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The reform of the agricultural policy in the European Economic Community: an Italian farm simulation study

by

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CHAPTER I.

PROBLEM AND JUSTIFICATION

Introduction

In Europe the last decade will certainly be remembered not only for the dramatic political revolution it brought along, but also for the many economic and institutional changes of great impact on the lives of millions throughout the whole Continent.

For more than 30 years, the Common Agricultural Policy (CAP) of the European Communities (EC) has determined the course of farm enterprises and has strongly influenced life in the rural areas of the member states.

Recently, the EC adopted the most drastic CAP reform package ever since its implementation, entailing a very significant reduction of the prices of all major grains and related products.

Questions now arise on how EC farmers will face this new challenge, on the consequences of this reform on the profitability of millions of farms and on the redistribution of farm income among producers and among the different regions of the EC. In particular, agricultural economists are challenged in trying to forecast the future changes at the farm level, which may affect cropping patterns, rotations and production techniques.

The purpose of this study is to explore the implications of the policy reforms by investigating the possible incorporation of new tillage practices by producers, as alternatives to the traditional farming systems, and evaluating the impact of these changes on farm yields and profit level.

Origins of the Problem

A brief history of the CAP

When the CAP was agreed on in 1962, its leading objectives, as defined in the Article 39 of the Treaty, were to obtain self-sufficiency in food production, a fair standard of living for farmers, stabilization of agricultural markets and a secure supply of food at reasonable prices for consumers.

In order to attain these goals, an articulated mechanism to control and regulate the agricultural markets was initiated. Traditionally, CAP support has not applied to every product and the level of support has greatly varied from one product to another. For the purpose of this study, the grains sector is certainly germane and, in particular, the case of cereals is examined in details.

Before the MacSharry reform was implemented, farmers income support was guaranteed by supporting market prices. The high domestic market price was maintained by restricting imports of cheaper world production and by removing from the market any actual excess supply that might be stimulated by the guaranteed price level (El-Agraa, 1990). A *target price* was set on an annual basis and was maintained at a level which the product was expected to achieve on the market in the area of shortest supply; in the case of cereals this area was identified with Duisburg in the German Ruhr Valley. Since it did not include transportation costs to dealers and storers, the target price was not a producer price. A *threshold price* was calculated in such a way that when transport costs incurred within the EC were added, import cereals collected at Rotterdam sold at Duisburg at a price equal to the target price. An *import levy* was imposed to prevent import prices falling short of the threshold price. This levy was calculated on a daily basis and resulted equal to the margin between the lowest price consignment entering the EC on that day and the threshold price. Hence, under this system the target price lost any reference with supply-demand market equilibrium. In fact, since the target price generally resulted in an excess supply of the product in the EC, an annual government buying became customary. A *basic intervention price* was introduced for this purpose at a fixed percentage below the Duisburg target price. National intervention agencies were compelled to buy any amount of the product offered to them at the relevant intervention price. Finally, an export subsidy, the *restitution*, was paid to EC exporters to dispose of these surpluses on the world markets. This subsidy was generally calculated as the difference between the EC intervention price and the world price.

Under the umbrella of this policy setting the Common Agricultural Policy has been successful, arguably too successful, in ensuring sufficiency of food supply in the EC. In fact, the output of EC agriculture has grown much faster than the domestic demand and surpluses in most agricultural markets have soared, with the consequence of an escalation of budget expenditures and conflicts with trade partners (Henrichsmeyer, 1990).

In July 1985, the EC Commission issued a Green Paper entitled "Perspectives for the Common Agricultural Policy", containing a major review of the CAP in the light of rising budget costs. Consultation on the basis of the Green Paper led to a series of guidelines which laid out a strategy for dealing with surplus capacity in the EC farm sector (Josling, 1990).

A first package of "weak" programs on set-aside, land conversion for ecological purposes, afforestation, and early retirement of farmers, was followed in 1988 by "stronger" measures intended to cut expenditures by reducing production levels, the "stabilizer mechanisms" (Henrichsmeyer, 1990; Leon and Mahe', 1990; De Filippis and Salvatici, 1991). Basically, full-guarantee production thresholds were fixed for most agricultural products and increasing price reductions (the *co-responsability levies*) were defined for over-the-quota marketed production. Nevertheless, the escalation of farm product surpluses and budget level continued unabatedly. At the end of 1991 the EC had over 20 million tons of cereals and 750,000 tons of beef in intervention and almost one million tons of dairy products in stock (Green Europe, 1991), while the agricultural budget peaked at the record level of 31.5 billion European Currency Units (ECU), a rise of over 155 percent in real terms from 1975 (Agricee, 1991).

Despite the remarkable level of financial transfers to producers, through the system of high guaranteed prices and production incentives, during the last two decades the farm sector has not thrived. Between 1975 and 1989 farming population dropped by 35 percent but the average purchasing power of the remaining farmers did not appear to improve very much. Also, the growing disparity among farms has generated mounting dissatisfaction for the distortions of a distribution system whereby 20 percent of the 9 million holdings of the EC, generally the largest and wealthiest operations, has received 80 percent of the total financial resources (Agricee, 1991).

Beyond its internal budgetary problems and structural inconsistencies, the leading force driving towards a transformation of the CAP has been its "international incompatibility" (De Filippis and Salvatici, 1991). Over the years the EC overproduction has contributed to depress international prices level and destabilize world markets, igniting bitter conflicts with major trading partners and strategic allies. The EC claims that the increase in production is mainly a consequence of technological change, structural policies, investment in input supply, processing and marketing facilities, and substitution of capital for labor in the modernization process. On the other hand, all major trade competitors, in particular the United States, emphasize that growth has simply been created by artificially high prices. European agriculture is seen as cost non-competitive, and it is argued that rather dramatic price-support reductions to bring internal prices to world levels would have large effects on agricultural input usage, investment and output (Bouchet et al., 1989).

The continuous irritation of agriculture in international affairs led to the widespread view that something had to be done. Using the words of Josling (1990):"...To a politician, all change is costly: reform takes place when the cost of doing nothing exceeds the cost of change". To the EC institutions, this point was reached in 1992.

The MacSharry Plan

On June 30, 1992, the Council approved Regulation N. 1765/92, which certainly represents the most fundamental reform todate of the mechanisms of the CAP, while keeping intact its basic principles of market unity, Community preference and financial solidarity.

The program is also known as "MacSharry Plan", from the EC Commissioner for Agriculture, Ray MacSharry, who first proposed an early draft of the plan in 1991. Its main features are the drastic price reduction for most major agricultural products, a system of support payments to compensate existing holdings for the loss of income due to the decline in market prices, a mandatory set-aside requirement on a fixed percentage of the farmed land, and the weakening of the link between support payments and yields by basing compensation payments on regional average yields rather than on individual farm yields. Institutional price changes for wheat and corn are summarized in Table 1.1.

As a result of this reduction in the level of support, during the next three years the market prices of wheat, corn and all other major cereals, historically very close to the intervention level, should fall by almost 40 percent and be aligned to world prices.

A system of payments has been introduced to compensate farmers for the loss of income caused by the reduction of prices. The payments have been set on a per-hectare (1 hectare = 2.47 acres) basis and are not related to current levels of output. For the purpose of establishing the aid to be paid to

Table 1.1 EC target, threshold and intervention prices for wheat and corn, 1992-1995

Marketing year	Wheat Target Price ECU/t	Wheat Inter. Price ECU/t	Wheat Thres. Price ECU/t	Corn Target Price ECU/t	Corn Inter. Price ECU/t	Corn Thres. Price ECU/t
1992/93[a]	226.47	163.49	221.68	206.16	163.49	201.3
1993/94[b]	130	117	175	130	117	175
1994/95[b]	120	108	165	120	108	165
1995/96[b]	110	100	155	110	100	155

[a] Reg. N. 1801/92 and 1802/92.
[b] Reg. N. 1766/92.

producers, every member state has drawn up a regionalization plan for its territory. In each region, an historical three-year average yield has been calculated for each crop, based on the average of three of the last five marketing years, 1986/87 to 1990/91, after eliminating the lowest and the highest figure. This regional average yield is the basis for translating the compensatory payment into a regional per-hectare aid.

The compensatory payments for cereals have been fixed at 25, 35 and 45 ECU/t, respectively for the 1993/94, 1994/95 and 1995/96 marketing years.

In the case of oilseeds, an EC reference compensatory amount, 359 ECU/ha, and a reference price for the world market, corresponding to the expected medium-term equilibrium price on a stabilized world market, 163 ECU/t, have been determined. Market prices will be maintained at world level and farmers income will be integrated with a compensatory payment, to be calculated adjusting the reference amount with the ratio between the regional and the average EC yields. In order to be able to participate in the compensatory payment program, farmers must set-aside a pre-determined percentage of their area under cereals, oilseeds and protein crops; this mandatory set-aside requirement has been initially set at 15 percent.

For environmental reasons, this set-aside has to be organized on the basis of a rotation of surfaces and the land set-asided has to be cared for so as to meet certain minimum environmental standards.

Under the new provisions, farmers can be classified as *small* producers, when they farm an area equivalent to an annual production of no more than 92 tons of cereals, and *professional* producers, when their farmed area is larger. On the basis of the average EC cereal yield, a *small* producer farmed area should correspond to a holding of about 20 hectares.

Under the new plan, *small* producers have been exempted from the set-aside requirement and can receive the compensatory payments on the whole area they farm; however, they have the option of choosing the *professional* scheme,

should this be to their advantage, with the same supply control obligations applied to *professional* producers.
In the way it has been conceived, the MacSharry plan suffers from some internal inconsistencies. In order to qualify for payments, farmers are required to keep land in production of program crops, although set-aside of land on program crops is, at the same time, also required.

As Josling and Tangermann (1992) note, a fully decoupled system of payments would not require any set-aside, as production decisions would be based on market price which reflected the competitive position of EC agriculture.

Nevertheless, uncertainty remains on the future level of the market price. The MacSharry reform plan was written to bring EC farm prices closer to the world level. In the intentions of EC legislators, lower prices will gradually eliminate current overproduction. In fact, with the intervention price tied to the world price, the current export subsidy mechanism will virtually cease to exist and without the traditional incentive to dispose of agricultural surpluses onto the foreign markets, EC overproduction will necessarily be discouraged. By the time the new equilibrium is achieved, the intervention price should constitute just a price floor for occasional market support and producers should base their decisions not on the intervention level but on the market supply-demand equilibrium. For this purpose, in the MacSharry plan the target price has been fixed 10 percent above the intervention price, to serve as a guide in production and as a reference for market equilibrium.

Concern over the possibility that the lower market price may still be above that which would clear the market without export subsidies or intervention buying presumably led to the inclusion of set-aside. Also, fear over possible depopulation of rural ares probably has led to the requirement that land be kept in production to receive payments. Thus, the combination of these two concerns has led "...to a somewhat incongruous policy" (Josling, Tangermann, 1992).

