Energy balance of five fodder cropping systems in the irrigated lowlands of Northern Italy

Cesare Tomasoni,1 Lamberto Borrelli,1 Massimo Brambilla2

1CRA-FLC Centro di Ricerca per le Produzioni Foraggere e Lattiero Casearie, Lodi; 2Dipartimento VSA, Facoltà di Medicina Veterinaria, Università Statale di Milano, Italy

Abstract

Extensification has recently become an important option in Western European agriculture, driven both by economic considerations (product surpluses together with the fact that developed countries cropping systems have been heavily relying on fossil energy) and growing public concern on the possible adverse effects of intensive farming on the environment and human health. The adoption of rational fodder crop rotations, with the rediscovery of the beneficial effect of the meadow, is viewed as a possible mean to reduce the impact of farming systems in the lowlands of northern Italy, characterised by highly intensive cropping and animal husbandry. For this reason our study examines the effects of crop rotation on the energy balance during 1985-2007 period in a long-term crop rotation trial in Northern Italy comparing five fodder crop systems, different in the degree of crop intensification and for the presence or absence of the meadow: a 1-year continuous cereal double cropping (R1); a 3-year rotation (R3); a 6-year rotation (R6); a permanent meadow (PM); and a continuous grain maize cropping (CM). Each rotation was subjected to two input treatments, defined as high (mostly used in lowlands of northern Italy) and low (input reduction of ca. 30%) respectively, in terms of nutrient levels, herbicide doses, and soil tillage methods. The crop rotations exerted a marked influence on the energy balance. The most efficient rotations in terms of net energy production energy efficiency have been characterized by reduced length and presence of maize and catch-crops.

Introduction

The outstanding technological progress occurred in the second half of the last century in various fields (e.g. chemistry, mechanics, genetics, etc.) and the actions taken by the E.U. Common Agricultural Policy, were the causes of the agriculture extreme intensification which occurred in the regions with favourable pedo-climatic conditions. A dramatic increase was subsequently induced in the yields of all the crops as well as the simplification, and the consequent specialisation, of farming systems (Parente, 1996). In particular, during the last decades Western European countries experienced some crucial changes to reduce the impact of cropping on soil pollution. On one hand, the surpluses of many agricultural products causing stagnation of prices, and, on the other, the growing concern of public opinion about the possible side effects of intensive farming on environment and human health, because of the massive recourse to potentially pollutant factors, led the Common Agricultural Policy to pursue the goal of agricultural extensification (Smith and Olesen, 2010; Postma-Blaauw et al., 2010; Cruse et al., 2010).

Therefore, sustainable farming systems based on cropping and/or animal husbandry requiring lower amounts of non-renewable inputs have been increasingly encouraged and, accordingly, financially supported (Parente, 1996; Castoldi and Bechini, 2010).

In the last 40 years, the lowland area of the Po Valley in northern Italy experienced a process of outstanding cropping intensification and simplification together with the related livestock systems so that, nowadays, they are almost exclusively based on continuous cereal cropping (autumn-sown Italian ryegrass, Lolium multiflorum Lam., followed by spring-sown maize, Zea mais L., both used for silage), and on the rearing, under confinement, of Holstein dairy cows with high genetic and productive standards. This process caused a drastic reduction of permanent and rotational meadows, which despite representing the main forage resource before the 1960, have decreased of about 50% in land area since then (Giardini and Ziliotto, 1988). The overwhelming capital input and the large availability of production factors not belonging to the farm allowed carrying out such an extensive agriculture whose products were transformed into milk both for human consumption and dairy industry.

Energy analysis as indicator of farming system sustainability was developed during the 70’s as consequence of the oil crisis (Bonari et al., 1982; Giardini et al., 1983; Pimentel, 1983). Energy analyses of non-renewable source use is preferable when the reduction of the used energy has pursued in the agricultural systems. Up to now many authors focused their work on energy balance of both conventional and low energy input cropping systems considering both food and biomass crops (Sharma et al., 2011; Arvidsson, 2010; Deike et al., 2008; Gelfand et al., 2010; Boehmnel et al., 2008; Rathke et al., 2007; Rathke and Diepenbrock, 2006; Monti and Venturi, 2003; Hülsbergen et al., 2001) and with reference to external energy inputs (Cruse et al., 2010; Wiens et al., 2001).
et al., 2008); nevertheless, an in depth study considering the presence of meadow in the cropping system is still missing.

