSION FACTORS. CASE STUDY OF THE SANTA FE AGRO-ECOSYSTEM

As an example of the use of the database, we offer a case study of the municipality of Santa Fe (Granada) in the south-east of the Iberian Peninsula, in the mid-18th century. This case study has been widely described in a book and several articles, which makes it possible to investigate the agrarian social metabolism of Santa Fe from the mid-18th until the end of the 20th century (González de Molina & Guzmán, 2006, Guzmán & González de Molina, 2007, Guzmán & González de Molina, 2009).

The agricultural area and agricultural production in the municipality of Santa Fe (Granada) in 1752 are shown in Table 1. The information about the agricultural area, crop production and forestland comes from historical sources. The aerial production of pastureland was obtained as dry matter using models which take into account edapho-climatic and vegetation variables.

Table 1. Agricultural area and harvest in Santa Fe (Granada) in 1752

Crops	Agricultural Area (hectares)	Yield (kg fresh matter)
Dry beans	67.7	124,568
Hemp	20.4	6,780
Wheat	564.7	1,030,013
Flax	199.8	60,228
Corn	6.3	14,364
Irrigated barley	52.2	91,768
Chickpeas	3.9	600
Millet	20.1	44,300
Onions	1.5	1,074
Grass peas	7.3	600
Common beans	5.3	3,794
Safflower	2.5	600
Dryland barley	376	110,168
Olives	189	27,062
Grapes (cultivated with olives)	-	191,268
Pasture		kg dry matter
Fallow	1,180	2,049,660
*Dehesa*pastureland	366.3	331,684
Floodable pastureland	700	980,000
Forestry		kg fresh matter
Poplars/riverbank vegetation	3.4	31,897
TOTAL	**3,766**	

From this data, we can obtain an approximate figure for the real biomass production of the agro-ecosystem using the conversion factors in the database.

For example, in the case of beans, we would have to multiply the harvest (124,568 kg of fresh material) by the dry matter conversion factor for beans (0.915) to obtain the harvest of dry matter (114,021 kg of dry matter in the harvest of beans).

To obtain the aerial dry biomass of the residues generated by the bean harvest we would multiply 124,568 kg of fresh matter harvested by the residue index for beans (1.56) and by the dry matter conversion factor for bean residue (0.886), giving a figure of 172,449 kg of dry matter.

To calculate the dry root biomass, we add the dry biomass of the harvest and the residue (286,470 kg of dry matter) and multiply it by the root biomass:aerial biomass ratio for beans (0.6). The aerial biomass of the root would come to 172,837 kg of dry matter, an amount similar to that of the residues (straw) of the bean crop.

Table 2. Net primary productivity (dry matter) of the Santa Fe agro-ecosystem in 1752.

Crops	CROPS				WEEDS		
	Aerial part			Root	Aerial part	Root	Total
	Harvest (kg)	Residues (kg)	Accumulated perennial structures (kg)	kg	kg	kg	t
Dry beans	114,021	172,449		172,837	59,125	47,300	565.7
Hemp	6,177	1,544		1,418	17,816	14,253	41.2
Wheat	905,381	2,257,516		2,024,254	493,174	394,539	6,074.9
Flax	55,952	12,798		12,627	174,493	139,594	395.5
Corn	12,382	15,467		6,769	5,502	4,402	44.5
Irrigated barley	81,215	149,345		147,558	45,588	36,471	460.2
Chickpeas	566	911		87	3,406	2,725	7.7
Millet	39,006	48,730		21,325	17,554	14,043	140.7
Onions	66	131		0	2,451	1,961	4.6
Grass peas	550	926		87	6,375	5,100	13.0
Common beans	3,730	5,667		556	4,629	3,703	18.3
Safflower	547	2,124		2,672	2,183	1,747	9.3
Dryland barley	97,499	179,290		177,145	328,375	262,700	1,045.0
Olives	14,586	17,931	18,635	3,883	567,000	453,600	1,079.5
Grapes	55,704	66,677	5,600	2,240	0		130.2
Pasture							
Fallow	420,668			336,535			757.2
Dehesa pasture	331,684			398,021			729.7
Floodable pasture	980,000			784,000			1,764.0
Forestry							
Poplars	23,923		34,771	11,993	13,760	11,008	95.5
TOTAL	**3,143,656**	**2,931,506**	**62,890**	**4,104,006**	**1,741,433**	**1,393,146**	**13,376.6**

In the case of crops for which we have not found data, we have used equivalents in similar crops. For example, we have considered that flax is similar to hemp where we did not have any conversion factor available. Grass peas were compared to "other legumes" or peas, depending on the conversion factor.

The aerial biomass of the vegetation accompanying the crops was obtained by multiplying the crop area (hectares) of the beans withvalue of average dry matter productionof weeds per hectare for extensive crops (873 kg dry matter/ha). The dry root biomass is obtained by multiplying the dry biomass of the aerial parts (59,125 kg dry matter) by the root biomass:aerial biomass ratio for pasture land (0.8), which we have given a similar value to weeds. In this way, we obtain a dry root biomass figure for weeds of 47,300 kg of dry matter.

The sum of the total dry biomass of the crop would come to 565.7 t of dry matter.

For cereals, we have used the conversion factors for old varieties given in Annex 1 which refer to harvest indices typical before 1940, which are surely more similar to those used in 1752 than those used today.

