The environmental impact of maize cultivation in the European Union: practical options for the improvement of the environmental impact

Italian case study

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Geographic location of the case study area

The Po River is the longest in Italy, with its 652 km in length. The whole watershed covers about 70,000 km² comprised in 7 Italian regions (further subdivided into 27 provinces and 3200 communes). Part of the Canton Ticino, in Switzerland is also included. The population of this area is around 15 millions (one fourth of the total of Italy) including large towns like Torino, Milano and Bologna.

The present works focuses on the Po Plain, which represents the vastest plain of Italy and consists in the flat area situated along the course of the Po River and within its watershed. A more precise definition, taken from previous works on the same (Giardini et al., 1994), identifies this area with the communes of the Po watershed having at least a part of their territory laying below an altitude above the sea level of 300 m.

Having adopted this criterion for the identification of the Po Plain, the surface of the study area is 3,770,000 ha in total and is bordered by the Alps to the north and west, by the Garda Lake and the watershed of the Adige River to the north-east, by the Adriatic Sea to the east, and by the Apennines and the watershed of the Reno River to the south. The study area, subdivided into 22 provinces encompasses four regions (see figure 1).

Owing to the most recent census data by the Italian Institute of Statistics (Istat, 1992) 2,270,000 ha are classified as Utilisable Agricultural Land (UAL). 

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Owing to the most recent census data by the Italian Institute of Statistics (Istat, 1992) 2,270,000 ha are classified as Utilisable Agricultural Land (UAL).
About 37% of the whole UAL is in Lombardia 31.5% in Piemonte, 30% in Emilia Romagna and only 1.5% is in Veneto.

For the purposes of the present study another intermediate administrative level is of interest: the Agrarian Regions (AR) by Istat, made up with aggregations of communes, within the provinces, characterised by relative homogeneity in terms of cultivation environment (see figure 2). In total 156 RA’s are interested by the previously defined Po Plain.

**Physical and agronomic characteristics of the area**

The soils
As previously stated the study area coincides mostly with the plain of the Po River, the soils of the area are therefore characterised by the alluvial origin and their main characteristics

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Figure 1: The Po Plain in northern Italy and the four interested regions.

Figure 2: Agrarian regions belonging to the Po Plain (white border) and the Provinces (black borders).
depend upon the rocks from which the deposits originated (see Giardini et al., 1994 for details). The main distinction that should be made at this regard is between the deposits originated from the Alps and those coming from the Apennines. The Alps mainly feature rocks of igneous or crystalline origin; in the Apennines most common rocks are of sedimentary origin: marl, sandstone, limestone and claystone. Those features determine the presence of gravely soils in the upper plain closer to the Alps (northern Po Plain), while the soils located closer to the Apennines mainly encompass sandy and clayey textures.

From the geomorphologic viewpoint the study area can be subdivided into two main areas: the upper plain and the lower plain. The first is located along the borders, close to the mountains and has fluvial-glacial origin. The soils are characterised by coarser textures and strong alteration phenomena due to the longer geologic age. The second area presents instead finer textures and in particular loamy and clayey soils.

In the upper alpine plain, springs originating from the aquifers of coarse soils and geologic layers are frequent along the transition belt between coarse and fine textured deposits with lower permeability.

In the lower plain the soil texture depends upon the velocity of water fluxes which originated the sediments: sandy soils are located along the path of present or ancient water courses, while finer deposits (silt and clay) are located far from the main courses and were originated by slower water fluxes. Where the elevation of the plain is relatively low ponds and wetlands originated peaty soils, now usually reclaimed for agricultural and sanitary purposes.

Owing to the previous brief presentation of the soils of the Po Plain, four main pedologic areas can be identified for the purposes of the present paper:

1 – coarse textured soils, including sandy, sandy-loamy soils and those with a gravel content greater than 10 % in weight. Main characteristics are the high infiltration capacity and permeability and the low water retention volume. Quite often those soils are very shallow (even less than 50 cm) and lay over deep layers of gravel (tens to hundreds of meters in depth) rich of groundwater resources.

For the above, these areas are very vulnerable for fast and strong phenomena of deep leaching of drainage water, causing the transport of significant amounts of pollutants of agricultural origin to deeper layers and impacting highly valued water resources.
2 – loamy soils (silty-clay-loam, loam, silty-loam), with negligible gravel content and optimal or sub-optimal depth (> 100 cm). Water retention capacity is usually good and water excesses due to shallow groundwater are infrequent. These characteristics determine optimal condition for the agricultural exploitation and for the cultivation of a widest range of crops. The vulnerability to groundwater pollution is medium to low.

3 – clayey soils (silty-clay, loamy-clay and clay), usually referred to as “heavy soils of the plain”. These soils are deep with no gravel and no gleyfication symptoms. The fine texture determines problems in the cultivation, in particular for what concerns irrigation and tillage operations which should be timely organised depending upon the hydrologic conditions of the plough layer, to avoid negative structure deterioration. Quite common in the southern plain are montmorillonitic clay soils (vertisols), which expand and shrink depending on water content, causing the typical formation of deep cracks. Those cracks determine a remarkable complexity of the water regime, featuring slow water movements in the clayey soil matrix and fastest fluxes along the cracks.