In this paper we compare the productivity and energy balance of five forage crop systems which represent different models of forage production in Lombardy plain where low input farming systems are expected to be preferred to the current widespread high input farming systems using large amounts of agrochemicals and machinery: the present paper reports the results gathered in 22 years after the trial’s establishment.

### Materials and Methods

The experiment was carried out in Lodi, Italy (45°19’ N, 9°30’ E, 81 m asl), which is a location representative of the alluvial Po Valley. The used soil was a sandy-loam one of the mollic Hapludalf family, with sub acid pH (6.2), low in nitrogen, organic matter, and exchangeable potassium, and with good provision of assimilable phosphorus. The climate is typical of the lowlands of northwestern Italy: the average annual rainfall is about 800 mm (well distributed along the year) and the average annual temperature is 12.5°C with a minimum of 1.1°C in January and a maximum of 22.9°C in July.

Five cropping systems have been included in this investigation since 1984: i) one annually-repeated double crop (coded as R1) of autumn-sown Italian ryegrass + spring-sown maize both for silage; ii) a three-year rotation (coded as R3) made of autumn-sown barley (*Hordeum vulgare* L.) + spring-sown maize both for silage purpose; Italian ryegrass + maize (both for silage)/grain maize; iii) a six-year rotation (R6): 3 years of Italian ryegrass + maize (both for silage) / 3 years of meadow (Ladino white clover, *Trifolium repens* L., + tall fescue, *Festuca arundinacea* Schreb.) for hay making; iv) a continuous grain maize cropping (CM); and v) a permanent meadow (PM) (Table 1). Each rotation underwent two kind of treatments corresponding to an high input level (H, mostly used in northern Italy lowlands) and low input level (L). The difference among these was “L” one was made of about 70% of the organic, chemical fertilisation and herbicide amounts given with the H one (Onofri et al., 1993, 1996).

A further difference between H and L treatments concerned soil tillage before autumn-sown crops. In the H treatment, soil was ploughed to a depth of 30 cm and then rotary-cultivated, while in the L one it was rotation-cultivated to a depth of 15 cm only. In both treatments all maize crops, either for silage or grain production, were ploughed before sowing, and rotary-cultivated along the rows after plant emergence also to enhance the covering of the nitrogen fertiliser applied at post-emergence stage (half of total required amount).

Every year, in both the treatments, four border irrigations of about 1000 m³ ha⁻¹ each were provided to the whole trial; for the sowing period and all the other cultural practices we referred to those typical for each considered crop in the region. The experimental design on annual basis was a strip-plot with three replications in as many blocks; the main plots being represented by the input level and the sub-plots by the compared rotations. All the phases (crops) contemplated by the rotations, as indicated in Table 1, were present at the same time in each year, in each combination of block and input level, to avoid possible confounding effects of the factor year when comparing rotations made up of different phases in different years. In the experimental layout, two crops present in the same year in one rotation (e.g. Italian ryegrass and maize) were considered as just one crop. Altogether the trial included 72 plots (12 crop-phases × 3 blocks × 2 input levels), each measuring 60 m² (6×10 m).

The different cropping systems have been compared according to the energy balance sheet, using the gross energy method to determine the energy inputs of the cropping systems. This method takes into account only fossil energy sources without considering both renewable sources and human labour (Cecon et al., 2002). It calculates the fossil energy directly used in crop production (e.g. oil, lubricants) as well as the energy embedded in agricultural requisites (e.g. machinery, seeds, agrochemicals, etc.). To this purpose, basic data on agricultural requisite use were regularly recorded from 1985 to 2006 taking into account the type of used machinery and its working times, the mass of applied fertilisers and agrochemicals, the seed rates and the irrigation depths. Table 2 summarises the energy conversion rates for agricultural requisites (Pimentel, 1980; Pellizzzi, 1992, Jarach, 1985). Energy for machine depreciation was estimated combining mass conversion rate, reliable life, and finding machinery val-

### Table 1. List and sequence of the twelve crops in the five crop rotations under comparison.

| Crop Sequence | Rotation |
|---------------|----------|
| R1            | 1         |
| R2            | 2         |
| R3            | 3         |
| R4            | 4         |
| R5            | 5         |
| R6            | 6         |