Previous Research

In the eyes of EC legislators, the substantial compensation granted to producers, along with the income stability inherent in the system of direct payments, should provide an attractive future for the 10 million farmers in the Community.

Using the words of MacSharry, "...the revised policy should encourage farmers, through changed input/output price relationships, to switch to less intensive farming methods, thereby reducing the risks to the environment and curtaining surplus production" (Green Europe, 1991).

Questions concerning the attainability of these expectations now arise, focusing on the impact of the reduction of prices on farming techniques, yields and production levels.

In recent years, the political debate over agriculture trade liberalization within the Uruguay Round of the GATT has fostered the production of many studies on the consequences of various levels of price reduction on EC agriculture.

Utilizing a dynamic, general equilibrium model, Frohberg et al. (1988) estimated the effects of an EC unilateral dismantlement of the CAP protection barriers in the world market; Barniaux (1988) focused on the consequences of the liberalization of the CAP on the redistribution of income between North and South, while Breckling et al. (1987) studied the effects of CAP protection on the other traded goods sectors and the economy as a whole for each member state.

Other authors utilized partial equilibrium models, with different degrees of regional and sectorial specificity. Mahe' and Moreddu (1988) simulated the intra-Community effects of several alternative price policies; De Veer (1988) and Thomson (1988) tackled the inter-sector redistribution of income among EC producers and consumers following a liberalization of the CAP; Munk (1988) and Pierani and Frohberg (1988) evaluated the effects of the abating of protection policies on EC agricultural production and demand for inputs; Gallagher (1988), Sarris (1988) and Weindlmaier (1988) utilized a similar approach but focused their research on the EC grain sector only.

The authors of these studies, with only minor quantitative differences, seem to agree on the possible effects of the termination of the CAP protective policy. Within the EC, they forecast a consistent drop of agricultural and food prices, a decline in farm population and income and a sharp decrease in input demand, yields and aggregate output level.

Generally, these authors simply linked the transformation of the CAP to a reduction of the institutional prices at international market levels.

More recently, after the new proposals for the reform of the agricultural policy have been forwarded by the EC Commission, new studies on the impact of the liberalization of the EC agricultural market have been produced. They incorporate the system of compensatory payments as a mean of protecting farmers income and consequently seem more reliable in their forecasts of the effects of policy changes at the farm level. Doluschitz (1992) extended the results of his farm profit optimization model to investigate the potentiality of the MacSharry plan in achieving a drastic reduction of agricultural output. His results underline a very low elasticity of yields to output prices, due to the low cost of fertilizers and their relatively insignificant low weight in the total cost of production. Alternatively, Josling and

Tangermann (1992) forecasted an effective reduction of EC average grain yields, harvested area, output and export levels and, as a consequence of the reduced EC pressure on the international market, a strong rise in world grain prices. Koesling (1992) investigated the relationship between farm size and production cost. In his findings, in Europe grain production at world average costs can be achieved only in very large units, over 3,000 hectares, with extreme "extensivization" of production, e.g., very low input and labor requirements and great reduction in yields. He has found these conditions only in some former East Germany ex-collective farms, which, however, are now being dismantled into smaller units to be rented to local farmers. In his conclusions, unless support payments are provided to compensate farmers, only a very significative decrease in land values will maintain a sufficient level of profitability in EC grain production at world prices. A similar study on the relative competitivity level of the main wheat producing areas of the EC was recently presented by the AGPB, the French Wheat Producers Association (Rees, 1990). Utilizing a sample of almost 3,000 european farms, the French researchers compared the different levels of productivity and profitability among farms located in the traditional EC wheat basins and evaluated their responsiveness to changing market conditions in terms of their potentiality in reducing the costs of production. To our knowledge, this study is the most complete, detailed and reliable report on EC wheat production up to date.

In the specific contest of Italian agriculture, many contributions have been produced during the past few years. Among them, on agriculture trade liberalization and CAP reform, Tarditi (1987), De Filippis (1988), De Filippis (1990), Salvatici (1990), De Benedictis et al. (1991), De Filippis and Salvatici (1991), Amadei (1992) and Tarditi (1992); on farm productivity, technological innovation and international competitivity, Giardini (1991), Giacomini (1992) and Grillenzoni and Sarti (1992).

Objectives and Overview of the Thesis

This study proposes to analyze quantitatively the effect of policy changes by simulating representative farm models. Specifically, a mathematical programming model for a representative northern Italian grain farm is built. By solving the optimization model of the farm under alternative policy scenarios, it is possible to assess the impact of proposed policy reforms on yields and acreage response, a question of great importance not only for european farmers but also for producers in competing exporting countries such as the United States. In addition, this framework of analysis will allow interesting analysis concerning the impact of policy changes on farm income and the shadow price of fixed assets.

Clearly, no one production setting can be fully representative of EC agriculture. Nevertheless, if warranted by the results of this study, the methodology could later be extended to other EC regions.

This thesis is organized as follows. Chapter II provides a description of analytical procedures and data. Chapter III presents empirical results and a discussion of their main implications. Chapter IV includes a summary and conclusions.

CHAPTER II.

METHODOLOGY AND DATA

The effects of proposed policy changes are analyzed at the farm level, solving a mathematical programming model. Specifically, the optimum farm plan after the introduction of the MacSharry program is compared to the optimum plan before its implementation. Such a procedure, as previously stated by Boggess and Heady (1981), shows the impact of the change on the response variables, but it does not, however, provide information on the dynamics of moving from the old to the new optimum equilibrium. Thus, this model provides comparative static rather than dynamic analysis.

The Model

The main purpose of this study is to investigate the effects of the policy changes introduced with the MacSharry reform on farm yields, cropping patterns and tillage systems. Thus, a model must be set up for the contemporaneous determination of all these variables.

This is achieved with the identification of a representative farm where a definite combination of crops are grown. For each crop a yield response function to nitrogen fertilization is defined. These response functions are introduced in the farm profit function, which is maximized subject to a series of specific constraints. In the maximization process, the optimal values of nitrogen fertilization and crop yields are then determined. As it will be shown in the following sections, the optimum farm plan, to be identified with the optimal long-run crop rotation and the profit-maximizing combination of tillage systems, is also identified in this model.

Crop yield response functions definition

Observed yields depend on many variables and can be represented as:

$$y = f(\boldsymbol{W}, \boldsymbol{S}, \boldsymbol{Z}, \boldsymbol{G}, \boldsymbol{O}) \tag{1}$$

where

$\boldsymbol{W}$, is a vector of weather variables,

$\boldsymbol{S}$, is a vector of soil type variables,

$\boldsymbol{Z}$, is a vector of total supply of macronutrients, naturally supplied by the soil or applied with fertilization,

$\boldsymbol{G}$, is a vector of genetic load, and

$\boldsymbol{O}$, are other influencing factors (e.g., planting density).

Although a simplification of reality, relation (1) is still too general and, consequently, a simpler functional form has to be introduced.

In particular, in the specification and estimation of agronomic response function to nutrients, Cobb-Douglas, Mitscherlich, linear response and plateau (LRP) and polynomial functions of varying degree have been used, although among agronomists and agricultural economists the choice of the particular functional form is still a controversial issue. Koster and Whittlesey (1971) rejected the Cobb-Douglas specification because it is unable to represent negative marginal productivity and a maximum yield is not defined. Polynomial functions, praised for their computational simplicity and high fit, have been criticized for their input level over-estimation (Anderson and Nelson, 1975; Lanzer and Paris, 1981). The proportionality concept assumed in the von Liebig's "law of the minimum", inherent to the LRP model, was rejected by Mitscherlich, who proposed, instead, his "principle of relative yields", and has been criticized by many soil scientists in favor of a response with diminishing marginal productivity.

The Mitscherlich function has generally collected a large consensus among researches for its agronomic validity and relatively easy applications. Economists have also found it convenient because of its nice properties and the technical characteristics (a growth plateau combined with positive factor substitution) which imposes on the response curve. Assuming only one variable nutrient, the principle of relative yields postulates that (1) can be respecified as:

$$y = A * g(b + x, \mathbf{G}, \mathbf{O}) \tag{2}$$

where

A,	is maximum yield attainable for some levels of weather and soil type variables, w and s,
$g(\cdot)$,	is the "relative yield response" function,
b,	is the nutrient level already in the soil, and
x,	is the corresponding application.

As Mitscherlich postulated it, the function $g(\cdot)$ does not depend on weather and soil variables; it varies between zero and one, hence its name of relative yield function.

As suggested in Lanzer and Paris (1981), the relative yield theory proposed by Mitscherlich and described by (2) contains an implicit assumption about separability of weather and soil type variables, on one hand, and nutrients on the other. In fact, equation (2) can adequately be represented by the following weakly separable function:

$$y = s(\mathbf{W}, \mathbf{S}) * g(b + x, \mathbf{G}, \mathbf{O}) \tag{3}$$

where Mitscherlich's maximum yield parameter A is a function of given levels of weather and soil type variables. Hence, by combining (2) and (3) the final general form of the Mitscherlich relative yield model can be derived as follows:

$$y = Aws * g(b + x, \mathbf{G}, \mathbf{O}) \tag{4}$$

where Aws is now a location parameter measuring the yield plateau of a given experiment conducted with weather conditions *w* and soil class *s*.

Following ideas given in Giardini (1992), in this study a modified version of the original Mitscherlich function is utilized. Explicitly, in this model the functional relationship expressed in (4) takes the following functional form:

$$(5) \qquad y = y(x) = Aws * \frac{[1-10^{-c(b+x)}] * 10^{-k(b+x)^2}}{1 + 10^{[1-c(b+x)]}}$$

where

c,	is the "action coefficient", which describes the steepness of the response curve,
b,	is the amount of nitrogen released by the soil which is utilized by the crop,
x,	is the level of nitrogen fertilization, and
k,	is the "depression coefficient", which describes the tendency of yields to fall for nitrogen applications greater than the level corresponding to the maximum yield attained.

The conditioning factors ***G*** and ***O*** are omitted for convenience, while a denominator is added to the original form to allow for increasing marginal productivity for some range of the input, a possibility ruled out in the original version of the Mitscherlich function. This particular function has been utilized in several studies on crop response to nutrients

(Giardini et al., 1987; Giardini et al., 1988) and to irrigation (Giardini and Borin, 1985).

Profit function definition

For each crop, profit per hectare is defined as follows:

$$\Pi = p * y(x) - [(r * x) + Q + K] - P_{HL} * HL \tag{6}$$

where

p,	is the market price of output,
$y(x)$,	is the yield response function,
r,	is the market price of nitrogen,
x,	is the level of nitrogen application,
Q,	are the direct costs (nitrogen excluded),
K,	are the imputed costs (depreciation, insurance,...),
P_{HL},	is the hired labor wage rate, and
HL,	is the hired labor requirement.