The gross energy of the aerial biomass of the crop is obtained by multiplying the fresh biomass of the crop and of residues by the corresponding gross energy value. Specifically, in the case of beans, the harvested biomass (124,568 kg of dry matter) is multiplied by 15.59 MJ/kg fresh matter, while the biomass of the residues (194,637 kg fresh matter) is multiplied by 15.57 MJ/kg fresh matter (beans talks).

The gross energy of the roots of the crop and of the weeds (aerial part and roots) have been calculated by multiplying their respective dry biomass values by 17.57 Mj/kg dry matter, which, as explained in the text, is an approximate value for biomass composed fundamentally of carbohydrates. The gross energy of the biomass generated in the municipality of Santa Fe in 1752 is shown in Table 3.

Table 3. Net primary productivity (gross energy) of the Santa Fe agro-ecosystem in 1752.

Crops	CROPS				WEEDS		
	Aerial part			Root	Aerial part	Root	Total
	Harvest (MJ)	Residues (MJ)	Accumulated perennial structures (MJ)	MJ	MJ	MJ	GJ
Dry beans	1,942,015	3,030,405		3,037,227	1,038,992	831,193	9,880
,Hemp	108,540	27,135		24,918	313,079	250,463	724
Wheat	14,258,264	39,670,874		35,571,815	8,666,450	6,933,160	105,101
Flax	983,230	245,808		221,886	3,066,330	2,453,064	6,970
Corn	207,393	271,796		118,946	96,686	77,349	772
Irrigated barley	1,433,967	2,624,413		2,593,013	801,113	640,891	8,093
Chickpeas	9,457	16,006		1,535	59,853	47,883	135
Millet	669,984	856,323		374,735	308,475	246,780	2,456
Onions	1,069	2,300		0	43,078	34,462	81
Grass peas	11,064	16,268		1,533	112,033	89,626	231
Common beans	52,319	99,593		9,762	81,339	65,071	308
Safflower	10,544	37,333		46,949	38,367	30,694	164

Dryland barley	1,721,485	3,150,622		3,112,926	5,770,471	4,616,377	18,372
Olives	215,843	338,529	425,142	68,236	9,963,778	7,971,022	18,983
Grapes	543,434	1,285,978	108,005	39,363	0	0	1,977
Pasture							0
Fallow	7,392,320			5,913,856			13,306
Dehesa pasture	5,828,621			6,994,345			12,823
Floodable pasture	17,221,344			13,777,075			30,998
Forestry							0
Poplars	442,567		653,319	210,752	241,802	193,441	1,742
TOTAL	53,053,460	51,673,383	1,186,466	72,118,872	30,601,846	24,481,476	233,116

For pastures, aerial biomass of the dehesa (905.4 kg dm/ha) was calculated by applying an algorithm adapted to the growing conditions in Santa Fe (Passera Sassi *et al*., 2001). However, the productivity of floodable pasture (1400 kg dm/ha) and fallows (356 kg dm/ha) is based on studies with similar agro-climatic and management conditions (San Miguel Ayanz, 2009, Campos & Naredo, 1980). The root:shoot ratio of grass is 0.8, except for the dehesa, which has been considered 50% of mediterranean scrub (ratio: 1.6) and 50% herbaceous grass (ratio: 0.8) (Annex 2). Gross Energy of pasture is 17.57 MJ/kg dry matter.

From this, again taking as a basis the historical sources and information, we can determine the biomass socialized by the human population, that was used to maintain the livestock and that which was available for the remaining heterotrophic organisms. This part, together with that consumed by livestock, is the recirculating biomass of the agro-ecosystem.

The high livestock population at the time meant that straw and stubble were all consumed, and so we suppose that they were not burnt during that period. Likewise, we have supposed that the pruning and sucker waste was not burnt in the fields, since the firewood demand by the local population for cooking and heating far exceeded availability in the municipality.

We can also estimate the biomass that was stored annually in perennial vegetation (trees and shrubs) both in the root system and the aerial part. The annual biomass accumulated in the olive groves as been estimated on the basis of Almagro *et al*. (2010). These authors estimated the accumulated dry biomass in the aerial part to be 17,298 kg dry matter/hectare and 3,604 kg dry matter/hectare in the roots, in 100-year-old dry-farmed olive groves with trees planted in a 10×10 m^2 pattern. Such olive groves are similar to those in the Santa Fe case. This would mean an accumulation of 2.1 kg of dry material annually per tree (1.7 in the aerial part and the rest in the roots). In our case, there were 57 trees per hectare and 189 ha of olive groves. Therefore, the annual accumulation would be 18,635 kg of aerial dry matter and 3,883 kg dry matter.in the roots in the olive groves in the municipality. This is a simplification, since the process is not linear. To calculate the amount of aerial biomass stored annually in poplars, we have divided the total amount of wood obtained after felling by the number of years of growth until the felling (15 years). The dry root biomass accumulated annually has been calculated taking into account the root biomass:aerial biomass ratio of the poplar. For grape-vine, we have considered 30-year-old vine and so the total biomass accumulated in the plant is divided by the total number of years of the plantation.

In our case, the direct appropriation of biomass (*Socialized Vegetal Biomass*) by the population represented 7% of the dry matter, that used for animal feed was 30%, that available for other heterotrophic species came to 62.5%, although most of this (66%) recirculated in the soil. Very little biomass was stored annually in perennial plants (0.5%) due to the small crop area devoted to perennial crops or forestry. The *dehesa* pastureland was without trees and had an herbaceous and shrub cover, according to descriptions from the time.