4 – gley soils with various textures, having in common the presence of water excesses (and oxygen deficits) along the profile. Those soils are frequent in the areas of lower elevation and in the most recent reclamation districts. Typical are the presence of peat, a bad soil structure and a low permeability, which make their agricultural potential to be quite low. The shallow water table makes those soils also suitable to pollution phenomena of surface and ground water resources.

The most important soil category is the second (loamy soils), which spreads over 45 % of the cultivated area of the Po Plain, the coarse textured soils reach 18 %, mainly in the northern part, while the gley soils (9 %) are typical of the south-eastern part, close to the Adriatic Sea. The clay soils cover only 2 % of the cultivated area and the rest of the territory is characterised by intermediate characteristics, which can be assimilated to the second category (loamy soils), which reaches therefore almost 70 % of the Po Plain.

The water resources

Rainfall represents the main natural source of water for the crops of the Po Plain. The spatial distribution of precipitation in the area is quite variable, depending upon the geomorphology, the proximity to the relieves and the geographical location. The long term average for the area is 850 mm per year. In general the highest rainfall are observed in the areas closer to the Alps.
(northern plain), with average annul rainfall above 1000 mm. On the contrary, the lowest precipitations are observed in the central part of the plain and in the delta of the Po River to the east (average annual values of 6-700 mm) (see CER-MAF, 1990 for details).

Similar patterns, but more exacerbated, can be described for the precipitation during the cultivation cycle of the maize crop and in particular during summer when the flowering and seed development take place. Focusing on the time period of interest for maize cultivation (from April to September), average precipitations range between more than 600 to less than 300 mm. Therefore in the Po Plain there is a wide range of climatic conditions and soils, determining irrigation needs for the maize crop ranging from once every several year, to the extreme of several application every year (see below).

Previous studies on the area have estimated the amount of potential evapotranspiration of the Po Plain (CER-MAF, 1990) with annual values ranging between 666 mm in the north-western part and 764 mm in the central area. On the average 85 % of the ETp is concentrated during the semester of maize cultivation, with a peak in July.

By comparing the annual amounts of potential inputs and outputs an average water surplus of 135 mm can be calculated on an annual basis, while an average deficit of 180 mm is observed the April-September semester. The highest deficit values (250-300 mm) during maize cultivation are located along all the southern part of the Po Plain, due to the combination of the geographic distribution of precipitations and evapotranspiration.

**Figure 3: Maize cultivated surface per province in the whole country (ha).**

![Map showing maize cultivation distribution](attachment:image)

**Trends of maize cultivation in Italy and in the Po Plain**

The cultivation of maize has a primary role for Italy and the Po Plain in particular. Figure 3 depicts the distribution of maize in the whole country; form it one
can clearly realise that northern regions and, in particular, the four regions belonging to the Po Plain represent the Italian maize belt. In fact more than 780,000 ha in 1996 were cultivated with maize in those four regions with respect to a national total of about one million hectares (Istat, 1999).

The total production of 1998 in Italy reached 9.1 millions of tons (Ismea, 1999), remarkably lower than that of the previous two years (9.6 and 10.2 millions of tons respectively), because of both a reduction of the cultivated surface (-6.4%) and a meteorological pattern during the 1998 growing season which caused severe water deficits in many areas during the most critical period of the crop and determining a general reduction of yield by 5.1%.

The following table summarises the recent trends of Italian maize-culture.