In this modeling procedure, crop yields depend exclusively on the level of nitrogen application, given a well-defined combination of all the other necessary inputs (other chemicals, seed and, eventually, irrigation), the tillage system and technology. Thus, for a specific farming system the sequence of mechanical operations and input requirements (Q) are to be considered system-specific and, consequently, fixed, while the only variable input is the level of fertilization (x). Computationally, Q is then equal to:

$$(7) \qquad Q = j' * J$$

where

j', is a vector of input prices and mechanical operation rates, and

J, is a vector of direct inputs (nitrogen excluded) and tillage system-specific mechanical operations requirements.

Changing the mechanization techniques or the level of any of the direct inputs, e.g., reduced tillage operations or chemicals application, would then change the crop farming system and lead to a new yield response function to nitrogen. A detailed definition of the direct and imputed costs is contained in the "budgeting crop activities" section.

The rotational model

A mathematical programming model consists of a simultaneous equation system representing the constraints of the model plus an additional equation to represent an optimized functional relationship (Boggess and Heady, 1981).

In the model utilized in this study, the objective function maximizes farm profit, given a definite choice of land utilization activities, farm technology and a set of specific constraints. The optimum farm plan, to be identified with the optimum long-run crop rotation strategy, is also identified.

The choice of crop rotations can occur in either a timeless equilibrium or dynamic disequilibrium setting. For the latter, multiyear linear programming models [Loftsgard and Heady (1959), Dean and De Benedictis(1964), Irwin (1968)] and dynamic models [Burt and Allison (1963), Burt (1965, 1982)] have been used. Either approach makes the crops chosen in year *t* depend upon acreage in year *t-1*, where the early-period solutions are influenced by the initial conditions. Generally, however, after the first few periods the model solutions tend to stabilize, as it is shown in the early studies by Loftsgard and Heady (1959) and Dean and De Benedictis (1964), and are independent of initial conditions, as the turnpike theorem would imply (El-Nazer and McCarl, 1986). An alternative modeling approach, formalized by Throsby (1967) and developed by El-Nazer and McCarl (1986), uses an annual, timeless equilibrium model where a continuously repeatable crop rotation is chosen. This solution, which should correspond to the stabilized solution of the dynamic model (the *steady state*), does not depend on the initial conditions and gives a long-run optimum plan. This modeling approach is adopted in this study.

It is supposed that N crops are grown in the representative farm. Also, the yield of a crop depends upon the tillage system adopted and the particular crop grown on the same land in the previous year. Under these assumptions, if the crop yield response functions and the profit functions take the form given, respectively, in (5) and (6), a maximum profit rotation plan is obtained by solving the following rotational model:

$$(8) \qquad \underset{\{t_{is}^{\delta\epsilon}, x_{is}^{\delta\epsilon}, HL_{is}^{\delta\epsilon}\}}{Max} \quad \textstyle\sum_{\delta=1}^{M} \sum_{\epsilon=1}^{M} \sum_{i=1}^{N} \sum_{s=1}^{N} t_{is}^{\delta\epsilon} * \Pi_{is}^{\delta\epsilon}$$

Subject to

$$(9) \qquad \textstyle\sum_{\delta=1}^{M} \sum_{i=1}^{N} t_{is}^{\delta\epsilon} - \sum_{\theta=1}^{M} \sum_{q=1}^{N} t_{sq}^{\epsilon\theta} \le 0, \quad \forall\ s^{\epsilon}=1,2,\ldots,(N*M)$$

$$(10) \qquad \textstyle\sum_{\delta=1}^{M} \sum_{\epsilon=1}^{M} \sum_{i=1}^{N} \sum_{s=1}^{N} t_{is}^{\delta\epsilon} \le T$$

$$(11) \qquad \boldsymbol{A} * \boldsymbol{t} \le \boldsymbol{z}$$

$$(12) \qquad t_{is}^{\delta\epsilon} \ge 0$$

where

$t_{is}^{\delta\epsilon}$, is land allocated to crop i, under δ farming system, following crop s, under ϵ farming system, in preceding year,

δ,	is the index of crop *i* farming systems,
ϵ,	is the index of crop *s* farming systems,
θ,	is the index of crop *q* farming systems,
$\Pi_{is}^{\delta\epsilon}$,	is the unitary (per-hectare) profit function,
T,	is total farmed land,
$\mathbf{A}$,	is a matrix of specific constraints parameters,
$\mathbf{t}$,	is a vector of all rotational activities, and
$\mathbf{z}$,	is a vector of specific constraints parameters.

The objective function (8) maximizes profit, subject to the choice of technology, the model rotational constraints (9), the land constraint (10), and a set of farm-specific constraints (labor), condensed in (11). A detailed description of these labor constraints is provided in the "fieldwork and labor constraints" section.

A profit function, whose general form was given in equation (6), is now defined for each rotational activity as follows:

$$(13) \qquad \Pi_{is}^{\delta\epsilon} = p_i * y_{is}^{\delta\epsilon}(x_{is}^{\delta\epsilon}) - [(r * x_{is}^{\delta\epsilon}) + Q_{is}^{\delta\epsilon} + K_{is}^{\delta\epsilon}] - P_{HL} * HL_{is}^{\delta\epsilon}$$

Under such a modeling approach, a yield response function, as expressed by $y_{is}^{\delta\epsilon}(x_{is}^{\delta\epsilon})$, would need to be defined for each crop farmed under each tillage system for all possible rotational combinations. Even for a small number of crops, this procedure becomes cumbersome and data collection hardly possible. Hence, for the purpose of this study a simplified approach resulted necessary. First, a relative yield response function *g(x)* for each crop grown was estimated. As it was shown before, this rather general function describes the crop response to nitrogen application only. However, it is to be assumed that yields are also dependable on several other factors, such as the effects of tillage and the interrelationships among succeeding crops on weed and insect infestations, plant diseases, soil organic matter content, water holding capability and productivity, and so on. To capture these effects, the relative yield response functions were modified with the introduction of specific coefficients estimated on farm data and experimental results. In particular, for each crop a yield plateau (the location parameter *Aws*) for all tillage systems adopted, and a rotational yield-adjusting coefficient (α) for all possible crop combinations were defined. Hence, a reasonable approximation of the yield response function for each combination of crops, tillage systems and rotation possibilities could be determined. The complete form of the crop response function takes the following form:

$$(14) \qquad y_{is}^{\delta\epsilon}(x_{is}^{\delta\epsilon}) = \alpha_{is}^{\delta\epsilon} * Aws_i^{\delta} * \frac{[1-10^{-c_i(b_i+x_{is}^{\delta\epsilon})}] * 10^{-k_i(b_i+x_{is}^{\delta\epsilon})^2}}{1 + 10^{[1-c_i(b_i+x_{is}^{\delta\epsilon})]}}$$

where

$\alpha_{is}^{\delta\epsilon}$, is the rotation yield correction coefficient.

Model rotation activities definition

The activity $t_{is}^{\delta\epsilon}$ gives the acreage of crop i, farmed under a well-defined tillage system δ, which is planted following crop s in the preceding year, also farmed under a well-defined tillage system ϵ. The objective function (8) sums the returns to the planting of all possible two-year crop sequences, under all tillage systems adopted by the farmer.

The land constraint (10) allows no more than the total acreage available (T) to be planted.

The set of constraints (9) imposes the rotation linkages. They require that the sum of the acreage planted of all crops which follow the preceding crop s^{ϵ} be no more than the sum of the acreage previously planted to crop s^{ϵ} over all possible rotations with the other crops and all feasible farming systems.

This formulation allows multiple-year rotations and can be easily extended to situations where several crops are grown, multiple tillage practices are possible and crop yields depend on more than one year of preceding crop.

In general, a model covering N crops, M farming systems and all possible K-year sequences would have $(N*M)^{(K+1)}$ activities and $(N*M)^{K}$ constraints. For example, if N=2, with crops denoted by *A* and *B*, M=2, with tillage systems defined as *a* and *b*, and the yield of each crop depends upon the crop previously grown on the same land, the model will present 16 activities and 4 constraints, as it is shown in Table 2.1. It is important to notice that $t_{is}^{\delta\epsilon} - t_{sq}^{\epsilon\theta} = 0$ when $i=s=q$ and $\delta=\epsilon=\theta$, which represents continuous cropping; so there are no coefficients in the rotation constraints for the continuous cropping activities. In this example, a continuously repeatable 2-year rotation *A-B* with tillage *a* would be obtained by having one-half of the acreage in each of the activities numbered 3 and 9; alternatively, a continuously repeatable 3-year rotation *A-B-B* with tillage *b* would have one-third of the acreage in each of activities 8,14 and 16. On the other hand, continuous *A* with tillage *b* would have all the acreage in activity 6, while a two-year *A-B* rotation with alternating tillage practices *a* and *b* would have 50 percent of the acreage in both activities 4 and 13. Thus, the structure of this model allows for the widest variety of rotations.

Farm Description

A representative northern Italy farm was selected. This farm is located in the south part of the river Po valley, the "Pianura Padana", within the administrative Province of Bologna.

The Po Valley is the largest plain and, traditionally,

Table 2.1 Sample model constraints tableau

	Activity[a]																
	Aa	Aa	Aa	Aa	Ab	Ab	Ab	Ab	Ba	Ba	Ba	Ba	Bb	Bb	Bb	Bb	
	Aa	Ab	Ba	Bb	Aa	Ab	Ba	Bb	Aa	Ab	Ba	Bb	Aa	Ab	Ba	Bb	
Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
Land	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	≤ T
Aa		-1	-1	-1	1				1				1				≤ 0
Ab		1			-1		-1	-1		1				1			≤ 0
Ba			1				1		-1	-1		-1			1		≤ 0
Bb				1				1				1	-1	-1	-1		≤ 0

[a] The rotation order gives the crop sequence in the years; thus, *Aa-Ba*, activity number 3, stands for crop *A* following crop *B*, both farmed with tillage system *a*.

the most productive agricultural area in the country; it is also one of the most important grain producing basins in the European Economic Community. It extends over four geographicalRegions of northern Italy, namely Piemonte, Lombardia, Veneto and Emilia Romagna. Emilia Romagna comprehends almost entirely the part of the plain which lies on the south of river Po, the main Italian water course.

In Emilia Romagna agriculture is very important. On a national basis, 20 percent of common wheat, 25 percent of sugarbeet, 15 percent of soybean and 7 percent of corn are harvested in this Region, a vocation which is particularly strong within its main Province, Bologna, where grain farms are over 70 percent of total existing farms and land harvested on cereals and sugarbeet represents about 75 percent of total farmed area (ISTAT, 1991).