The agro-ecosystem in Santa Fe in 1752 provided the flows of biomass necessary to maintain the human population and livestock, which in turn guaranteed the supply of the flows of energy and nutrients necessary to sustain agricultural production, achieving very high levels of sustainability (González de Molina & Guzmán, 2006).

El 37% of the non-stored aerial biomass would have been available for non-domesticated species, allowing the maintenance of wild animals in the municipality.

Table 4. Distribution of the vegetal biomass produced annually by the Santa Fe agro-ecosystem in 1752

		Biomass (kg dry matter)	**Gross energy (MJ)**	**%**
Socialized Vegetal Biomass	**Foodstuffs**	868,349	13,321,555	
	Fibre	62,676	1,102,313	
	Wood and firewood	89,455	1,707,377	
Subtotal		1,020,480	16,131,245	7
Reused Biomass (for animal feed and bedding, seed, etc.)		3,968,050	69,048,225	30
Un-harvested Biomass (available for other species)	Aerial	2,828,064	50,149,219	21.5
Un-harvested Biomass (available for other species)	Underground	5,497,152	96,600,348	41
Stored		62,890	1,186,466	0.5
	TOTAL	**13,320,035**	**233,115,503**	**100**

At the other extreme, there is the biomass contributed by edaphic heterotrophic organisms since, to the enormous amount of underground biomass which was directly recirculated (5,497 t of dry matter) must be added the biomass of the manure of the livestock which became incorporated into the soil, and which amounted to 2,831 t. (González de Molina & Guzmán, 2006). Such a high recirculation of biomass in the soil guaranteed the magnificent condition of the resource, as well as edaphic biodiversity, which was not damaged by the use of biocides, which were unknown at the time.

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ANNEX I. HARVEST AND RESIDUES INDICES. All indices refer to fresh weight (moisture content at the time of harvest).

CROPS	Harvest index	Residues indices		
	Mean kg product/ kg aerial biomass	Mean kg residue/ kg aerial biomass	Mean kg residue/ kg product	Standard Deviation kg residue/kg product
Cereals (modern varieties)				
Barley	0.45	0.55	1.20	0.31
Maize	0.52	0.48	0.94	0.05
Millet	0.45	0.55	1.22	
Oat	0.41	0.59	1.43	1.06
Rice	0.45	0.55	1.20	0.44
Rye	0.43	0.57	1.30	0.42
Sorghum	0.37	0.63	1.69	0.88
Summer cereals, other	0.45	0.55	1.22	
Wheat	0.42	0.58	1.36	0.33
Winter cereals, other	0.45	0.55	1.22	
Cereals (old varieties)				
Barley	0.35	0.65	1.88	0.22
Maize	0.45	0.55	1.22	
Oat	0.33	0.67	2.03	
Rice	0.30	0.70	2.33	
Wheat	0.28	0.72	2.53	0.05
Legumes				
Chickpea	0.37	0.63	1.70	
Faba bean/Broad bean	0.39	0.61	1.56	0.97
Legumes, other	0.37	0.63	1.72	
Lentils	0.32	0.68	2.08	0.07
Lupin	0.30	0.70	2.33	
Pea, green, with pod	0.39	0.61	1.57	0.63
Peanuts	0.33	0.67	2.03	
Soybeans	0.35	0.65	1.86	0.87
Vetch	0.45	0.55	1.24	0.56
Root crops				
Potato	0.59	0.41	0.70	0.42
Sweet potato	0.53	0.47	0.89	
Tigernuts	0.50	0.50	1.00	
Vegetables				
Artichoke	0.42	0.58	1.40	1.56
Artichoke thistle	0.78	0.22	0.28	
Asparagus	0.22	0.78	3.59	3.61
Beans, green	0.38	0.62	1.60	0.61
Beet	0.51	0.49	0.95	
Belgian endive	0.78	0.22	0.28	
Borage	0.86	0.14	0.16	
Cabbage, Broccoli	0.45	0.55	1.23	1.15
Carrot	0.53	0.47	0.87	0.02
Cauliflower	0.65	0.35	0.54	0.40
Celery	0.86	0.14	0.16	
Chard	0.91	0.09	0.10	0.07