### Table 2. Energy (MJ=mega Joule) conversion rates for agricultural requisites/commodities.

| Category | Agricultural practice/requisite | Size unit | Value | Reference |
|----------|---------------------------------|-----------|-------|-----------|
| Machine  | Agricultural practices          | MJ×Hp×h⁻¹ | 7.68  | Pimentel 1980 |
| Contents | Tractors and combines           | MJ kg⁻¹  | 92.00 | Pimentel 1980 |
|          | Other equipment                 | MJ kg⁻¹  | 69.00 | Pimentel 1980 |
| Fertiliser| Nitrogen                        | MJ kg⁻¹  | 62.00 | Pimentel 1980 |
|          | Phosphorous                     | MJ kg⁻¹  | 13.65 | Pimentel 1980 |
|          | Potassium                       | MJ kg⁻¹  | 7.68  | Pimentel 1980 |
| Seeds    |                                | MJ kg⁻¹  | 15.00 | Pimentel 1980 |
| Agrochemicals | Herbicides                  | MJ kg⁻¹  | 189.00 | Pimentel 1980 |
|          | Geo-insecticides                | MJ kg⁻¹  | 67.00  | Pimentel 1980 |
|          | Plastic material                | MJ kg⁻¹  | 100.80 | Pimentel 1980 |
| MFU      |                                | MJ      | 7.24  | Chase 1981 |

M, mass of the machine; CR, conversion rate; V, unit value (dimensionless) at the end of the reliable life; RL, reliable life; WT, working time; MFU, milk feed unit.
ues and working times. Fuel consumption of machinery was set at 180 gr Hp⁻¹ h⁻¹. The output energy content of the produced forage has been estimated with NIRS method (Chase, 1981) as net energy for milk cow production (Milk Feed Units=MFU=7.24 MJ).

The results were subjected to analysis of variance (ANOVA) performed with the SAS software.

**Results and Discussion**

Table 3 reports the milk feed units yield in the different crop systems at two different intensification levels over the twenty-two year period of the trial: on average, short rotation and level low of intensification (L) showed large yield oscillations among the years, as indicated CV values higher than 20%. This suggests that in the R6 treatment it occurs the establishment of satisfactory agricultural practices for these crop systems. Differences among mean values of milk feed units from each cropping systems systems are very high, ranging from 22,477 and 20,281 MFU ha⁻¹ yr⁻¹ (for R1, at H and L input levels) to 8587 and 7210 (for PM). At both input levels each rotation productivity is significantly different from the others according to the following rank: R1>R3>R6>CM>PM.

Table 4 depicts the overall energy use for crop growth (MJ ha⁻¹ year⁻¹) in the 22-years trial under different crop systems by grouping homogeneous agricultural practices into four categories (machinery, irrigation, seed and agrochemicals included fertilisers) while cumulated values and share of the total energy use for single rotation are reported in Table 5. It comes out that great part of machinery energy (more than 50%) was spent for harvesting in the meadow (mowing, as well as hay raking, conditioning, baling and transporting) while in other crop systems the highest energy requirements were those for maize tillage and fertilisation. The maximum energy requirement (machinery, irrigation, seed and agrochemicals) is the one of maize grown in the R3 trial both at H and L energy level with 44,986 and 38,439 MJ ha⁻¹ year⁻¹ respectively and with an incidence percentage of machinery ranging from 49.8% to 56.1%. Italian ryegrass and silage barley are the crops requiring the lowest energy (about 26,000 MJ ha⁻¹ year⁻¹) while silage maize requires 39,789 and 33,641 MJ ha⁻¹
In all the studied rotational farming systems, energy required for fertilization and agrochemicals was on average the most relevant item whose cost of use exceeded the harvesting one in all the rotations at H input level with exception for the permanent meadow. With reference to the L input level, the most important energy input reduction is ascribable to the fertilization amount.