The choice of a representative farm is not an easy task. The first data elaborations from the most recent general agricultural survey (ISTAT, 1990) show a national average farm size of 7.4 hectares (18.3 acres), considerably small compared to EC average size and almost insignificant compared to the U.S. average size. Even though grain farms in the Pianura Padana are generally of larger size, about 20 hectares (49.5 acres) (Piccinini, 1989), for the purpose of this study a larger farm was chosen to reflect a commercially viable operation. The gross farm size of the representative farm is

45 hectares (111.15 acres). Approximately 5 hectares of land are used for the homestead, roads, drainage ways, equipment shelter and other non-agricultural purposes. The land is owned entirely by the farmer, who lives with his family on the farm. The owner works full-time in the farm, with some extra-help from his wife and, when needed, hired labor and custom operations.

Soil description

The farm soil is a clay soil without any relevant slope (Table 2.2). It is a productive, well-structured soil with a good mineral composition of the clay; its fertility level is partly due to the residual effects of natural manure fertilization and meadow crops, mostly common farming practices in this area until the late 1970s.

Land utilization

The crops grown in the farm are common ("soft") winter wheat, sugarbeet, soybean and corn. Although historically other crops have been grown, in recent years these four crops have made up more than 90% of the total harvested area in the farm.

During the last few years, the most common rotations, shown in table 2.3, included four-year sequences of alternating wheat and spring crops, or wheat followed by a

Table 2.2 Main characteristics of the farm soil

Soil characteristics	Units
Altitude (m a.s.l.)	8
Sand (2>Ø>0.02 mm) in %	20.6
Silt (0.02>Ø>0.002 mm) in %	20.6
Clay (Ø<0.002 mm) in %	58.8
Chemical Reaction (pH)	7.9
Limestone in %	14.2
Organic matter (Lotti Method) in %	1.9
Total N (Kjeldahl Method) in %	1.5
Available phosphorous as adsorbable P_2O_5 (Ferrari Method) in %	108
Available potassium as exchangeable K_2O in p.p.m.	404
C/N Ratio	7.36
Clay mineral composition (Ø<0.002 mm):	
Kaolinite	+++
Illite	+++
Smectite	++
Vermiculite	+
Illite/Smectite	++

Table 2.3 Most common crop rotations

Duration	Rotation
Four years	wheat-sugarbeet-wheat-soybean wheat-sugarbeet-wheat-corn
Three years	wheat-sugarbeet-soybean wheat-sugarbeet-corn
Two years	wheat-soybean

two-year combination of spring crops.

Generally, four-year rotations have been preferred for their agronomic superiority and higher economic performance, since the spring crops seem to benefit from the land tillage during the preceding dry summer season, for the more accurate seedbed preparation and the higher mineralization of the organic matter in the soil, with resulting higher fertility and final productivity levels.

Combinations shorter than three-year rotations have been limited to alternating wheat and soybean, while other two-year rotations and continuous cropping have been avoided for a number of reasons. Continuous cropping, even when agronomically feasible as in the case of wheat, soybean or corn, has been typically discarded for the drastic decrease in production it brings along. In the specific case of sugarbeet, continuous cropping is not feasible for parasites infestations and, to prevent quality problems, sugar processing plants, which allocate sugarbeet production quotas to the farms, encourage producers to keep a minimum three-year time span between successive plantings of sugarbeet on the same land, thus limiting any two-year rotations as well. Two-year rotations of corn with another spring crop has been generally avoided by farmers for the production losses due to the more troublesome land preparation, to be carried out in the late fall and early spring, a time of the year generally characterized by rainy weather and, consequently, heavy soils. Soybean is a relative new crop in Italian agriculture and little is known on its behavior in short rotations or continuous cropping; consequently, farmers have introduced soybean into their traditional rotations, where succeeding crops can benefit from its positive fertilization residual effect.

Farm tillage systems

In the Pianura Padana farming has traditionally been intensive, for the fertility of the soils, the favorable weather conditions and, in general, the natural vocation of the environment for agricultural production. Also, the high level of market prices, fostered by the strong EC protection of the agricultural sector, have enhanced the diffusion among farmers of expensive highly-productive farming practices.

Production data have been collected at the representative farm for several years. In general, spring crops require an accurate seedbed preparation, with moldboard plow to bury previous crop residues, followed during the fall by a fertilizer application and a disking or field cultivation. The land is then harrowed in the early spring just before planting. This is followed by a cultivation, a fertilization and two herbicide applications; summer irrigation is generally required before crop maturity and harvest follows in the early fall. Specifically, sugarbeet requires manual extra-weed control and two pesticide applications but generally no irrigation.

The wheat tillage system mainly differs from the previous ones for the simpler seedbed preparation, which is completed with just field cultivation and harrowing in the fall. In the traditional rotations, wheat succeeds a spring crop and consequently seedbed preparation time is limited to the late fall. As previously noted, during this time of the year soils are generally wet and heavy for the abundant rains and excessive compaction, caused by heavy equipment, can determine fertility problems and reduced production levels. Since field research has clearly proven the low sensitivity of wheat yields to reduced tillage (Toderi and Bonari, 1986), farmers have gradually abandoned the traditional moldboard plow tillage on wheat and reduced the number of operations. Thus, reduced tillage is assumed to be the most common practice for wheat in this area.

During the past years, the agronomic research has been focused on different tillage practices; in particular, the effects of reduced and no-tillage systems on the production response of crops have been investigated. A complete review of the existing literature would be truly lengthy, but for this purpose it is possible to refer to Toderi and Bonari (1986), who offer a very exhaustive summary of the results of past and current research in this area.

Upon consultation with agronomists at the University of Bologna, reduced tillage and no-tillage requirements for each crop grown in the representative farm have been defined, since for these particular farming practices no data from the farm were available. In fact, although the results of scientific research have proven the feasibility of these different systems, farmers in the Pianura Padana have hardly switched from their traditional farming practices to less-intensive, cost-reducing techniques, due to the favorable prices received in the past. Until now, with the exception of wheat, reduced tillage systems have been very uncommon, while no-tillage definitely scarce or nil.

Reduced tillage includes a quicker and simpler seedbed preparation, with a reduction in ploughing's depth and spring harrowing; field cultivation can also be substituted with disking or rotary harrowing. Further reductions in costs are achieved with the exclusion of irrigation and, possibly, of summer cultivation and a reduction in manual weed control and fertilizers broadcasting, mainly accomplished by localization at planting and/or cultivation.

In this study no-till is defined as no preplant tillage. Wheat can represent an exception, since no-tillage might include ploughing to bury stalks if corn is preceding crop. But in general, soil tillage is completely eliminated, sod-seeding with phosphorous localization replaces traditional planting and nitrogen is localized at cultivation. In conservation tillage, the mechanical weed control is substituted with the chemical one and, consequently, the use of chemicals is generally increased.

These system are defined in terms of the field operations for all the different crops in the study in Tables 2.4 to 2.7.

The Pre-MacSharry Optimization Model

The optimum farm plan is first identified for the conditions of the market pre-dating the MacSharry reform. The base year is considered 1990.

Four crops are allowed in the farm: wheat, sugarbeet, soybean and corn. Year-average farm prices, expressed in Lire per ton, have been the following:

wheat = 332,600,

sugarbeet = 74,100,

Table 2.4 Description of tillage systems for wheat

Field operation	Reduced tillage	No tillage
Molboard plow		X[a]
Broadcast granular N and P	X	X
Field cultivator	X	
Rotary harrow	X	
Peg-tooth harrow	X	
Drill planter	X	
No-till planter with P distrib.		X
Herbicide	2X	2X
Harvest	X	X

[a] Only in case preceding crop is corn.

Table 2.5 Description of tillage systems for sugarbeet

Field operation	Traditional tillage	Reduced tillage	No tillage
Molboard plow	X	X	
Broadcast granular N and P	X		
Field cultivator	X		
Rotary harrow		X	
Disk			X
Peg-tooth harrow	2X	2X	
Planter	X		
Planter with P distrib.		X	X
Herbicide	3X	3X	3X
Cultivator	X		
Cultivator with N distrib.		X	X
Pesticide	2X	3X	3X
Harvest	X	X	X

Table 2.6 Description of tillage systems for soybean

Field operation	Traditional tillage	Reduced tillage	No tillage
Molboard plow	X	X	
Broadcast granular N and P	X	X	
Field cultivator	X		
Rotary harrow		X	
Peg-tooth harrow	2X	X	
Planter	X	X	
No-till planter with P distrib.			X
Herbicide	3X	2X	4X
Cultivation	X		
Irrigation	X		
Harvest	X	X	X

Table 2.7 Description of tillage systems for corn

Field operation	Traditional tillage	Reduced tillage	No tillage
Molboard plow	X	X	
Broadcast granular N and P	X	X	
Field cultivator	X		
Rotary harrow		X	
Peg-tooth harrow	2X	X	
Planter	X	X	
No-till planter with P distrib.			X
Herbicide	2X	2X	3X
Cultivator	X		
Cultivator with N distrib.		X	X
Irrigation	X		
Harvest	X	X	X

Table 2.8 Complete choice of tillage systems available to the farmer

Crop	System
Wheat	Reduced tillage (WH2) No-tillage (WH3)
Sugarbeet	Traditional tillage (SU1) Reduced tillage (SU2) No-tillage (SU3)
Soybean	Traditional tillage (SO1) Reduced tillage (SO2) No-tillage (SO3)
Corn	Traditional tillage (CO1) Reduced tillage (CO2) No-tillage (CO3)

soybean = 578,600, and

corn = 329,000.

All feasible tillage practices are supposed possible; hence not only traditional systems but also reduced and no-tillage systems are considered available choices to the producer. The complete set of these tillage systems is presented in Table 2.8.