<table>
<thead>
<tr>
<th>Year</th>
<th>Cult. Area (ha)</th>
<th>Var. %</th>
<th>Avg. Yield (t/ha)</th>
<th>Var. %</th>
<th>Total Prod. (t)</th>
<th>Var. %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1985</td>
<td>911,163</td>
<td>-</td>
<td>6.94</td>
<td>-</td>
<td>6,322,000</td>
<td>-</td>
</tr>
<tr>
<td>1986</td>
<td>848,600</td>
<td>-6.9</td>
<td>7.61</td>
<td>9.7</td>
<td>6,461,200</td>
<td>2.2</td>
</tr>
<tr>
<td>1987</td>
<td>768,378</td>
<td>-9.5</td>
<td>7.56</td>
<td>-0.7</td>
<td>5,807,600</td>
<td>-10.1</td>
</tr>
<tr>
<td>1988</td>
<td>842,484</td>
<td>9.6</td>
<td>7.53</td>
<td>-0.3</td>
<td>6,347,700</td>
<td>9.3</td>
</tr>
<tr>
<td>1989</td>
<td>804,200</td>
<td>-4.5</td>
<td>7.99</td>
<td>6.0</td>
<td>6,424,300</td>
<td>1.2</td>
</tr>
<tr>
<td>1990</td>
<td>767,780</td>
<td>-4.5</td>
<td>7.71</td>
<td>-3.5</td>
<td>5,918,100</td>
<td>-7.9</td>
</tr>
<tr>
<td>1991</td>
<td>858,906</td>
<td>11.9</td>
<td>7.34</td>
<td>-4.7</td>
<td>6,308,320</td>
<td>6.6</td>
</tr>
<tr>
<td>1992</td>
<td>853,857</td>
<td>-0.6</td>
<td>8.80</td>
<td>19.8</td>
<td>7,514,038</td>
<td>19.1</td>
</tr>
<tr>
<td>1993</td>
<td>926,677</td>
<td>8.5</td>
<td>8.71</td>
<td>-1.1</td>
<td>8,069,468</td>
<td>7.4</td>
</tr>
<tr>
<td>1994</td>
<td>909,865</td>
<td>-1.8</td>
<td>8.32</td>
<td>-4.4</td>
<td>7,573,426</td>
<td>-6.1</td>
</tr>
<tr>
<td>1995</td>
<td>942,475</td>
<td>3.6</td>
<td>9.01</td>
<td>8.2</td>
<td>8,491,097</td>
<td>12.1</td>
</tr>
<tr>
<td>1996*</td>
<td>1,022,670</td>
<td>8.5</td>
<td>9.43</td>
<td>4.6</td>
<td>9,639,879</td>
<td>13.5</td>
</tr>
<tr>
<td>1997*</td>
<td>1,034,909</td>
<td>1.2</td>
<td>9.90</td>
<td>5.0</td>
<td>10,243,397</td>
<td>6.3</td>
</tr>
<tr>
<td>1998*</td>
<td>968,799</td>
<td>-6.4</td>
<td>9.40</td>
<td>-5.1</td>
<td>9,103,186</td>
<td>-11.1</td>
</tr>
</tbody>
</table>

Source: Istat, 1999 (*Provisional data).

A similar trend was observed in the whole European Union, where the total production decreased from 39.2 million tons in 1997, to 34.5 in 1998. This caused a relative recovery of
the price during the 1998-99 market campaign, which, in Italy, increased by 14 % with respect to the previous year.

The following table describe the trends of maize price (ITL/q) during the last two market campaigns.

<table>
<thead>
<tr>
<th>Month</th>
<th>1997-98</th>
<th>1998-99</th>
<th>Var.%</th>
</tr>
</thead>
<tbody>
<tr>
<td>July</td>
<td>24.657</td>
<td>25.669</td>
<td>4,1</td>
</tr>
<tr>
<td>August</td>
<td>24.933</td>
<td>25.832</td>
<td>3,6</td>
</tr>
<tr>
<td>September</td>
<td>23.858</td>
<td>24.565</td>
<td>3,0</td>
</tr>
<tr>
<td>October</td>
<td>23.001</td>
<td>26.422</td>
<td>14,9</td>
</tr>
<tr>
<td>November</td>
<td>23.962</td>
<td>27.835</td>
<td>16,2</td>
</tr>
<tr>
<td>December</td>
<td>24.156</td>
<td>27.983</td>
<td>15,8</td>
</tr>
<tr>
<td>January</td>
<td>24.466</td>
<td>28.891</td>
<td>18,1</td>
</tr>
<tr>
<td>February</td>
<td>24.483</td>
<td>28.695</td>
<td>17,2</td>
</tr>
<tr>
<td>March</td>
<td>24.247</td>
<td>28.142</td>
<td>16,1</td>
</tr>
<tr>
<td>April</td>
<td>24.753</td>
<td>28.866</td>
<td>16,6</td>
</tr>
<tr>
<td>May</td>
<td>25.433</td>
<td>30.693</td>
<td>20,7</td>
</tr>
<tr>
<td>June</td>
<td>25.655</td>
<td>31.174</td>
<td>21,5</td>
</tr>
<tr>
<td>Average</td>
<td>24.467</td>
<td>27.897</td>
<td>14,0</td>
</tr>
</tbody>
</table>

Source: Ismea, 1999 (1 Euro = 1936.27 ITL)

The most recent elaboration of the Italian Institute for the Agricultural Markets (ISMEA, May 1999), show a recovery of the total cultivation area of the crop up to the highest level of recent years: a raise of 6.5 % is expected with respect to 1998, which should bring the total cultivated area over one million hectare in 1999. The greater increases are observed in northern Italy (Veneto and Emilia Romagna in particular), compensated, as usual, by a reduction of the cultivation of oil seed crops: soybean and sunflower.

A projection of future trends of maize cultivation is indeed very difficult, also because the importance of world market prices and their fluctuations should play a stronger role in the EU in the coming years.

Moreover, the cultivation of maize in Italy and in its most important area, the Po Plain will depend heavily on the process of local implementation of the newest reform of the Common
Agricultural Policy: Agenda 2000. This process is not concluded yet, but a reduction of the intervention price by 20% is expected, with a parallel increase of the support per unit of land and other possible actions seem to reduce the economic advantage of maize with respect to other crops and in particular winter cereals (Zuppiroli and Mancini, 1999).