Table 6 summarises the main variables of the input/output balance sheet. On average, during the 22 years trial, rotations across input treatments produced different amounts of estimated energy for milk production: R1 showed the highest energy output with 162,733 MJ ha\(^{-1}\) year\(^{-1}\) and R3 to have the higher values of inputs. At high treatment level (H) there is an appreciable increase of energy required by rotations whose the mean values range from 65,520 (R1) to 36,027 MJ ha\(^{-1}\) year\(^{-1}\) (PM). On average, the amount of energy required by rotations was different for each input treatment level. The effect of rotations and input treatment on net energy is shown in Table 7. Here it can be pointed out how the net energy (energy output - energy input) was substantially different between rotations at the same level of input treatment, while comparing the two intensification levels at varying treatment, while comparing the two intensification levels at varying levels within the same rotation (Table 7) shows that R1, R3 and R6 are can therefore ranked as follows: R1>R3=R6>CM>PM.

The results of the comparison between the two input treatment levels within the same rotation (Table 7) shows that R1, R3 and R6 are more efficient when the inputs are reduced because they show an higher out/in ratio under low (L) input treatment level.

Another consideration that can be done is that, according to the discussed results and under the pedological, climatic and agricultural conditions occurring during the trial, the most efficient rotations turned out to have the following features: i) shortness; ii) including maize; iii) including catch crops (e.g. Italian ryegrass – silage maize or silage barley).

Limiting factors to crop productivity (e.g. water, light and nitrogen) year 1 for treatment H and L respectively spending great part of energy for agrochemicals.

In the compared farming systems and share of energy content (%).

### Table 5. Energy content of agricultural practices/requisites (MJ ha\(^{-1}\) year\(^{-1}\)) grouped in 4 principal categories for different crops and input treatments in the compared farming systems and share of energy content (%).

| Rotation/category | Crop/input treatments | Machinery | Irrigation | Seed | Agrochemicals | Total |
|-------------------|-----------------------|-----------|------------|------|--------------|-------|
|                   | H %                   | L         | H %        | L %  | H %         | L %  |
| R1                | Italian ryegrass      | 13,398    | 43         | 28,176 | 50          | 2823 | 3          | 2151 | 70        | 0    | 0    | 13,577 | 38 |
|                   | Silage maize          | 27,037    | 47         | 28,042 | 52          | 2823 | 4          | 2823 | 5        | 1450 | 2    | 1450   | 3   |
| R3                | Italian ryegrass      | 13,398    | 43         | 28,176 | 50          | 2823 | 3          | 2823 | 8        | 700  | 2    | 700    | 7   |
|                   | Silage barley         | 13,419    | 51         | 12,109 | 55          | 2823 | 7          | 2823 | 8        | 1,583 | 45  | 1,583  | 45  |
|                   | Silage mea. lt. ryegras| 17,207    | 43         | 16,776 | 50          | 2823 | 2          | 2823 | 8        | 19,059 | 48 | 19,059 | 48  |
|                   | Silage mea. barley     | 16,700    | 43         | 16,639 | 50          | 2420 | 6          | 2420 | 7        | 3,000 | 300 | 3,000  | 300 |
|                   | Grain maize           | 22,404    | 50         | 25,165 | 56          | 2823 | 2          | 2823 | 7        | 19,659 | 42 | 19,659 | 42  |
| R6                | Italian ryegrass      | 25,027    | 50         | 25,565 | 56          | 2532 | 5          | 2532 | 6        | 825   | 2    | 825    | 2   |
|                   | Silage mea. lt. ryegras| 17,207    | 43         | 16,776 | 50          | 2823 | 7          | 2823 | 8        | 19,059 | 48 | 19,059 | 48  |
|                   | Rotated meadow 1st yr | 25,548    | 62         | 23,014 | 68          | 2420 | 6          | 2420 | 7        | 11,278 | 30 | 11,278 | 30  |
|                   | Rotated meadow 2nd & 3rd yr | 17,000 | 53         | 17,126 | 59          | 2151 | 6          | 2151 | 7        | 13,586 | 41 | 13,586 | 41  |
| CM                | Grain maize           | 19,985    | 47         | 19,146 | 53          | 2823 | 7          | 2823 | 8        | 19,659 | 42 | 19,659 | 42  |
| PM                | Permanent meadow      | 20,239    | 56         | 19,543 | 62          | 2151 | 6          | 2151 | 7        | 1,577 | 38 | 1,577  | 38  |