Model rotation activities definition

Under the modeling procedure chosen, given the choice of tillage systems available, the four crops grown and one year of preceding crop influence on yields, 112 two-year rotation activities ($t_{is}^{\delta\kappa}$) are defined. The list of these activities is as follows:

Continuous RT Wheat (WH2WH2)
RT Wheat following NT Wheat (WH2WH3)
RT Wheat following TT Sugarbeet (WH2SU1)
RT Wheat following RT Sugarbeet (WH2SU2)
RT Wheat following NT Sugarbeet (WH2SU3)
RT Wheat following TT Soybean (WH2SO1)
RT Wheat following RT Soybean (WH2SO2)
RT Wheat following NT Soybean (WH2SO3)
RT Wheat following TT Corn (WH2CO1)
RT Wheat following RT Corn (WH2CO2)
RT Wheat following NT Corn (WH2CO3)
NT Wheat following RT Wheat (WH3WH2)
Continuous NT Wheat (WH3WH3)
NT Wheat following TT Sugarbeet (WH3SU1)
NT Wheat following RT Sugarbeet (WH3SU2)
NT Wheat following NT Sugarbeet (WH3SU3)
NT Wheat following TT Soybean (WH3SO1)
NT Wheat following RT Soybean (WH3SO2)
NT Wheat following NT Soybean (WH3SO3)
NT Wheat following TT Corn (WH3CO1)
NT Wheat following RT Corn (WH3CO2)
NT Wheat following NT Corn (WH3CO3)
TT Sugarbeet following RT Wheat (SU1WH2)

TT Sugarbeet following NT Wheat (SU1WH3)

TT Sugarbeet following TT Soybean (SU1SO1)

TT Sugarbeet following RT Soybean (SU1SO2)

TT Sugarbeet following NT Soybean (SU1SO3)

TT Sugarbeet following TT Corn (SU1CO1)

TT Sugarbeet following RT Corn (SU1CO2)

TT Sugarbeet following NT Corn (SU1CO3)

RT Sugarbeet following RT Wheat (SU2WH2)

RT Sugarbeet following NT Wheat (SU2WH3)

RT Sugarbeet following TT Soybean (SU2SO1)

RT Sugarbeet following RT Soybean (SU2SO2)

RT Sugarbeet following NT Soybean (SU2SO3)

RT Sugarbeet following TT Corn (SU2CO1)

RT Sugarbeet following RT Corn (SU2CO2)

RT Sugarbeet following NT Corn (SU2CO3)

NT Sugarbeet following RT Wheat (SU3WH2)

NT Sugarbeet following NT Wheat (SU3WH3)

NT Sugarbeet following TT Soybean (SU3SO1)

NT Sugarbeet following RT Soybean (SU3SO2)

NT Sugarbeet following NT Soybean (SU3SO3)

NT Sugarbeet following TT Corn (SU3CO1)

NT Sugarbeet following RT Corn (SU3CO2)

NT Sugarbeet following NT Corn (SU3CO3)

TT Soybean following RT Wheat (SO1WH2)

TT Soybean following NT Wheat (SO1WH3)

TT Soybean following TT Sugarbeet (SO1SU1)

TT Soybean following RT Sugarbeet (SO1SU2)

TT Soybean following NT Sugarbeet (SO1SU3)

Continuous TT Soybean (SO1SO1)

TT Soybean following RT Soybean (SO1SO2)

TT Soybean following NT Soybean (SO1SO3)

TT Soybean following TT Corn (SO1CO1)

TT Soybean following RT Corn (SO1CO2)

TT Soybean following NT Corn (SO1CO3)

RT Soybean following RT Wheat (SO2WH2)

RT Soybean following NT Wheat (SO2WH3)

RT Soybean following TT Sugarbeet (SO2SU1)

RT Soybean following RT Sugarbeet (SO2SU2)

RT Soybean following NT Sugarbeet (SO2SU3)

RT Soybean following TT Soybean (SO2SO1)

Continuous RT Soybean (SO2SO2)

RT Soybean following NT Soybean (SO2SO3)

RT Soybean following TT Corn (SO2CO1)

RT Soybean following RT Corn (SO2CO2)

RT Soybean following NT Corn (SO2CO3)

NT Soybean following RT Wheat (SO3WH2)

NT Soybean following NT Wheat (SO3WH3)

NT Soybean following TT Sugarbeet (SO3SU1)

NT Soybean following RT Sugarbeet (SO3SU2)

NT Soybean following NT Sugarbeet (SO3SU3)

NT Soybean following TT Soybean (SO3SO1)

NT Soybean following RT Soybean (SO3SO2)

Continuous NT Soybean (SO3SO3)

NT Soybean following TT Corn (SO3CO1)

NT Soybean following RT Corn (SO3CO2)

NT Soybean following NT Corn (SO3CO3)

TT Corn following RT Wheat (CO1WH2)

TT Corn following NT Wheat (CO1WH3)

TT Corn following TT Sugarbeet (CO1SU1)

TT Corn following RT Sugarbeet (CO1SU2)

TT Corn following NT Sugarbeet (CO1SU3)

TT Corn following TT Soybean (CO1SO1)

TT Corn following RT Soybean (CO1SO2)

TT Corn following NT Soybean (CO1SO3)

Continuous TT Corn (CO1CO1)

TT Corn following RT Corn (CO1CO2)

TT Corn following NT Corn (CO1CO3)

RT Corn following RT Wheat (CO2WH2)

RT Corn following NT Wheat (CO2WH3)

RT Corn following TT Sugarbeet (CO2SU1)

RT Corn following RT Sugarbeet (CO2SU2)

RT Corn following NT Sugarbeet (CO2SU3)

RT Corn following TT Soybean (CO2SO1)

RT Corn following RT Soybean (CO2SO2)

RT Corn following NT Soybean (CO2SO3)

RT Corn following TT Corn (CO2CO1)
Continuous RT Corn (CO2CO2)
RT Corn following NT Corn (CO2CO3)
NT Corn following RT Wheat (CO3WH2)
NT Corn following NT Wheat (CO3WH3)
NT Corn following TT Sugarbeet (CO3SU1)
NT Corn following RT Sugarbeet (CO3SU2)
NT Corn following NT Sugarbeet (CO3SU3)
NT Corn following TT Soybean (CO3SO1)
NT Corn following RT Soybean (CO3SO2)
NT Corn following NT Soybean (CO3SO3)
NT Corn following TT Corn (CO3CO1)
NT Corn following RT Corn (CO3CO2)
Continuous NT Corn (CO3CO3)

In this list, TT is traditional tillage, RT is reduced tillage and NT is no-tillage.

As explained earlier, continuous sugarbeet was not included as a feasible rotation activity because of the serious parasites problems and the product quality deterioration it brings along.

Budgeting crop activities

An attempt to model the four crops for each tillage system and one-year precedence would require data on all 112 cropping possibilities. Such data were not available. In fact, only for a limited number of rotations data from the representative farm could be obtained. The remaining crop activities have been defined upon consultation with agronomists at the Institute of Agronomy of the Bologna University. For each activity, the field operations and labor requirements have been identified and, consequently, the direct costs could be estimated.

Crop budgets for the representative farm have been constructed to reflect profits, returns over direct and imputed costs. Direct costs represent the crop-related inputs, custom operations labor and machinery expenses; imputed costs are farm capital repairs and insurance expenses, administration and management costs, taxes and interests.

Within the direct costs, farmer-owned machinery and equipment costs are based on the number of field hours and are comprehensive of fuel and motor oil consumption, repairs and depreciation; custom operation costs (no-tillage planting, harvest and transport) are based on 1990 custom rates; hired labor costs are computed on the basis of the market wage rate level, 15,000 Lire per hour. Nitrogen expenses were not added to the direct costs, since the level of nitrogen fertilization is a variable in the model, to be determined in the optimization process.

Imputed costs were estimated upon consultation with economists at the Institute of Farm Accounting of the Bologna

University; they represent an average of imputed costs for family farm enterprises of the area considered in this study. The interests are then computed on the sum of total direct expenses and the imputed costs, with a 13 percent interest rate and a 6-month average anticipation period.

Total direct costs, with the exclusion of nitrogen, and total imputed costs for all rotational activities are attached in the Appendix.

Fieldwork and labor constraints

Labor requirements for each rotation activity were calculated upon consultation with agronomists and farm equipment technicians at the Bologna University. They were estimated by attaching farm machinery capacities to the operations listed for the tillage systems; results are attached in the Appendix.

Average labor time available per season was given by the farmer as follows:

Spring = 650,
Summer = 850, and
Fall = 650.

By defining labor requirements by season, a labor constraint is obtained for three different periods: spring, summer and fall. The model specific constraints, whose general form was given as (11), are now specified as follows:

$$(15) \qquad \sum_{\delta=1}^{M} \sum_{\epsilon=1}^{M} \sum_{i=1}^{N} \sum_{s=1}^{N} t_{is}^{\delta\epsilon} * l_{is}^{\delta\epsilon(se)} \leq L^{(se)} + HL^{(se)}$$

$$(16) \qquad HL^{(se)} = \sum_{\delta=1}^{M} \sum_{\epsilon=1}^{M} \sum_{i=1}^{N} \sum_{s=1}^{N} HL_{is}^{\delta\epsilon(se)}$$

where

$l_{is}^{\delta\epsilon(se)}$, is the seasonal labor requirement for each rotational activity,

$L^{(se)}$, is the farmer seasonal labor availability, and

$HL^{(se)}$, is the seasonal hired labor total requirement.

Equation (15) is the set of seasonal labor constraints and imposes that for each season farming labor be no more than total labor available, including hired one.

Finally, total annual hired labor necessary for each rotational activity, as indicated in the objective function (8) and in the profit function (13), results the following:

$$(17) \qquad HL_{is}^{\delta\epsilon} = \sum_{(se)=1}^{3} HL_{is}^{\delta\epsilon(se)}$$

Crop yield response functions definition

A yield response function to nitrogen was estimated for each crop grown in the farm under all feasible tillage systems and rotational combinations. Upon consultation with agronomists at the Institutes of Agronomy of the Bologna and Padova Universities, the maximum yield levels (*Aws*) for the tillage systems adopted in this study and the fertility level of the soil, the *b* values, were defined; the *c* and the *k* coefficients were estimated at Padova University, based on farm data from experiment stations. The results of the parameters estimation are presented in Table 2.9 and the crop response functions are shown in Figures 2.1 to 2.4.

Table 2.9 Estimates of crops response functions parameters[a]

Crops	Tillage systems	*Aws* (ton/ha)	$c * 10^{-4}$	$k * 10^{-7}$	*b* (kg/ha)
Wheat	RD	7.50	70	1.5	120
	NT	6.75			
Sugarbeet	TT	60.00	73	0.0	137
	RT	54.00			
	NT	45.00			
Soybean	TT	4.50	70	0.0	317
	RD	4.23			
	NT	3.82			
Corn	TT	9.00	65	1.0	125
	RD	8.55			
	NT	7.65			

[a] Source: Institute of Agronomy, Padova University.