CROPS	Harvest index	Residues indices		
	Mean kg product/ kg aerial biomass	Mean kg residue/ kg aerial biomass	Mean kg residue/ kg product	Standard Deviation kg residue/kg product
Chicory	0.78	0.22	0.28	
Chili pepper	0.30	0.70	2.33	
Collard	0.80	0.20	0.25	
Cucumber	0.80	0.20	0.25	
Cultivar for pickled cucumber, gherkins	0.80	0.20	0.25	
Eggplant/Aubergine	0.59	0.41	0.69	
Endive	0.67	0.33	0.50	
Faba bean/Broad bean, green, without pod	0.34	0.66	1.97	
Garlic	1.00	0.00	0.00	
Leek	1.00	0.00	0.00	
Lettuce	0.78	0.22	0.28	0.31
Melon	0.75	0.25	0.33	0.33
Mint and peppermint	0.80	0.20	0.25	
Onion	0.62	0.38	0.61	0.24
Parsley	0.86	0.14	0.16	
Pea, green, with pod	0.30	0.70	2.33	
Pepper	0.58	0.42	0.73	0.14
Radish	0.53	0.47	0.89	
Spinach	0.91	0.09	0.10	0.07
Squash/pumpkin	0.88	0.12	0.14	
Strawberry	0.50	0.50	1.00	
Tomato	0.51	0.49	0.96	0.94
Turnip	0.53	0.47	0.89	
Watermelon	0.91	0.09	0.10	
Welsh onion	1.00	0.00	0.00	
Zucchini	0.80	0.20	0.25	
Industrial crops				
Anise	0.20	0.80	4.00	
Caper	0.33	0.67	2.00	
Castor oil plant	0.33	0.67	2.00	
Cotton fiber	0.39	0.62	1.60	
Cotton seed	0.40	0.60	1.50	
Cumin	0.33	0.67	2.00	
Hemp	0.80	0.20	0.25	
Hop/Common hop	0.33	0.67	2.00	
Linseed	0.26	0.74	2.85	
Liquorice	0.50	0.50	1.00	
Mustard (Black mustard)	0.29	0.71	2.45	
Rape	0.29	0.71	2.45	0.17
Safflower	0.22	0.78	3.54	0.65
Saffron	0.17	0.83	5.00	
Sugar beet	0.51	0.49	0.95	0.78
Sugarcane	0.70	0.30	0.43	
Sumac	0.40	0.60	1.50	
Sunflower	0.30	0.70	2.30	0.69
Tobacco	0.67	0.33	0.50	0.71

CROPS	Harvest index	Residues indices		
	Mean kg product/ kg aerial biomass	Mean kg residue/ kg aerial biomass	Mean kg residue/ kg product	Standard Deviation kg residue/kg product
Fruit trees				
Almonds	0.30	0.70	2.28	1.14
Apple	0.73	0.27	0.37	0.40
Apricot	0.71	0.29	0.41	0.08
Avocado	0.71	0.29	0.41	-
Bananas, platains	0.40	0.60	1.50	
Cherry	0.66	0.34	0.50	0.46
Figs	0.62	0.38	0.61	
Grapevine	0.65	0.35	0.53	0.29
Hazelnuts growing	0.37	0.63	1.70	0.28
Holm oak	0.23	0.77	3.33	
Kiwifruit	0.68	0.32	0.46	0.09
Lemon	0.83	0.17	0.20	0.22
Mandarin	0.78	0.22	0.28	0.32
Oil palm	0.19	0.81	4.26	
Olive tree	0.51	0.49	0.95	0.46
Orange	0.86	0.14	0.17	0.12
Papaya	0.99	0.01	0.01	
Peach	0.80	0.20	0.25	0.13
Pear	0.74	0.26	0.34	0.39
Pistachio	0.40	0.60	1.50	
Pomegranate	0.78	0.22	0.28	
Walnut tree	0.40	0.60	1.50	

ANNEX II. ROOT:SHOOT RATIO. All ratios refer to fresh weight (moisture content at the time of harvest).

CROPS	Mean Root:shoot ratio	Standard Deviation Root:shoot ratio
Cereals (modern varieties)		
Barley	0.21	0.18
Canary grass	1.50	0.71
Maize	0.24	0.15
Oat	0.40	0.03
Sorghum	0.09	
Triticale	0.19	0.02
Wheat	0.20	0.15
Cereals (old varieties)		
Wheat	0.64	
Legumes		
Faba bean/Broad bean	0.60	0.24
Pea, green, with pod	0.06	0.02
Soybeans	0.39	0.38
Industrial crops		
Hemp fiber	0.18	0.06
Sugar beet	14.29	
Green fodder		
Alfalfa	1.20	0.58
Alfalfa (mixed cropping)	1.14	0.25
Brome	4.11	3.09
Brome grasses	2.44	0.77
Cat's-tail	1.42	0.82
Clover	0.56	0.37
Cocksfoot	1.10	0.47
Corn (silage)	0.10	
Fescue grass	1.13	0.62
Grass	0.80	
Perennial ryegrass	1.58	1.30
Rye	0.85	0.19
Rye+Hairy vetch	0.61	0.08
Ryegrasss	0.51	0.31
Subterranean clover	0.25	
Switchgrass	0.99	0.70
Fruits		
Kiwifruit	0.67	
Olive tree	0.21	
Forest trees		
Holm oak	0.84	0.43

CROPS	Mean Root:shoot ratio	Standard Deviation Root:shoot ratio
Mediterranean scrub	1.60	0.84
Poplar	0.50	
Willow, Sallow	0.45	0.14

ANNEX III. DRY MATTER CONVERSION FACTORS (% dry matter in fresh weight biomass (at the time of harvest)

CROPS	Product (%)	Residues (%)
Cereals		
Barley	0.885	0.864
Brown rice	0.864	0.910
Maize	0.862	0.881
Millet	0.881	0.900
Oat	0.867	0.907
Rye	0.876	0.924
Sorghum	0.865	0.870
Spring cereals, other	0.872	0.907
Triticale	0.878	0.922
Wheat	0.879	0.867
Winter cereals, other	0.873	0.893
Legumes		
Bard vetch/Oneflower vetch	0.967	
Beans, white	0.983	0.871
Bitter vetch	0.900	0.914
Chickpea	0.944	0.893
Faba bean/Broad bean, dry	0.915	0.886
Grass pea, Chickling vetch		0.915
Hard vetch		0.886
Legumes, other	0.916	0.811
Lentils	0.897	0.928
Pea, dry	0.902	0.907
Soybeans	0.860	0.886
Vetch	0.900	0.911
White lupin	0.894	
Vegetables		
Artichoke	0.119	0.20
Artichoke thistle	0.061	0.20
Asparagus	0.053	0.30
Basil, fresh	0.075	
Beans, green	0.104	0.30
Beet	0.108	0.12
Belgian endive	0.066	0.00
Borage	0.065	0.00
Broccoli	0.097	0.00
Cabbage	0.103	0.18
Carrot	0.081	0.21
Cassava	0.416	0.30
Cauliflower	0.076	0.21
Celery	0.046	0.10
Chard	0.125	0.19
Chicory		0.00
Chili pepper	0.105	0.30
Chives	0.077	
Common mushroom	0.086	
Coriander	0.148	