In any case, from the environmental viewpoint, it is absolutely insufficient to know the extent and the location of maize cultivation, for understanding the impacts of agriculture, associated with this production. As referred later, maize cultivation can play quite different roles in the environment depending on several important aspects: first of all its combination with the other crops in rotations and the local land use and, very important the specific cultivation techniques combined with the environment of cultivation. A detailed description of the present agricultural land use of the study area follows.

**Land use in the area**

The last available census data refers to the 4° Censimento Generale dell'Agricoltura of 1991 (Istat, 1991), therefore other more recent sources were used to characterise the agricultural land use of the Po Plain. Main sources were in particular a previous study on the same area by Giardini et al. (1994), the most recent statistics by the Istat (1999) and the newsletters about agricultural markets by Ismea (1999a; 1999b).

Owing to the available information the agricultural land use of the study can be described with acceptable details in terms of crop and livestock distribution.

The following crop categories can be distinguished in the Po Plain:

- winter cereals: wheat and barley
- summer cereals: maize (silage and grain) and rice
- industrial crops: sugar beet, tobacco, soybean and sunflower
- forage crops (permanent meadows and alfalfa)
- fruit crops: apple, peer, peach and others
- vineyard
- vegetables: potato, tomato and others

Forage crops are the most diffused over the area (27% of UAL), especially along the borders closer the Alps and the Apennines (even more than 90% in some areas of the provinces of Torino, Novara, Bergamo and Brescia to the north and Parma to the south).
The cultivation of maize covers (with not negligible annual fluctuations) something less than one fourth of the UAL. Typical maize cultivation areas are located in the central plain of Lombardia (provinces of Milano, Como, Cremona, Bergamo, Brescia and Mantova), the provinces of Torino and Rovigo.

The rice crop is cultivated on 9% of the UAL, in very specialised areas located mainly in the north-west, provinces of Vercelli, Novara and Pavia.

Winter cereals cover less than 20% of the UAL on the average, with maximum values in the plain of Alessandria (>50%); other typical areas are located in the central plain to the south of the Po River in the provinces of Pavia, Modena and Bologna.

Industrial crops cover about 10% of the UAL, with higher percentages in the eastern part of the Po Plain. Sugar beet and soybean are the most important: the first located in particular in the provinces of Bologna, Modena, Reggio-Emilia and Parma.

Fruit crops cover about 3% of the UAL, mainly in the eastern part of the area and in particular in the provinces of Ferrara and Verona.

Vineyards cover 5% of the UAL in highly specialised areas (provinces of Asti, Alessandria, Pavia, Verona, and others), where the cultivated surface often overpasses 50%.

Vegetable crops (3% of the UAL) are located in particular in the agrarian regions of the provinces of Ferrara (maximum 17%), Piacenza, Mantova, Cremona and Alessandria.

The distribution of livestock rearing plants is of interest for the present work, for at least two reasons:

- one of the main utilisations of maize if for livestock rearing;
- maize fields are often preferred for the application of animal wastes in the fertilisation plans.

Recent estimates of livestock productions in the area feature circa 3.2 million heads of cattle, concentrated especially in the provinces of Torino, Cuneo, Piacenza, Modena, and in general Lombardia. Milk production (1.2 million heads) is particularly important in the provinces of Brescia, Cremona, Milano and Mantova and also in Cuneo, Torino, Parma, Reggio-Emilia e Modena. Meat production (2.0 million heads) is concentrated mainly in the Provinces of Brescia, Mantova, and also in Cremona, Milano, Cuneo and Torino.

Swine farms are total around 4.7 million heads and are located in the provinces of Cuneo, Brescia, Mantova, Cremona, Bergamo, Milano, Reggio Emilia e Modena, where 80% of heads are concentrated.
In the Po Plain 40.4 million of poultry are reared mainly in the provinces of Brescia, Mantova, Bergamo, Verona and Cremona.
Ovine and horse rearing plants are marginal in the area.

**Farming systems and cropping systems of the area**

Maize is one of the most important crop of the Po Plain, strictly linked to livestock productions and the agri-food industry. Its traditional place in crop rotations is in alternation with winter wheat and other crops, with the role of renewing soil fertility by applying relevant amounts of organic and chemical fertilisers, providing deep ploughing and incorporating crop residues. In the traditional four year rotations of the Po Plain maize usually return every 2 or four years in succession with wheat (or barley), sugar beet and legumes (soybean in particular); other crops are also important but mainly in some specific areas, as previously mentioned.

The economic scenario of the last decades and the evolution of farming techniques determined an ever greater abandonment of traditional rotations and maize become quite often the only crop cultivated in large areas. New terms were proposed at this regard, like the “Maize Desert”, for instance. In recent years (especially after mid 80’s) a partial substitution of maize was seen by soybean with annual fluctuations due to the ratio between the prices of the two crops and even more by the changing policy of the European Union.