### Table 6. Energy input and output (MJ ha\(^{-1}\) year\(^{-1}\)) for different rotations.

| Rotation/input treatment | Energy output L (MJ ha\(^{-1}\) year\(^{-1}\)) | Energy input L (MJ ha\(^{-1}\) year\(^{-1}\)) |
|--------------------------|---------------------------------------------|---------------------------------------------|
| R1                       | 162,733                                    | 46,894                                      |
| R3                       | 136,300                                    | 48,386                                      |
| R6                       | 114,689                                    | 50,113                                      |
| CM                       | 86,308                                     | 42,396                                      |
| PM                       | 62,170                                     | 36,027                                      |

### Table 7. Net Energy (MJ ha\(^{-1}\) year\(^{-1}\)) and energy efficiency for different rotations.

| Rotation/input treatment | Net energy\(^{\circ}\) L (MJ ha\(^{-1}\) year\(^{-1}\)) | Energy efficiency\(^{\circ}\) L |
|--------------------------|---------------------------------------------------|-------------------------------|
| R1                       | 97,213\(^{\circ}\)                                 | 1.48\(^{\circ}\)               |
| R3                       | 77,366\(^{\circ}\)                                 | 1.33\(^{\circ}\)               |
| R6                       | 64,583\(^{\circ}\)                                 | 1.29\(^{\circ}\)               |
| CM                       | 43,744\(^{\circ}\)                                 | 1.03\(^{\circ}\)               |
| PM                       | 26,143\(^{\circ}\)                                 | 0.73\(^{\circ}\)               |

\(^{\circ}\)Means followed by same letter are not different for Duncan’s test at P<0.05; a-dvalid between the rotations; a-dvalid between the levels of intensification H.
are better used if rotations are more efficient: as a matter of fact, maize, belonging to C4 species, having a more efficient light use subsequently requires and uses higher amounts of water and nutrients. On the contrary, mixed cropping systems (meaning a main crop and followed by one catch crop within the same year: R1, R3 and R6 rotations) allow a better use of water and nutrients because of their prolonged soil coverage. On the contrary permanent meadow, despite having very high soil coverage, shows a low energy efficiency that can be due to its characteristic low yield potential. In case of low input level, the increase of the efficiency shown by R1, R3 and R6 rotations suggest that, to limit consumption of not renewable resources and environmental pollution by intensive agriculture, the change of energy input reduction for these cropping systems should be seriously taken into account.

Conclusions

The data discussed in this paper can be considered representative of farming systems in the area of evaluation in as results of long-term experiments and some conclusions can be made.

- Energy analysis provides important information on fodder cropping systems properties.
- The overall productivity of the cropping systems was affected by the level of intensification and by the productivity of single crops especially maize.
- Farming systems mainly using external inputs seemed to induce higher crop yield stability than the more self-sufficient farming systems.
- Both net energy and energy efficiency evaluated on a cropping systems basis emphasise big differences among the compared types of agriculture and it seems that energy efficiency is mainly related to system outputs.
- A final consideration suggested by our results concerns the level of intensiveness commonly applied to cropping systems in the region of evaluation. The fact that a 25-30% reduction of inputs, above all agrochemicals and fertilisers, involves a decrement of production less than proportional to the reduction of inputs and in the case of the net energy a no significant decrement in R1 and R6 should drive farmers to consider the change of adopting less intensive agronomic practices, obtaining in exchange an increase of sustainability both under the economic and the environmental point of view.