A complete set of yield adjustment factors, the $\alpha_{is}^{\hat{\delta}\epsilon}$ coefficients, have been defined. These factors are based on the results of long-term studies conducted by the agronomists of the Bologna University at several experiment stations in the area of interest and represent the full range of interaction effects of rotations in crops response to nitrogen

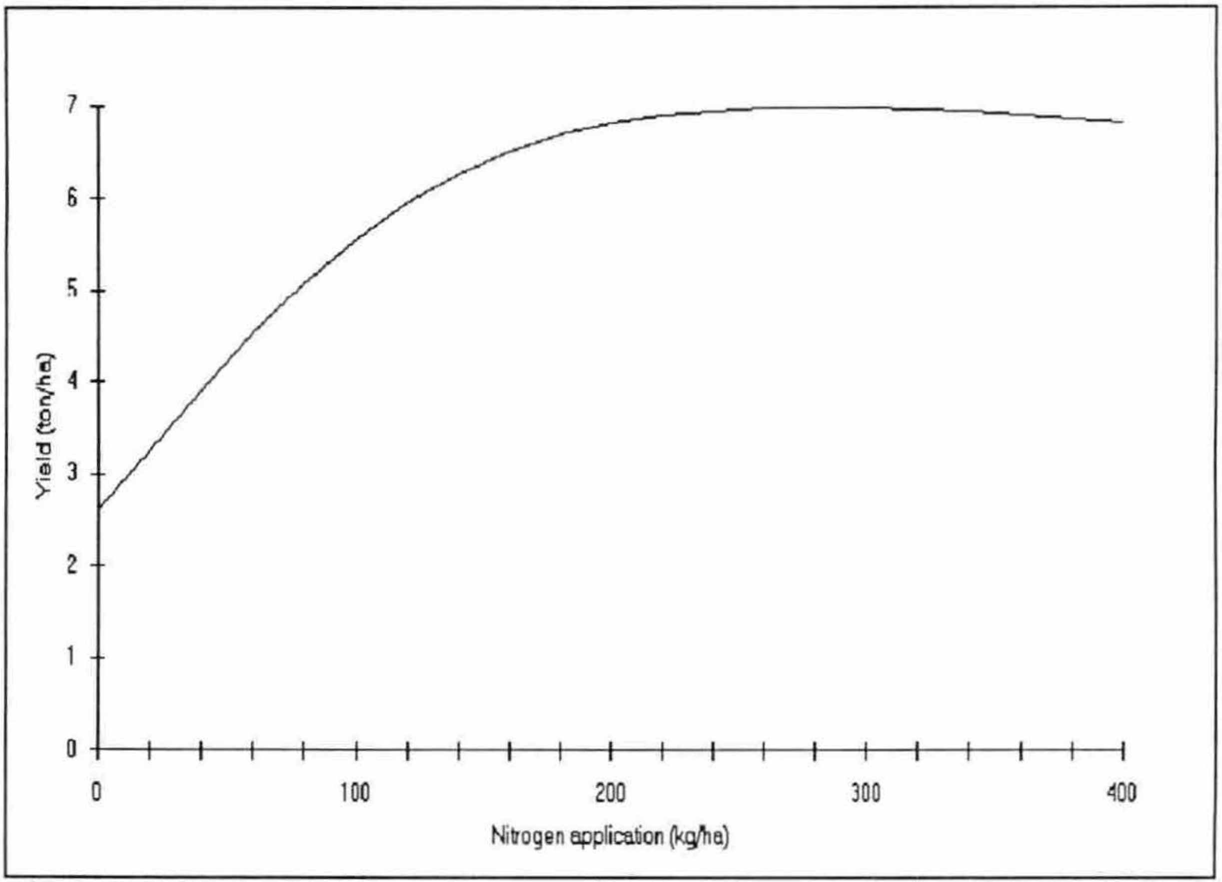

Figure 2.1 Wheat response to nitrogen

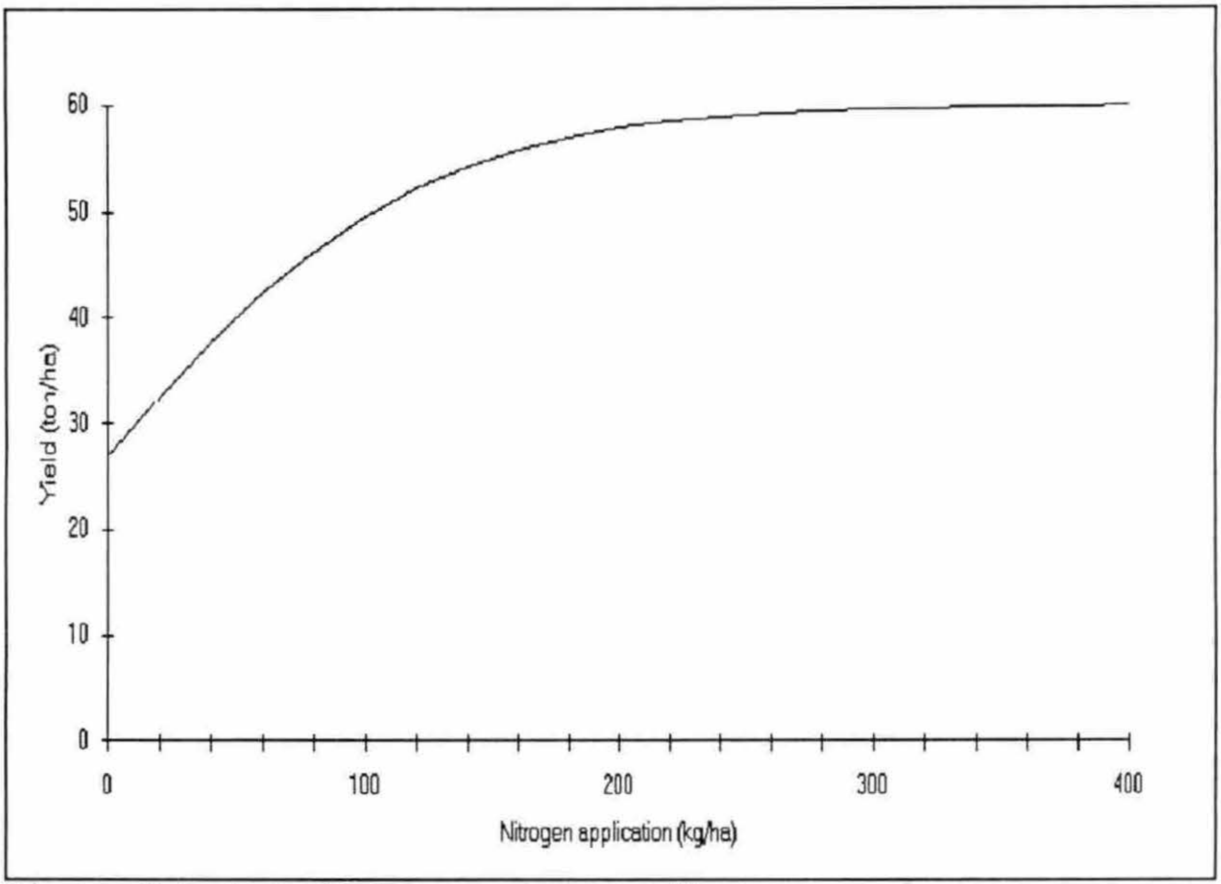

Figure 2.2 Sugarbeet response to nitrogen

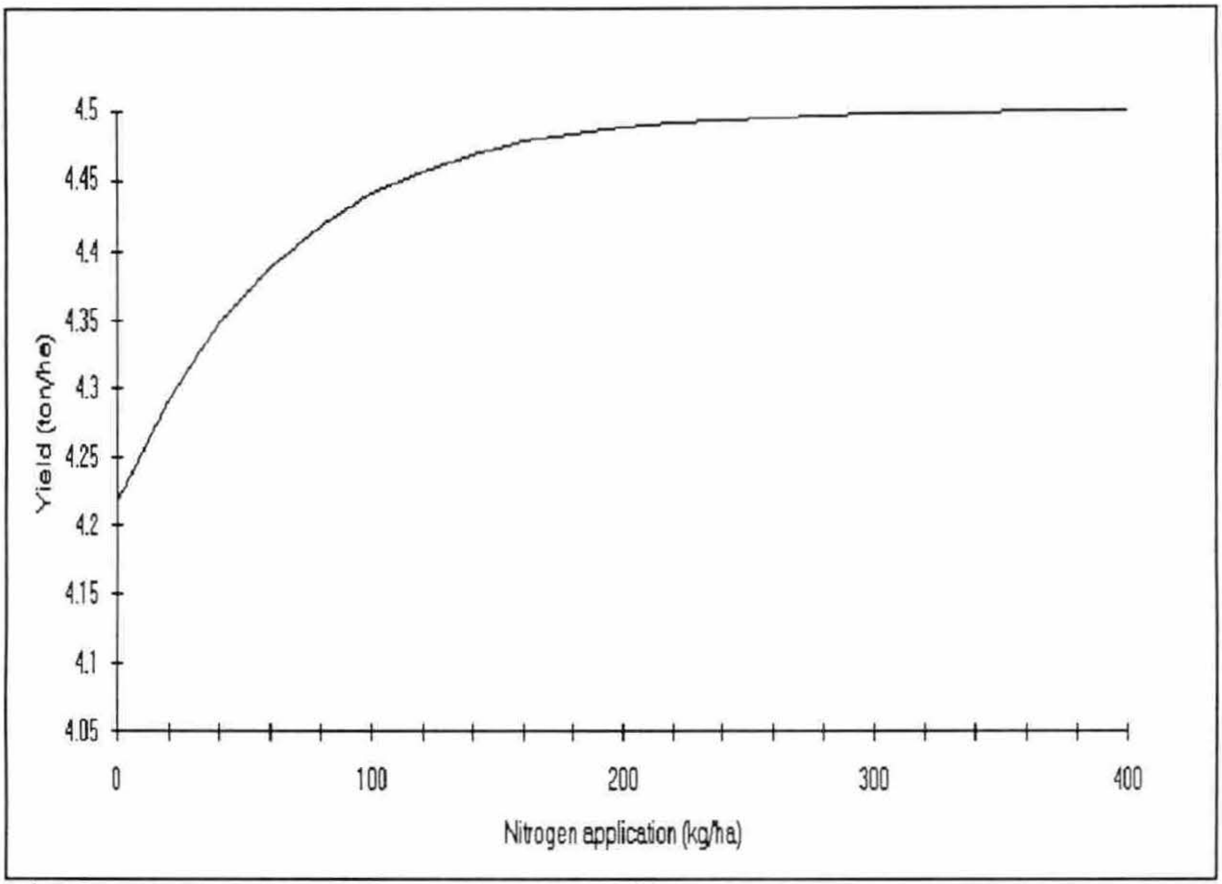

Figure 2.3 Soybean response to nitrogen

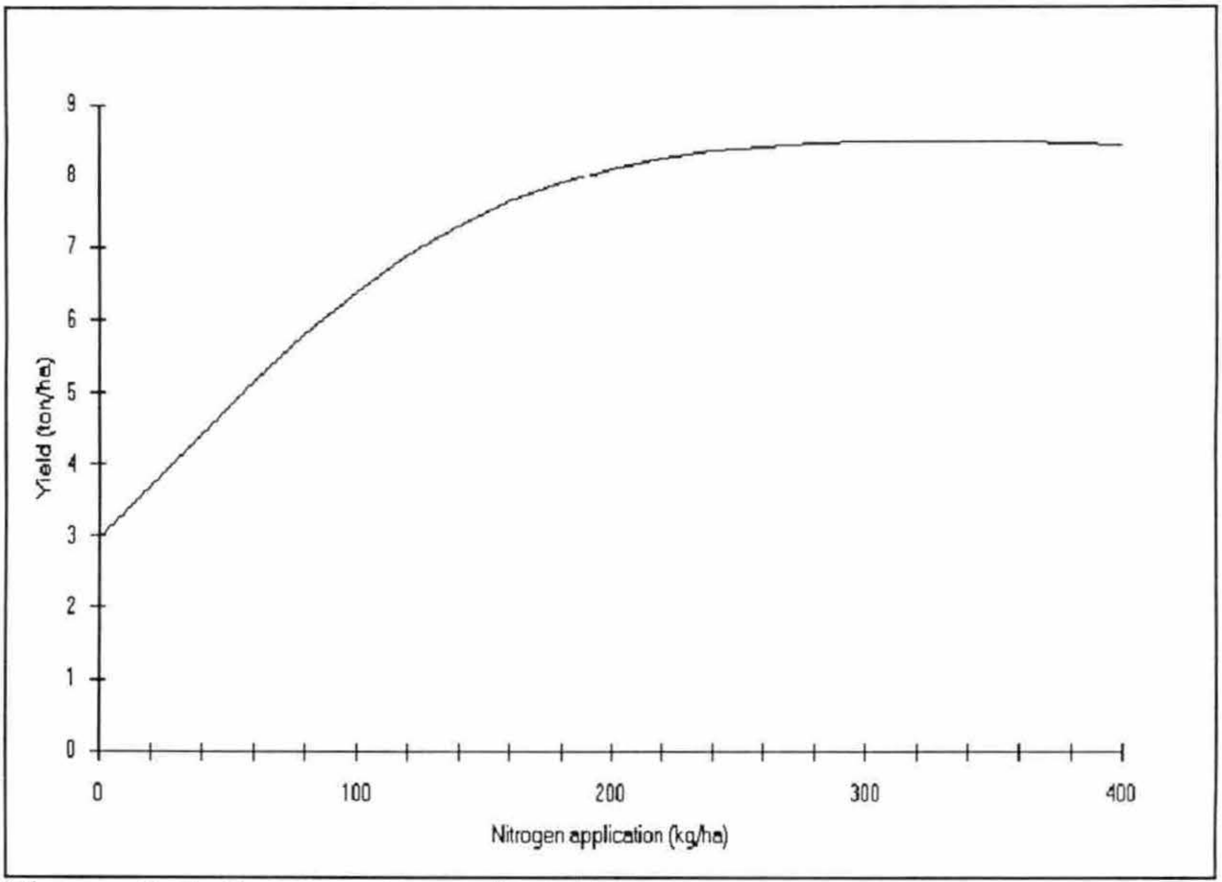

Figure 2.4 Corn response to nitrogen

application. Results are attached in the Appendix.

The Post-MacSharry Optimization Model

Professional **producer**

A second optimum farm plan is identified for the stabilized market conditions following the introduction of the policy changes of the MacSharry plan. The base year is considered 1995.

A new production scheme must be adopted to comply with the provisions of the MacSharry plan. 15 percent of wheat, soybeans and corn farmed area must be idled from production under the new rotational set-aside requirements and, in return, the farmer is eligible to receive program support payments.

Given the provisions laid out in Reg. NN. 1765/92, 1766/92, 2293/92 and 2294/92, and the results of the Italian regionalization plan (Confagricoltura, 1992), the compensatory payments (C_i), expressed in Lire per hectare, result the following:

$C_{(wheat)}$ = regional yield (t/ha) * compensatory aid (L/t) =
= 5.927 * 79,265.25 = 469,805

$C_{(soybean)}$ = EC reference price (L/ha) * conversion factor =
= 632,360.55 * (61/46) = 838,565

$C_{(corn)}$ = regional yield (t/ha) * compensatory aid (L/t) =
= 8.044 * 79,265.25 = 637,610.

No payment is provided for sugarbeet, since no sugar policy reform is specified in the MacSharry plan.

Given these changes, the per-hectare profit definition, whose general form was given in equation (6), now takes the form:

$$
\begin{aligned}
\Pi_{is}^{\delta\epsilon} = {} & (1-R_i)\,[\,P_i * y_{is}^{\delta\epsilon}(x_{is}^{\delta\epsilon})\,] + C_i \\
& - \{(1-R_i)\,[\,(r * x_{is}^{\delta\epsilon}) + Q_{is}^{\delta\epsilon}\,] + K_{is}^{\delta\epsilon}\,\} \\
& - R_i * D^{(set)} - P_{HL} * HL_{is}^{\delta\epsilon}
\end{aligned}
\qquad (18)
$$

where

C_i,	is the per-hectare compensatory payment,
R_i,	is the rotational set-aside requirement, and
$D^{(set)}$,	is the set-aside maintenance cost.

The cost of the set-aside land maintenance operations, to be carried out with land harrowing in early spring and late summer, plus the mowing of the spring natural grass cover, have been estimated at 260,000 Lire per hectare.

The imputed costs, $K_{is}^{\delta\epsilon}$, need to be adjusted for the different composition of the interests, which are now to be computed on a 1-R_i percentage of the crops direct costs and on a R_i percentage of the set-aside maintenance expenses.

Wheat and corn market prices are approximated at the intervention levels fixed by the Council in Reg. N. 1766/92, while soybeans price is expected to fall at the world market reference price of 163 ECU/t. Sugarbeet price, instead, is supposed to remain unaltered. Expressed in Lire per ton, the prices of the four crops result the following:

wheat = 180,000,
sugarbeet = 74,100,
soybean = 280,000, and
corn = 180,000.

Small producer

The choice of the representative farm for this study was carried out with the purpose of evaluating the effects of the policy changes on both *professional* and *small* producers. As previously explained, *small* producers are granted a special regime under the MacSharry plan. This regime is optional, since the farmer, should he find it more convenient, is free to participate to the *professional* regime instead.

The evaluation of the effects of the MacSharry reform on small farms is a matter of great interest for Italian agriculture. Small family operations represent over 80 percent of total Italian farms (ISTAT, 1989) and consequently their response to the proposed policy changes is important for the success of the MacSharry plan in this country.

For this purpose, it is supposed that the representative farm chosen in this study can be divided into two identical, smaller units of 20 hectares of arable land in size. Land division expenses are assumed irrelevant, here. The 20 hectare-unit production costs do not differ from those of the full-size farm, since the same equipment and technology would be utilized in the farm operations.