The 1992 agricultural policy reform of the European Union (CAP) places new decisional problems to the farmers, linked to the possibility of choosing between different systems of income support and joining subsidised programmes of reduced environmental impact of production techniques. Concerning this, the CAP reform poses problems of choice that require the adaptation and/or development of the models used up to now, as the decision-making process is complicated by new components which are only in part manageable with the classical linear programming used traditionally in farm management. In fact, currently, the choice of farm cropping system involves two different aspects:

- the choice among four alternative farming systems: general or simplified scheme of income support (EC Reg. 1765/92) and traditional or low environmental impact techniques (EC Reg. 2078/92);
- the choice of land use (e.g. how much maize, soybean, sugar beet, etc.).
Recent studies conducted during the national project CNR-RAISA by several Italian universities investigated in depth the agricultural systems of the north Italian plains (Polelli, 1993, Giardini and Giupponi, 1995). The relationships between the evolving CAP and market scenarios on one side and the behaviour of farmers on the other were specifically focussed with respect to combined socio-economic and environmental indicators.

Statistical analyses of census data, socio-economic and agro-physcal modelling were applied to the agricultural systems located in the northern Italian plains and the results were taken as the basis for the elaboration of the present work. Results of field experiments and modelling reported in Giardini and Giupponi (1995) and Agostini and Rosato (1998) constitute the background of what follows. More specifically the discussion of alternative maize cultivation systems is based on Borin et al. (1997), Morari and Giupponi (1997) and Giupponi (1998).

**Crop management of maize**

The set of possible cultivation techniques for the maize crop ranges widely between very intensive systems, also with possible use of livestock wastes, to organic cultivation using no chemical inputs. Previous studies have demonstrated the dramatic wideness of the ranges of socio-economic and environmental performaces of those alternative management techniques.

Three main alternatives are available for tillage:
- deep ploughing at 35-40 cm
- reduced depth ploughing at 25-30
- minimum tillage at 10-15 cm
- zero tillage

The second is the most widely adopted, the first was adopted in the past and is now typical oonly for clay soils, the other are not diffused, but show a positive trend.

Maize responds dramatically to fertilisation levels. Ordinary techniques encompass the distribution of phosphorous and potassium before sowing with incorporation (40-50 kg/ha of P and 50 kg/ha of K), or a reduced dose of P (30-40), localised with sowing. Nitrogen fertilisation is usually split: 90 kg/ha with sowing and 120-160 in one of two later applications.
In Italy the most widely used *cultivars* are of the FAO classes between 400 and 700, 500 and 600 are more used, the first in less productive soils or where it is important to anticipate the harvest date, the latter where optimal condition are expected, to obtain higher yields. Traditionally, the *sowing* period is between late April and early May, but there is a diffused tendency to anticipate even four weeks before, to guarantee a much better utilisation of natural water inputs by rainfall, before the dry season (Mundula, 1999). This was favoured by relatively good spring weather in recent years. On the average for grain maize a distance of 75 cm between the rows is adopted to obtain 6-7 plants/m$^2$ while higher numbers of plants are adopted for silage maize.

In about 70 % of the cultivated surface weed control is done with one pre-emergence treatment, 20 % receive also a post-emergence application, while the rest (10 %) is treated only with post-emergence herbicides (Rapparini, 1999).

*Pest control* is done against *Agriotes* spp. and *Agrostis* spp., when needed.

As previously stated, the variability of rainfall within the Po Plain makes *irrigation* a techniques always useful, but often not indispensable. Watering is concentrated during the period before flowering and end two weeks after the emission of the female flowers.

The *harvest* period is between September and October, depending on the cultivars.

Besides the ordinary techniques described above, nowadays, at least two main cultivation scenarios should be considered to discuss crop management alternatives and their environmental impacts: one driven by the 1992 market reform (EC Reg. 1765/92), typical of ordinary farms, and another ruled by the EC Reg. 2078/92, characterised by reduced-input techniques. These two policy contexts were used to define the reference crop management techniques described below.

To exemplify the wide set of possible techniques, the following part will refer to four alternative maize cropping systems: A, B, C and D. Those systems, were firstly defined during the CNR-RAISA Project and tested at the Vallevecchia Experimental Farm, from 1989 to 1995 (see Giardini and Giupponi, 1995 for details). After that the four alternatives were further developed by Giupponi and Rosato, 1998, making use of simulation models and multi-criteria evaluation, in cultivation environments whose characteristics closely meet the average soil and climate conditions of the Po Plain:

- deep alluvial loamy soil;
- average annual precipitation around 850 mm;
- negligible slope;
- ditches for drainage of excess water;
- availability of irrigation water.

The four reference maize management systems had the following basic characteristics (see table 1):

A) silage maize, typical of intensive agricultural and livestock farms (market scenario driven by EC Reg. 1765/92), with a rye-grass catch crop, intensive use of chemical fertilisers and liquid manure, and normal use of herbicides;

B) grain maize, typical of intensive cereal production farms of market scenario, with intensive use of chemical fertilisers, normal use of herbicides, and no liquid manure;

C) grain maize, typical of farms following the EC Reg. 2078/92 regulation regarding ecologically compatible agriculture, with moderate use of chemical fertilisers and herbicides, and no manure applications;

D) grain maize, representing proposed techniques for minimisation of environmental impact (e.g. protected areas, regional parks), even involving poor yield rates, poor cost/income ratio, and minimal use of pesticides and fertilisers, and a winter cover crop.