References

Aridsson J., 2010. Energy use efficiency in different tillage systems for winter wheat on a clay and silt loam in Sweden. Eur. J. Agron. 33:250-256.
Boehmel C., Lewandowski I., Clauepin W., 2008. Comparing annual and perennial energy cropping systems with different management intensities. Agr. Syst. 92:224-236.
Bonari E., Mazzoncini M., Peruzzi A., Silvestri N., 1992. Valutazioni energetiche di sistemi produttivi a diverso livello di intensificazione culturale. Inform. Agr. 1:1-11.
Castoldi N., Bechini, L., 2010. Energy, Nutrient and Economic Cross Indicators of Cropping Systems in Northern Italy. Ital. J. Agron. 5:19-26.
Ceccon P., Coiutti C., Giovanardi R., 2002. Energy balance of four farming systems in north-eastern Italy. Ital. J. Agron. 6:73-84.
Chase L.E., 1981. Energy prediction equations in USA at NY Hydiah Forage Laboratory. Production Agricultural Training School, Ithaca, NY, USA.
Cruse M.J., Liebmann M., Raman D.R., Wiedenhoeft M.H., 2010. Fossil Energy Use in Conventional and Low-External-Input Cropping Systems. Agron. J. 102: 934-941.
Deike S., Pallutt B., Melander B., Strassenmeyer J., Christen O., 2008) Long-term productivity and environmental effects of arable farming as affected by crop rotation, soil tillage intensity and strategy of pesticide use: A case-study of two long-term field experiments in Germany and Denmark. Eur. J. Agron. 29:191-199.
Gelfand I., Snapp S.S., Robertson G.P., 2010. Energy Efficiency of Conventional, Organic, and Alternative Cropping Systems for Food and Fuel at a Site in the U.S. Midwest. Environ. Sci. Technol. 44:4006-4011.
Giardini L., Giovanardi R., Mosca G., 1983. Studio del bilancio energetico in quattro rotazioni colturali eseguite per un decennio con diversi livelli di concimazione e di irrigazione. Nota I: energia della sostanza secca prodotta e del prodotto agrario utile. Riv. Agron. 17:261-278.
Giardini L., Ziliotto U., 1988. Foraggicoltura e ambiente nella pianura padana. In: Il Futuro della Foraggicoltura Prativa nella Pianura Padana, ISCF, Lodi, Italy, pp 245-262.
Hülsbergen K.J., Feil B., Biermann S., Rathke G.W., Kalk W.D., Diepenbrock W., 2001. A method of energy balancing in crop production and its application in long-term fertilizer trials. Agr. Ecosystems and Environ. 86:303-321.
Jarach M., 1985. Sui valori d’equivalenza per l’analisi energetica in agricoltura. Riv. Ing. Agr. 2:102-114.
Monti A., Venturi G., 2003. Comparison of the energy performance of fibre sorghum, sweet sorghum and wheat monocultures in northern Italy. Eur. J. Agron. 19:35-43.
Onofrii M., Tomasoni C., Borrelli L., 1993. Confronto tra ordinamenti ceralicolo-foraggeri, sottoposti a due livelli di input agrotecnico, nella pianura irrigua lombarda. I. Produzioni quanti-qualitative. Riv. Agron. 27:60-172.
Onofrii M., Tomasoni C., Borrelli L., 1996. Effects of cereal and forage cropping systems on soil fertility. pp 807-810 in Proc. 16th Meet. EFG. ERSA, GORIZIA, Italy.
Parente G., 1996. Grassland and land use systems. pp 23-34 in Proc. 16th Meet. EFG. ERSA, GORIZIA, Italy.
Pellizzi G., 1992. Use of Energy and Labour in Italian Agriculture. J. Agr. Eng. Res. 52:111-119.
Pimentel D., 1980. Handbook of energy utilization in agriculture. CRC Press, Boca Raton, FL, USA.
Pimentel D., 1993. Economics and energetics of organic and conventional farming. J. Agr. Environ. Ecol. 6:53-59.
Postma-Blaauw M.B., de Goede R.G.M., Bloem J., Faber J.H., Brussaard L., 2010. Soil biota community structure and abundance under agricultural intensification and extensification. Ecology 91:460-473.
Rathke G.W., Diepenbrock W., 2006. Energy balance of winter oilseed rapeseed (Brassica napus L.) cropping as related to nitrogen supply and preceding crop. Eur. J. Agron. 24:35-44.
Rathke G.W., Wienhold B.J., Wilhelm W.W., Diepenbrock W., 2007. Tillage and rotation effect on corn-soybean energy balances in eastern Nebraska. Soil Till. Res. 97:60-70.
Sharma P., Abrol V., Sharma R.K., 2011. Impact of tillage and mulch management on economics, energy requirement and crop performance in maize–wheat rotation in rainfed subhumid inceptisols, India. Eur. J. Agron. 34:46-51.
Smith P., Olesen J.E., 2010. Synergies between the mitigation of, and adaptation to, climate change in agriculture. J. Agr. Sci. 148:543-552.
Wiens M.J., Entz M.H., Wilson C., Ominski K.H., 2008. Energy requirements for transport and surface application of liquid pig manure in Manitoba, Canada. Agr. Syst. 98:74-81.