Since both regimes are possible now, the optimum farm plans for the smaller 20-hectare unit under the *professional* and the *small* regimes can be computed and compared. This comparison will then provide a reasonable description of the diverse effects of the proposed policy changes on a *professional* and a *small* producer. It is evident that if the farmer is able to increase his profits as a *small* producer, an incentive to the reduction of the size of his enterprise is introduced by the MacSharry reform. Instead, the converse would hold if farm profits were higher in the *professional* producer case.

Obviously, the results of a single-farm model do not hold for the whole farm sector, but it is not unreasonable to extend the result of this analysis to a large number of operations in the area of interest. The representative farm chosen in this study is in all respects very similar to many smaller family enterprises, with full-time family labor employed, extra-labor hired only when needed and all heavy equipment operations, as grains harvesting or sugarbeet extraction, purchased as custom services. Consequently, crops direct costs should not differ from those of smaller enterprises by any means. Among the imputed costs, some discrepancies might arise in the repairs and maintenance expenses, in the management cost and tax outlays, but in the estimation of these costs for the representative farm, the average values for many family operations in the area of interest have been utilized. Thus, they should be well-representative of a large number of farms.

Small producers are exempted from any rotational set-aside requirement and can receive the support payments for the whole area they farm. Although granted a simplified aid scheme, *small* producers do not benefit from the same level of income support granted to *professional* producers. In fact, the aid is paid to them on a per-hectare basis for the area under cereals, oilseeds and protein crops, independent of the mix of crops sown and referred to the regional all-cereal (corn included) average yield. The per-hectare profit definition for the *small* producer takes the following form:

$$\begin{aligned} \Pi_{is}^{\delta\epsilon} &= p_i * y_{is}^{\delta\epsilon}(x_{is}^{\delta\epsilon}) + C \\ &\quad - [(r * x_{is}^{\delta\epsilon}) + Q_{is}^{\delta\epsilon} + K_{is}^{\delta\epsilon}] - P_{HL} * HL_{is}^{\delta\epsilon} \end{aligned} \tag{19}$$

Given the results of the Italian regionalization plan (Confagricoltura, 1992), the compensatory payment for wheat, soybean and corn for the small producer, expressed in Lire per hectare, is to be calculated as follows:

C = regional yield (t/ha) * compensatory aid (L/t) =

= 6.100 * 79,265.25 = 483,518.

Model Computation

The software package utilized to solve the model is the General Algebraic Modeling System GAMS, version 2.5 (Brooke, Kendrick, and Meeraus; 1988). Non-linear programming was used as the solution algorithm. GAMS is designed to make construction and solution of large and complex mathematical programming models more straightforward and easier to understand by users of models from other disciplines.

GAMS was developed by an economic modeling group at the World Bank.

CHAPTER III.

RESULTS AND DISCUSSION

The results of this investigation are divided into two sections. First, the optimum farm plan for the period preceding the MacSharry reform is compared to the ordinary production plans of the farmer, as recorded from farm data. A model validation analysis is also performed, to test the robustness of the model assumptions and the goodness of the parameters utilized. Then, a second optimal solution is found for the period following the introduction of the reform. From the comparison with the pre-reform optimal solution, the effects of the MacSharry policy changes on farm yields, tillage systems and crop rotations are then evaluated. The influence of several policy variables on the model solution is finally investigated in a series of sensitivity analyses.

Definitions and Specifications

Before discussing the model results, several terms used in the text need to be defined or summarized:

1. There are four crops, wheat (*WH*), sugarbeet (*SU*), soybean (*SO*) and corn (*CO*).
2. The tillage systems discussed are traditional tillage (*1*), reduced tillage (*2*) and no-tillage (*3*), abbreviated in the text as TT, RT and NT, respectively.
3. No traditional tillage is considered in the case of

wheat.

4. It is supposed that the yield of a crop is influenced by the crop planted on the same land in the previous year and by the tillage system adopted in current and previous years.
5. A model rotation activity represents *year t* crop succeeding *year t-1* crop, with the tillage systems of both crops fully specified. For example, the activity *WH2SU1* stands for RT wheat following TT sugarbeet.
6. Continuous sugarbeet is assumed non-feasible. The area sown on this crop cannot exceed one-third of total farm arable land; two-year rotations including sugarbeet are discouraged.