CROPS	Product (%)	Residues (%)
Corn salad/Mâche	0.044	
Cucumber	0.033	0.18
Cultivar for pickled cucumber, gherkins		0.20
Eggplant/Aubergine	0.090	0.20
Endive	0.064	0.00
Faba bean/Broad bean, green, without pod	0.178	0.24
Fennel	0.067	
Garlic	0.297	0.30
Ginger, fresh	0.139	
Green pepper	0.087	0.30
Iceberg lettuce	0.042	
Leek	0.129	0.21
Lettuce	0.047	0.17
Melon	0.076	0.20
Melon (cantaloupe)	0.091	
Miniature lettuce	0.047	
Mint and peppermint	0.098	
Onion	0.061	0.20
Parnsnip	0.183	
Parsley	0.120	
Pea, green, with pod	0.248	0.30
Potato	0.227	0.20
Radish	0.047	0.19
Shallot	0.207	
Sorrel	0.070	
Spinach	0.104	0.19
Squash/pumpkin	0.108	0.30
Strawberry	0.104	0.30
Sweet potato	0.258	
Tomato	0.062	0.13
Tomato (cherry)	0.108	
Turnip	0.089	0.20
Watercress	0.074	
Watermelon	0.057	0.20
Welsh onion	0.078	
Yellow nutsedge, Tigernuts	0.897	
Zucchini	0.035	0.69
Industrial crops (before processing)		
Caper	0.114	
Cotton fiber	0.900	
Cotton seed	0.920	0.92
Esparto grass	0.721	
Hemp seed and fiber	0.911	0.91
Linseed/Flax	0.929	0.85
Mustard (Black mustard)	0.912	1.00
Rape	0.912	1.00
Safflower	0.912	0.16
Sugar beet	0.250	0.16
Sugarcane	0.295	0.48
Sunflower	0.936	0.93

CROPS	Product (%)	Residues (%)
Tobacco	0.150	0.80
Fruits		
Almonds	0.689	0.69
Apple	0.160	0.69
Apricot	0.186	0.71
Bananas, platains	0.249	
Blackberry	0.128	
Blackcurrant	0.144	
Blueberry	0.122	
Cherry	0.262	0.71
Chestnut	0.500	
Figs	0.197	0.81
Grapevine	0.291	0.65
Hazelnuts growing	0.930	0.75
Holm oak	0.625	
Kiwifruit	0.186	-
Lemon		0.63
Mandarin		0.63
Olive tree	0.539	0.70
Orange	0.121	0.63
Peach	0.208	0.69
Pear	0.180	0.69
Plum		0.82
Pomegranate	0.200	-
Raspberry	0.130	
Redcurrant	0.096	
Sour cherry, wild cherry	0.262	0.82
Walnut tree	0.753	0.83
Forest trees		
Bark (broad-leaved tree)	0.75	
Bark (conifers)	0.75	
Broad-leaved tree	0.75	
Conifers	0.75	
European beech/Commom beech	0.75	
Poplar	0.75	
Spruce	0.75	
Willow, Sallow	0.75	
Green fodder		
Alfalfa	0.280	
Artichoke thistle, for fodder	0.118	
Artificial swards	0.200	
Bard vetch/Oneflower vetch, green	0.249	
Barley, green	0.248	
Bitter vetch, green	0.193	
Carrot, for fodder	0.126	
Cereal-legume mixture	0.194	
Common sainfoin	0.202	
Crimson clover, in bloom	0.215	
Faba bean/Broad bean, green, for fodder	0.168	
Fenugreek, green	0.308	

CROPS	Product (%)	Residues (%)
Fodder	0.050	
Fodder beet	0.184	
Fodder cabbage	0.165	
French honeysuckle	0.153	
Jerusalem artichoke	0.234	
Maize, green	0.216	
Mixed swards	0.200	
Oat, green	0.303	
Other clovers (white, hybrid, subterranean, etc.)	0.215	
Other fodders (Lupin, thistle, parnsnip, tree medick)	0.194	
Other legumes for green fodder	0.180	
Other monospecific swards	0.200	
Other roots and tubers for fodder	0.200	
Other true grasses for fodder	0.194	
Pea, green, for fodder	0.182	
Perennial ryegrass	0.239	
Rye, green	0.194	
Ryegrasss	0.227	
Sorghum, green	0.202	
Squash, for fodder	0.108	
Subterranean clover	0.158	
Sugar beet, neck	0.203	
Tree medick	0.280	
Turnip, for fodder	0.126	
Vetch, green	0.376	
Wheat, green	0.158	
TRANSFORMED PRODUCTS		
Sugars		
Brown sugar	0.965	
White sugar	0.995	
Oils		
Coconut oil	0.999	
Maize germ oil	0.999	
Olive oil	0.999	
Palm oil	0.999	
Peanut oil	0.999	
Soybean oil	0.999	
Sunflowerseed oil	0.999	
Products from grape		
Fine wine	0.031	
Grape juice	0.165	
Sweet fortified wine	0.132	
Vinegar	0.010	
Wine	0.012	
Dried fruits		
Apricot, dry	0.705	
Date, dry, stoneless	0.823	
Fig, dry	0.77	
Plum, dry, stoneless	0.584	
Raisins	0.745	