Table 1: Fertiliser and herbicides used for the four maize cropping systems.

<table>
<thead>
<tr>
<th>Maize cropping systems</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Organic fertilisers</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type of fertiliser</td>
<td>liquid manure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrogen content (kg ha(^{-1}))</td>
<td>400</td>
<td>300</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>Phosphorus content (kg ha(^{-1}))</td>
<td>100</td>
<td>35</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td><strong>Mineral fertilisers</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ureic nitrogen (kg ha(^{-1}))</td>
<td>224</td>
<td>300</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>Phosphorus (kg ha(^{-1}))</td>
<td>0</td>
<td>35</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td><strong>Weed control</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of herbicides used</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Active ingredient</td>
<td>Metolachlor</td>
<td>Metolachlor</td>
<td>Metolachlor</td>
<td>Glyphosate</td>
</tr>
<tr>
<td>Dosage (kg ha(^{-1}))</td>
<td>1.5</td>
<td>1.5</td>
<td>0.75</td>
<td>0.900</td>
</tr>
<tr>
<td>Active ingredient</td>
<td>Terbuthylazine</td>
<td>Terbuthylazine</td>
<td>Terbuthylazine</td>
<td>Rimsulfuron</td>
</tr>
<tr>
<td>Dosage (kg ha(^{-1}))</td>
<td>0.75</td>
<td>0.75</td>
<td>0.375</td>
<td>0.008</td>
</tr>
<tr>
<td>-------------------------</td>
<td>------</td>
<td>------</td>
<td>-------</td>
<td>------</td>
</tr>
<tr>
<td>Active ingredient</td>
<td>Dicamba</td>
<td>Dicamba</td>
<td>Dicamba</td>
<td>Dicamba</td>
</tr>
<tr>
<td>Dosage (kg ha(^{-1}))</td>
<td>0.212</td>
<td>0.212</td>
<td>0.212</td>
<td>0.212</td>
</tr>
</tbody>
</table>

In the field experiment the performance of the four alternative maize cultivation systems were tested in the context of four rotations designed to represent the typical farms which could adopt those alternatives. From the agronomic viewpoint the field experiments demonstrated that no significant differences in yields should be expected between systems B and C. Maize D in the field experiment was an organic crop, cultivated after three years of alfalfa and the application of solid manure, which showed some beneficial effects able to compensate in part the absence of chemical fertilisers. The negative effects of manure and the following ploughing on nitrate releases suggested to switch to the alternative system described in Table 1, which, even not respecting the rules of organic, is more oriented towards the minimisation of environmental impacts.

The elaboration of field data demonstrated that, after considered the rotation effects, all the systems were fairly balanced in terms of nitrogen balance, except for maize A which adopted relevant inputs of liquid manure. This situation is typical of those farms with intensive livestock production, where the weight of rearing animals is excessive as compared with the available land, or even where the transport costs of spreading the liquid manure determine excessive applications only in closer fields.

From the economic viewpoints several attempts were made to compare traditional practices with low input ones.

It has been demonstrated that on the long range reductions of input like those required by the adoption of the EC Reg. 2078/92, should be expected in particular for the inability of low input techniques to take advantage of particularly favourable years and cultivation environments. At the same time it is clear that eco-compatible practices allow reduction of costs for machinery and chemical inputs.

Recent experiments in northern Italy have shown production costs ranging between 1050 and 1235 Euro per hectare with high input techniques, as compared to 720-930, for low inputs (Bin, 1997). At the same time yields decreased by 1.6-2.7 t/ha, depending on the cultivar. With subsidies for eco-compatible techniques around 200 Euro/ha these practices seems to be always convenient for ordinary farms even with very high prices 180 Euro/t or more. Without
the EU support price should be lower than 120-150 Euro/t, depending on the farms. The average prices during the period 1997-98 ranged between 120 and 145 Euro/t.

**Environmental impacts of maize**

The experimental evidences acquired in recent research project allowed the testing of simulation models. In particular, this study made use of results from long-term simulations performed with GLEAMS (Groundwater Loading Effects of Agricultural Management Systems; Knisel, 1993), a mathematical model for simulating complex climate-soil-management interactions in field-size areas. It was developed to evaluate edge-of-field and bottom-of-root-zone loadings of water sediment and agricultural chemicals from alternative management systems with a daily time step.

The results of field experiments and simulations showed for the study area relatively relevant leaching events, with moderate phenomena of surface runoff and negligible soil losses. With these patterns of soil water balance, phosphorus losses were generally low (flat plain environment) and unaffected by different crops.

Maize, with respect to other main field crops (winter wheat, sugar beet, soybeans and alfalfa), showed the widest field of variation and maximum values for nitrogen releases, thus confirming that this crop is a potential source of high releases (especially where livestock manure is used), but it is also a crop that can respond effectively to the introduction of low-input techniques (see Figure 5).

The following sections describe the methodology for calculating the values of environmental impact indices of the alternative management systems and the results of such calculation for four alternative maize cultivation systems (see Giupponi, 1998).