CROPS	Product (%)	Residues (%)
AGRO-INDUSTRY BYPRODUCTS		
Alfalfa meal and pellets	0.912	
Blood meal	0.952	
Brewers grains	0.243	
Cereal brans	0.888	
Citrus pulp	0.175	
Copra cake	0.909	
Corn cob	0.940	
Cotton seed cake	0.893	
Cottonseed hulls	0.904	
Legume brans	0.890	
Lin seed cake	0.910	
Maize gluten meal	0.890	
Palmkernel cake	0.914	
Peanut cake	0.912	
Rapeseed cake	0.892	
Rapeseed hulls	0.870	
Soy hulls	0.920	
Soybean cake	0.880	
Sugar beet molasses	0.753	
Sugarcane molasses	0.737	
Sunflower seed hulls	0.891	
Sunflowerseed cake	0.910	
Whey	0.956	
ANIMAL PRODUCTS		
Milk products		
Cow milk	0.119	
Goat milk	0.118	
Eggs		
Chicken eggs	0.236	
Duck eggs	0.281	
Quail eggs	0.247	
Honey		
Honey	0.785	
Meat		
Beef chop	0.375	
Beef meat	0.377	
Chicken	0.297	
Chicken breast	0.246	
Duck	0.360	
Goat meat	0.233	
Hen	0.297	
Horse meat	0.220	
Lamb chop	0.350	
Lamb, leg and chuck	0.366	
Lamb, other cuts	0.483	
Lean beef meat	0.261	
Lean pork meat	0.283	
Pork bacon	0.591	
Pork chop	0.449	

CROPS	Product (%)	Residues (%)
Pork chuck	0.507	
Pork fat	0.794	
Pork lard	0.950	
Pork loin (3% fat)	0.226	
Pork loin (9% fat)	0.268	
Pork meat	0.396	
Pork sirloin	0.261	
Quay	0.246	
Rabbit and Hare	0.276	
Red-legged partridge	0.246	
Steer sirloin	0.217	
Turkey breast, skinless	0.233	
Turkey drumstick	0.273	
Turkey, boneless, skinless	0.241	
Turkey, skinless	0.243	
Wild boar meat	0.229	

ANNEX IV. WEED BIOMASS (Dry matter)

	Method of Crop Production	Weed (kg/ha)
Vegetables		
Cabbage	Organic	2,087
Cabbage	Organic	615
Cabbage	Organic	491
Onion	Organic	4,257
Tomato	Organic	4,036
Tomato	Organic	587
Tomato	Low Inputs	527
Tomato	Conventional	212
Zucchini	Organic	475
Mean	**Organic/Low Inputs**	**1,634**
Mean	**Conventional**	**212**
Arable crops		
Barley	Conventional	130
Barley	Low Inputs	669
Barley	Organic	225
Corn	Organic	1,310
Corn	Low Inputs	717
Corn	Conventional	678
Corn	Organic	754
Corn	Organic	84
Durum wheat	Conventional	60
Flax	Organic	2,385
Flax	Organic	1,650
Rice	Organic	300
Rice	Organic	640
Wheat	Conventional	61
Mean	**Organic/Low Inputs**	**873**
Mean	**Conventional**	**232**
Fruit trees		
Citrus	Organic	3,800-4,500
Citrus	Conventional	700
Grapevine	Organic	983
Olive tree	Organic	3,000
Olive tree	Organic	2,248
Olive tree		800
Olive tree		6,243

ANNEX V. GROSS ENERGY (MJ/kg fresh weight).

CROPS	Gross Energy (MJ/kg)
Cereals	
Barley	15.63
Brown rice	15.18
Buckwheat	18.19
Canary grass	15.18
Einkorn	13.02
Foxtail millet	14.44
Maize	14.44
Millet	15.12
Oat	15.18
Rye	14.14
Sorghum	15.98
Spring cereals, other	15.18
Triticale	15.77
Wheat	13.84
White rice	16.58
Winter cereals, other	14.91
Legumes	
Bard vetch/Oneflower vetch	13.84
Beans, black	15.30
Beans, red	15.72
Beans, white	13.84
Beans, white and red	13.79
Bitter vetch	18.35
Chickpea	15.76
Faba bean/Broad bean, dry	15.59
Faba bean/Broad bean, dry, fodder varieties	18.52
Faba bean/Broad bean, green, with pod	11.46
Faba bean/Broad bean, green, without pod	2.68
Fenugreek	18.35
Grass pea, Chickling vetch	18.35
Hard vetch	18.35
Lentils	15.36
Pea, dry	15.39
Pea, dry, fodder varieties	18.44
Pea, green, with pod	10.14
Soybeans	18.20
Vetch	18.75
White lupin	20.03
Vegetables	
Artichoke	2.00
Artichoke thistle	1.01
Asparagus	0.86
Beans, green	1.49
Beet	1.48
Belgian endive	1.07
Borage	1.20

CROPS	Gross Energy (MJ/kg)
Broccoli	1.68
Brussels sprout	2.08
Cabbage (kale or borecole)	1.41
Cabbage	1.54
Carrot	1.51
Cassava	6.92
Cauliflower	1.16
Celery	0.67
Chard	1.63
Chicory	0.83
Chinese cabbage	1.43
Chives	1.21
Common mushroom	1.27
Corn salad/Mâche	0.69
Cucumber	0.57
Eggplant/Aubergine	1.12
Endive	1.03
Garlic	5.24
Green pepper	0.94
Iceberg lettuce	0.62
Leek	2.02
Lettuce	0.73
Miniature lettuce	0.70
Mushrooms	1.27
Onion	1.00
Parnsnip	2.86
Potato	3.74
Radish	0.74
Red cabbage	1.06
Red pepper	1.52
Saffron milk cap/Red pine mushroom	0.94
Shallot	3.49
Sorrel	1.28
Spinach	1.09
Squash/pumpkin	1.04
Sweet potato	4.24
Tomato	0.88
Turnip	1.26
Turnip greens/Turnip tops	0.74
Watercress	1.21
Welsh onion	1.22
Zucchini	0.60
Fruits	
Acerola	1.08
Apple	2.17
Apple guava	1.48
Apricot	2.92
Avocado	5.36
Bananas, platains	3.99

CROPS	Gross Energy (MJ/kg)
Black grapes	2.79
Blackberry	1.15
Blackcurrant	1.41
Blueberry	1.41
Cantaloupe	1.52
Cherimoya	3.85
Cherry	4.43
Cherry var. picota	2.70
Coconut, fresh	13.60
Coconut, milk	10.39
Coconut, water	0.68
Figs	3.07
Grapefruit	1.46
Kiwifruit	2.28
Lemon	1.88
Lime	0.65
Litchee	3.22
Loquat	2.74
Mandarin	1.81
Mango	2.80
Melon	1.23
Nectarine	1.93
Orange	1.74
Papaya	1.75
Passion fruit	2.36
Peach	3.42
Pear	1.95
Persimmon	3.03
Pineapple	2.18
Plum	2.07
Pomegranate	1.49
Prickly pear	2.91
Quince	1.69
Raspberry	1.22
Redcurrant	1.15
Strawberry	1.56
Table olives, with stone	7.98
Table olives, without stone	8.15
Tamarind	12.15
Tamarind, pulp	11.50
Watermelon	0.90
White grapes	2.90
Nuts and seeds	
Acorn, with shell	18.33
Acorn, without shell	18.56
Almonds, with shell	19.67
Almonds, without shell	26.06
Carobs	17.21
Cashew, without shell	25.92

CROPS	Gross Energy (MJ/kg)
Chestnut	9.66
Cotton seed	22.23
Hazelnuts, without shell	25.36
Hemp seed	25.96
Macadamia nut	32.20
Peanuts, without shell	26.77
Pine nuts	30.65
Pistachio	21.25
Rapeseed	27.33
Sesame	26.96
Sunflower seeds, with shell	23.38
Sunflower seeds, without shell	26.38
Tigernuts	17.87
Walnut, with shell	21.13
Walnut, without shell	26.79
Spices	
Basil, dry	8.35
Basil, fresh	0.89
Bay laurel	13.29
Black pepper	3.82
Caper	1.74
Chili pepper	6.43
Chili pepper, dry, milled	14.90
Cinnamon, milled	2.15
Cloves	18.98
Coriander	4.75
Cumin	18.91
Dill	13.47
Fennel	5.22
Ginger, dry, milled	15.29
Ginger, fresh	3.02
Jalapeño chili pepper	3.02
Mint and peppermint	2.05
Oregano, dry	14.96
Oregano, fresh	2.94
Parsley	1.66
Red pepper, dry, milled	14.41
Rosemary	14.97
Saffron	15.38
Thyme	14.69
Vanilla, extract	2.21
White pepper	3.21
Green fodder	
Alfalfa	4.92
Artichoke thistle, for fodder	1.00
Artificial swards	3.51
Bard vetch/Oneflower vetch, green	4.38
Barley, green	4.36
Beet pulp	4.38

CROPS	Gross Energy (MJ/kg)
Bitter vetch, green	5.89
Carrot, for fodder	1.53
Common sainfoin	3.55
Crimson clover, in bloom	3.78
Faba bean/Broad bean, green, for fodder	2.95
Fenugreek, green	5.41
Fodder	3.41
Fodder beet	3.23
Fodder cabbage	1.45
French honeysuckle	2.69
Jerusalem artichoke	4.12
Maize, green	3.80
Mixed swards	3.51
Oat, green	5.32
Other clovers (white, hybrid, subterranean, etc.)	3.78
Other fodders (lupin, thistle, parnsnip, medick, etc.)	3.41
Other legumes for green fodder	3.16
Other monospecific swards	3.51
Other roots and tubers for fodder	3.51
Other true grasses for fodder	3.41
Parnsnip, for fodder	2.97
Pea, green, for fodder	3.20
Perennial ryegrass	4.20
Rye, green	3.41
Ryegrasss	3.99
Sorghum, green	3.55
Squash, for fodder	1.90
Subterranean clover	2.78
Sugar beet, necks	3.57
Tree medick	4.92
Turnip, for fodder	2.21
Vetch, green	3.39
Wheat, green	6.61
Fiber	
Cotton, fiber	15.82
Flax	16.33
Hemp, fiber	16.01
Straw	
Barley	15.18
Beans, white	15.31
Bitter vetch	16.06
Brown rice	15.99
Chickpea	15.69
Faba bean/Broad bean, dry	15.57
Grass pea, Chickling vetch	16.08
Hard vetch	15.57
Legumes, other	15.81
Lentils	16.31
Maize	15.48