![Figure 5. Statistical distribution of annual leaching events of nitric nitrogen (results of 100 year simulations.](image-url)
The methodology for calculating impact indices
The proposed method is based on a flow chart (Figure 6) starting from the definition of possible alternatives (e.g., alternative techniques applicable to a particular crop, or more complex strategies, such as tillage systems, crop rotations, etc.). For each alternative, data on indicators is collected and then processed by calculating a set of impact indices in order to yield their significance in terms of various kinds of environmental impact.
As Figure 6 shows, the index values obtained are standardised for the set of alternatives by adopting a normalisation process within the domain of each index (Hwang and Yoon, 1981). In our case, linear rescaling computation is performed between the minimum value, set at zero, and the maximum (highest impact), set at one. This yields a matrix of n columns (indices) and m lines (alternatives), with values always ranging between zero and one.
Before actually applying the multi-criteria assessment procedure, index values are reprocessed by means of a matrix of weights (Saaty, 1977) to determine the relative importance to be attributed to each single index with respect to the decision-making process. The resulting assessment matrix is then usually combined with technical and economic indicators and is submitted to multi-criteria analysis, in order to identify best or compromise solutions, which take into account the specific characteristics of cultivation environments and the aims and expectations of the decision-maker.

The indices adopted here were determined for the purpose of describing potential risks, according to the general criterion that the release of foreign substances into the environment must always be reduced to a minimum. The adopted indices are calculated with very simple algorithms applied to indicators describing fertiliser and pesticide inputs and outputs at the scale of the cultivated field. Some of them make use of time series, like leaching events on a daily basis. In this case, multi-annual data should be available to give adequate estimates of average behaviours of cropping systems. The set of agricultural pollution impact indices adopted here may be subdivided into four groups: water, soil and air pollution, and health.

\[ \text{Figure 6. The methodology for calculating impact indices.} \]