CROPS	Gross Energy (MJ/kg)
Millet	15.82
Oat	15.94
Pea, dry	15.94
Rye	16.24
Sorghum	15.29
Soybeans	15.56
Spring cereals, other	15.48
Triticale	16.20
Vetch	16.01
Wheat	15.23
Winter cereals, other	15.65
Crops residues	
Artichoke	3.51
Artichoke thistle	3.06
Asparagus	5.27
Beans, green	5.27
Beet	2.13
Belgian endive	3.06
Borage	3.06
Broccoli	3.10
Cabbage	3.10
Carrot	3.60
Cassava	5.27
Cauliflower	3.69
Celery	1.74
Chard	3.25
Chicory	3.06
Chili pepper	5.27
Cucumber	3.13
Cultivar for pickled cucumber, gherkins	3.51
Eggplant/Aubergine	3.51
Endive	3.06
Faba bean/Broad bean, green, without pod	4.18
Garlic	5.27
Green pepper	5.27
Leek	3.60
Lettuce	3.06
Melon	3.51
Onion	3.49
Pea, green, with pod	5.27
Potato	3.51
Radish	3.29
Spinach	3.25
Squash/pumpkin	5.27
Strawberry	5.27
Tomato	2.33
Turnip	3.51
Watermelon	3.51
Zucchini	3.13

CROPS	Gross Energy (MJ/kg)
ANIMAL PRODUCTS	
Milk products	
Cow milk	3.01
Donkey milk	1.89
Goat milk	3.07
Sheep milk	4.43
Eggs	
Chicken eggs	2.25
Duck eggs	3.15
Quail eggs	2.41
Honey	
Honey	13.38
Meat	
Beef chop	9.29
Beef kidney	4.69
Beef liver	6.86
Beef meat	11.43
Beef tongue	8.71
Chicken	5.87
Chicken breast	6.11
Duck	9.36
Goat meat	4.20
Hen	5.87
Horse meat	5.22
Lamb chop	5.39
Lamb, brain	5.49
Lamb, leg and chuck	8.22
Lamb, other cuts	9.97
Lamb, sweetbreads	6.56
Lean beef meat	6.87
Lean pork meat	7.84
Pork bacon	18.52
Pork blood	4.53
Pork chop	10.83
Pork chuck	16.33
Pork fat	29.62
Pork lard	38.81
Pork liver	5.84
Pork loin (3% fat)	5.63
Pork loin (9% fat)	7.59
Pork meat	12.79
Pork sirloin	6.82
Quay	4.14
Rabbit and Hare	4.60
Red-legged partridge	4.14
Steer sirloin	4.39
Turkey breast, skinless	5.58
Turkey drumstick	5.63
Turkey, boneless, skinless	5.90

CROPS	Gross Energy (MJ/kg)
Turkey, skinless	3.40
Wild boar meat	5.81
TRANSFORMED PRODUCTS	
Sugars	
Brown sugar	16.41
White sugar	16.92
Oils	
Coconut oil	38.96
Maize germ oil	38.96
Olive oil	38.96
Palm oil	38.96
Peanut oil	38.96
Soybean oil	38.96
Sunflowerseed oil	38.96
Products from grape	
Fine wine	0.53
Grape juice	2.83
Sweet fortified wine	2.26
Vinegar	0.19
Wine	0.21
Dried fruits	
Apricot, dry	8.74
Date, dry, stoneless	12.73
Date, dry, with stone	11.97
Fig, dry	10.60
Plum, dry, stoneless	7.33
Plum, dry, with stone	7.32
Raisins	11.66
AGRO-INDUSTRY BYPRODUCTS	
Alfalfa meal and pellets	16.87
Blood meal	19.15
Cereal brans	19.40
Copra cake	19.35
Cotton seed cake	18.40
Legume brans	17.80
Lin seed cake	20.06
Maize gluten meal	19.24
Maize meal	16.95
Palmkernel cake	19.20
Peanut cake	19.81
Rapeseed cake	19.71
Soybean cake	19.54
Sugar beet molasses	16.14
Sunflowerseed cake	17.70
Whey	16.34
WOOD AND PRUNING	
Almonds, pruning	12.81
Apple, pruning	12.65

CROPS	Gross Energy (MJ/kg)
Apricot, pruning	13.70
Bark (broad-leaved tree)	14.66
Bark (conifers)	15.10
Broad-leaved tree, wood	14.52
Cherry, pruning	12.49
Conifers, wood	15.23
European beech/Commom beech, wood	13.80
Grapevine, branches	12.61
Lemon, pruning	11.00
Mandarin, pruning	11.00
Olive tree, pruning	13.16
Orange, pruning	11.59
Peach, pruning	13.32
Pear, pruning	12.82
Poplar, wood	13.88
Spruce, wood	14.10
Willow, Sallow, wood	13.80