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DEFINITION OF THE SET OF ALTERNATIVE FARMING SYSTEMS

EXPERIMENTAL DATA  SIMULATIONS

INDICATOR COLLECTION

CALCULATION OF INDEXES

BUILDING OF EVALUATION MATRIX
- NORMALISATION
- ASSIGNMENT OF WEIGHTS

COMBINATION WITH TERRITORIAL DATA

MULTI-CRITERIA ANALYSIS

MAPPING

DECISION SUPPORT SYSTEM FOR LAND PLANNING
```

17
risks for farmers.

Water pollution

The consequences of water pollution caused by agriculture were assessed with respect to four possible risk factors:
- risks related to water made unfit for drinking;
- toxicity risks for man;
- toxicity risks for aquatic life;
- risk of eutrophication of surface waters.

- **Regulatory Drinkability Index** (RD): this index assesses degradation of water drinkability on the basis of the number of release events in runoff (RD<sub>R</sub>) or leaching (RD<sub>L</sub>), either observed or simulated, which exceed the limits established by European Community regulations (EC, 1980) to 50 mg l<sup>-1</sup> for nitrates (RD<sub>NR</sub> and RD<sub>NL</sub>) and 0.1 µg l<sup>-1</sup> for every pesticide (RD<sub>PR</sub> and RD<sub>PL</sub>). In general, the following equation applies:

\[
RD = \sum \frac{e_i}{y}
\]

where \( \sum e_i \) is the total number of events exceeding the drinkability threshold in observed or simulated daily concentrations, and \( y \) is the number of years of the time series.

- **Mammal Toxicity Index** (MT): this index assesses risk factors for human health related to consumption of polluted water, disregarding the above-mentioned generic limits, on the basis of the critical toxicity factor expressed by the ADI parameter, which represents the maximum Acceptable Daily Intake of a given pesticide for man (Grilli, 1994). The MT index may be distinguished into MT<sub>R</sub> (pesticides in surface water) and MT<sub>L</sub> (pesticides in groundwater) and is calculated as follows:

\[
MT = \sum (l_i \cdot ADI_i^{-1})
\]

where \( l_i \) is the annual average of the quantity of each active ingredient lost into water in the period in question, and \( ADI_i \) is the corresponding chronic toxicity of that active ingredient.

- **Non-mammal Toxicity Index** (NT): this index assesses the impact on aquatic life, and is subdivided into two components. The first (NT<sub>R</sub>) is calculated on the basis of the number of surface discharge events which exceed toxicity values for fish (LC<sub>50</sub> for rainbow trout), as follows:

\[
NT_R = \sum \frac{e_2}{y}
\]
where $\Sigma e_2$ the total number of events in which $LC_{50}$ values are exceeded by at least one of the active ingredients used, in surface water.

The second index ($NT_D$) was introduced in order to take into account the risk of direct pollution to surface water (i.e., streams and ditches in the treated area) due to pesticide drift. Recent literature dealing with this issue (e.g.: Adriaanse, 1996) reports that this source of pollution, together with that caused by washing of pesticide distribution equipment, is in many cases far from negligible. The following equation was used to calculate the $NT_D$ index:

$$NT_D = \sum (d_i \cdot p \cdot LC_{50i}^{-1})$$

where $d_i$ is the annual dose of pesticide, $LC_{50i}$ the corresponding toxicity, and $p$ the estimated drift fraction, which is 0.01 for open field applications with downward spraying on crops less than 25 cm in height, 0.02 for taller crops, and 0.1 for lateral or upward-directed spraying on fruit crops (EPPO, 1993).

- **EUTROPHICATION RISK INDEX (ER):** this index assesses risk factors relating to eutrophication of surface water on the basis of the number of runoff events which exceed certain risk thresholds. For $ER_{Ni}$ (eutrophication risk due to nitrogen), the threshold is 30 mg l$^{-1}$ (total nitrogen), and for $ER_{Ph}$ (eutrophication risk due to phosphorus) it is 10 mg l$^{-1}$ (total phosphorus) (Marchetti, 1993). The following equation applies:

$$ER = \sum e_3$$

where $\Sigma e_3$ is the sum of events in which the above limits are exceeded in runoff water.

**Soil contamination by pesticides**

- **SOIL CONTAMINATION INDEX (SC):** this index assesses risk factors associated with the presence of pesticides in the soil exceeding the threshold value of 0.1 mg per kg. A soil is regarded as uncontaminated if this value is not reached (Cairney, 1995). The following equation applies:

$$SC = \sum e_4$$

where $\Sigma e_4$ is the sum of days during which the total quantity of pesticides exceeds the threshold limit in the top surface layer (30 cm) of cultivated soil.
Air pollution by ammonia

- **AMMONIA EMISSION INDEX (AE):** this index assesses atmospheric pollution due to ammonia emitted by the manure sometimes used in agriculture. Neither available experimental data nor the simulation tool adopted in the present work allowed the assessment of other forms of nitrogen emissions into the atmosphere. The index basically consists of a measured value or an estimate of the volatilisation rate of ammonia (kg ha\(^{-1}\) year\(^{-1}\)), expressed as:

\[
AE = q_i
\]

where \(q_i\) represents the annual average of ammonia released into the air.

Health risks for farmers

- **FARMER’S RISK INDEX (FR):** this index assesses human risks associated with handling and distributing pesticides. It is subdivided into two components: acute toxicity index \(FR_A\) and chronic toxicity index \(FR_C\), calculated as follows:

\[
FR_A = \sum (d_i \cdot LD_{50i})
\]

\[
FR_C = \sum (d_i \cdot ADI_{i-1})
\]

where \(d_i\) is the annual dose and \(LD_{50i}\) (rat) and \(ADI_{i-1}\) are the corresponding parameters for acute and chronic toxicity, for each active ingredient.

**Impact indices of alternative maize cultivation systems**

The results of the above simulations in terms of normalised impact indices are shown in Figure 7 as polar graphs, called “impact signatures”. The segments linking the values of each single index form a shape which, like a signature, makes identifies the peculiar combination of impact effects associated with each single cultivation system.
As expected, the results revealed relatively high impact index values for the intensive techniques of cases A and B. Disregarding index \( \text{NT}_R \), which was zero in all four cases, the maize produced using technique A, with liquid manure, had values nearly always close to 1 (i.e., maximum impact). Case B revealed high index values mainly due to the use of pesticides. Case C showed considerably lower impact, with values in all cases less than half the peak values of A and B. In case D, nearly all the impacts were close to zero, except index \( \text{RD}_R \), which had a peak due to release of herbicide used to desiccate the cover crop.

**Figure 7. Impact signatures of alternative maize cultivation systems**

*Discussion of possible improvement regarding environment*

The process of development and spread of eco-compatible agricultural practices is sustained by both appropriate technical and scientific inputs and by efficient tools of technical, economic and environmental evaluation. These tools have been the subject of intense development for some time and a great deal of progress has been made within the different disciplines involved. Yet the characteristics of the problems faced, clearly show the need for a tight integration of the evaluation phase that can only be satisfied by the development of models that can unite physico-environmental phenomena with technical and economic aspects into a single context. The advantages offered by such a combination are obvious and can be summed up by the possibility of simulating and fully evaluating alternative scenarios; under this viewpoint integrated models become useful development tools of agro-environmental policies (Giupponi and Rosato, 1995).

The available knowledge about potential impacts and technical-economic performances of alternative cultivation systems, could drive to optimistic conclusion about the possibility of
reducing the impacts of agricultural activities on the Po Plain. Maize has in fact demonstrated to be a crop highly suitable to the introduction of environmentally sound cultivation systems. In strict economic terms those improved systems have shown performances comparable to higher input (and impact) alternatives. Nevertheless the recent year have demonstrated that farmers are reluctant to the adoption of alternative techniques for several reasons: traditional culture, insufficient information, etc. Moreover, the low input systems proposed by local implementations of EC Reg. 2078/92 and supported with European resources often present doubtful environmental significance and substantial difficulties in effective controls (see for instance the effective possibility of controlling the real applications of pesticides and fertilisers by farmers).

This part could be further developed but I’d need the materials produced by ASCA regarding the evaluation of maize cultivation in view of the current EU socio-economic scenario and the new CAP reform

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