As previously specified, in this modeling procedure crop yields depend exclusively on the level of nitrogen application. Consequently, nitrogen usage is a variable to be optimized in the model. Nevertheless, this is not a free variable. In the case of wheat and sugarbeet an upper bound to the level of nitrogen application had to be introduced, to reflect the agronomic constraints faced by the farmer. Excessive nitrogen fertilization leads to lodging in wheat and a sharp decrease of the sugar content in sugarbeet, thus to reduced output and farm profits. Upon consultation with agronomists at the Bologna University, the upper limit was then fixed at 180 and 150 kg per hectare for wheat and sugarbeet, respectively. For soybean and corn no agronomical upper constraint needs to be imposed on the usage of this input. But to prevent unbounded solutions for the non-linear algorithm, a technical upper limit was set at approximately ten times the fertilization level recorded on the farm or defined with the agronomists at the University. To facilitate the solution of the program, a technical lower bound on the input level variable was also defined. In fact, when no initial value is provided, GAMS uses zero or, if the variable is bounded away from zero, the bound that is closest to zero. To avoid "corner point" solutions with all-zero or unreasonably low variable levels, for each crop a lower bound of 50 percent of the average fertilization level recorded at the farm was chosen. A summary of the variable bounds is presented in Table 3.1.

The Pre-MacSharry Equilibrium

Results from the profit-maximizing model are given in Table 3.2 and 3.3. The best plan involves a continuous three-year rotation including RT wheat, followed by TT sugarbeet and RT soybean, and then starting with RT wheat again. Compared with the most common solutions adopted by the farmer, this optimum farm plan allows for an increase in total farm profits ranging between 12 and 50 percent. Greater gains are shown over the wheat-soybean combination and the rotations which

Table 3.1 Lower and upper bound imposed on the nitrogen input variable, expressed in kg per hectare.

Crop	Lower Bound	Upper Bound
Wheat		
RT	75	180
NT	75	180
Sugarbeet		
TT	75	150
RT	50	150
NT	62.5	150
Soybean		
TT	25	500
RT	12.5	500
NT	0	500
Corn		
TT	150	3000
RT	125	3000
NT	150	3000

Table 3.2 Pre-MacSharry Model results: the optimum farm plan

Crop Rotation Activities	Total Arable Land Share
WH2SO2	0.33
SU1WH2	0.33
SO2SU1	0.33

include corn, while the profit gap reduces when both sugarbeet and soybean are included in the traditional rotation. Interestingly, the optimal farm plan is almost identical to the most profitable among the traditional solutions considered (*TFP3*), although reduced tillage now replaces traditional tillage in soybean. Relative to all traditional production schemes, higher farm profits in the optimum farm plan increase the returns on the limiting fixed factor, land, whose shadow price (λ) rises by over 40 percent. On the contrary, the shadow price of labor is always zero, implying that family labor is never a limiting factor and no hired labor is required in the operations of the farm.

In Table 3.3 optimal and traditional yields and nitrogen applications are also compared. In the optimum farm plan the fertilization level for wheat is increased by 20 percent, to the maximum usage allowed by in model, and average production is 5 percent higher than in traditional plans. A substantial increase in nitrogen application partly compensates for the

Table 3.3 Pre-MacSharry Model results: a comparison between the optimum farm plan (OFP) and some traditional farm plans (TFP)[a]

Model Variables	OFP	TFP1	TFP2	TFP3	TFP4	TFP5
Obj. Value (000 L/ha)	829.58	698.35	599.77	737.43	555.21	550.59
Land λ (000 L/ha)	661.16	460.54	460.54	460.54	460.54	460.54
Labor λ (000 L/ha)	0.00	0.00	0.00	0.00	0.00	0.00
Crop Yield (t/ha):						
wheat	6.61	6.29	6.23	6.39	6.27	6.39
sugarbeet	54.54	54.54	54.54	54.54	54.54	
soybean	3.91	4.33		4.33		4.33
corn			8.38		7.54	
Nitrogen Usage (kg/ha):						
wheat	180.00	150.00	150.00	150.00	150.00	150.00
sugarbeet	150.00	150.00	150.00	150.00	150.00	
soybean	85.00	50.00		50.00		50.00
corn			300.00		300.00	
Tillage System:						
wheat	RT	RT	RT	RT	RT	RT
sugarbeet	TT	TT	TT	TT	TT	
soybean	RT	TT		TT		TT
corn			TT		TT	

[a] The following TPP have been considered:
TPP1 = 4-year RT wheat-TT sugarbeet-RT wheat-TT soybean,
TPP2 = 4-year RT wheat-TT sugarbeet-RT wheat-TT corn,
TPP3 = 3-year RT wheat-TT sugarbeet-TT soybean,
TPP4 = 3-year RT wheat-TT sugarbeet-TT corn,
TPP5 = 2-year RT wheat-TT soybean.

reduced tillage effects on soybean output and, on average, the yield falls by 10 percent. Sugarbeet nitrogen usage and tillage system remain identical and no changes occur in the level of the output, while corn does not enter the optimal solution at all.

From these results, farm production in the period preceding the MacSharry reform can be summarized as follows:

1. General inefficiency in resources allocation, originating from expensive production techniques and/or low-profit crop rotations.
2. Low wheat and soybean nitrogen fertilization rates.
3. Low average wheat yield.
4. Non optimal soybean tillage system.
5. High profitability of sugarbeet in the rotations.
6. Low profitability of corn in the rotations.

Model Validation

The purpose of the model validation analysis is to investigate the stability of the optimal programming solution. The analysis is performed under a *ceteris paribus* condition, whereby the effects of a change in a single coefficient is considered with all the other coefficients held constant. As explained in Hazell and Norton (1986), the stability of the solution refers to the degree of variation in the coefficients that can be absorbed by the model before a change in the basis occurs. A change in the basis is said to occur when a new activity enters the solution, or one previously in the solution drops out. The value of the coefficient at which the change in the basis occurs is its critical turning point, while the change in a coefficient as required to span two critical turning points is referred to as the range for each coefficient under the *ceteris paribus* condition.

Unlike other software packages, described in Sposito (1975) and Hazell and Norton (1986), GAMS does not provide an option to test the stability of the optimal programming solution. Consequently, a validation analysis can be carried out by arbitrarily set a variation range and observe the behavior of the coefficients within the range. Should a change in the basis occur, this range would identify the interval containing the unknown critical turning point.

The coefficients analyzed in the validation analysis of the present model are the parameters of the crops response function to nitrogen, crops direct and imputed costs and the level of the interest rate. The model stability is tested on a 10 percent range variation of each of these parameters, observing whether the basis is altered (Δ) or left unmoved (-) by the change.

Results are presented in Table 3.4. Generally, the model solution is more responsive to a decrease in the value of the parameters. A change in the basis occurs for a 5 percent

Table 3.4 Model validation analysis: summary of the results

Parameter	Variation -5%	 +5%
Aws	Δ	-
c	Δ	-
k	-	-
b	Δ	-
α	Δ	-
Q	-	Δ
K	-	-
ir	-	-

reduction in the maximum yield levels (*Aws*), the action coefficients (*c*) and the soil fertility coefficients (*b*). A 10 percent variation in the depression coefficients (*k*) does not influence the model solution, since the optimal nitrogen application levels always fall within the increasing part of the crops response curves. Accuracy in the choice of the rotational yield correction coefficients (α) is also important, since the basis is changed by a 5 percent decrease of their values. A change in the direct (*Q*) and imputed (*K*) costs, as well as in the rate of interest (*ir*), reflects the influence of a variation in the cost of production on the optimum farm plan. No change in the basis occurs for a 10 percent variation in the level of the imputed costs and the interest rate chosen, while a rise in direct costs leads to the definition of a new solution, hence of a new optimum farm plan.

The Post-MacSharry Equilibrium

The *professional* producer

The optimum farm plan, as shown in Table 3.5, involves a continuous three-year rotation including NT wheat, followed by TT sugarbeet and RT soybean, and then starting with NT wheat again. The policy reforms introduced with the MacSharry plan leave the pre-reform optimal rotation unchanged but impose an additional budgetary constraint, forcing the farmer to adopt a less-expensive farming solution, achieved with the introduction of no-tillage in wheat cultivation.

Table 3.5 Post-MacSharry Model results: the optimum farm plan for a *professional* producer

Crop Rotation Activities	Total Arable Land Share
WH3SO2	0.33
SU1WH3	0.33
SO2SU1	0.33

In Table 3.6 the optimum farm plans for the *professional* producer before and after the reform are compared. The deterioration of the farmer situation is evident. Farm profits drop by almost 40 percent and the lower profitability induces a sharp reduction in returns over the fixed factor, land, whose shadow price falls by one-fourth of its original value. Wheat fertilization rate remains unaltered, but the adoption

Table 3.6 Post-MacSharry results: a comparison between the optimum farm plans before and after the reform; the *professional* producer case

Crop Rotation Activities	Pre-reform Optimum Farm Plan	Post-reform Optimum Farm Plan
Obj. Value (000 L/ha)	829.58	512.64
Land λ (000 L/ha)	661.16	502.20
Labor λ (000 L/ha)	0.00	0.00
Crop Yield (t/ha):		
wheat	6.61	5.95
sugarbeet	54.54	52.34
soybean	3.91	3.84
Nitrogen Usage (kg/ha):		
wheat	180.00	180.00
sugarbeet	150.00	150.00
soybean	85.00	38.00
Tillage System:		
wheat	RT	NT
sugarbeet	TT	TT
soybean	RT	RT

of minimum tillage determines a 10 percent reduction in its yield. Sugarbeet nitrogen usage and tillage system are also unchanged, but yield drops by 4 percent for the negative effect of minimum tillage of preceding crop, wheat, in the rotation. In the case of soybean, the same tillage system is maintained; nitrogen fertilization is reduced by over 50 percent but yield decreases by only 2 percent, due to the very low responsiveness of this crop to nitrogen fertilization.

These results are only partially modified if the optimum farm plan following the introduction of the policy changes is compared to the outcomes of the traditional plans in the period preceding the reform as given in Table 3.3. This comparison is certainly a useful one, since it fully assesses the impact of the MacSharry provisions on the ordinary operations of the farmer rather than on a optimal situation.

Assuming rational producer behavior and full transmission of technological innovations, it is reasonable to imagine that, following the introduction of the policy changes, the farmer is willing to quit his traditional production schemes and adopt the new optimal plan. In this case a 15-30 percent reduction in average farm profits would occur, a more moderate result than in the previous case. Again, output levels would be reduced for all crops. A 20 percent increase in nitrogen application would partly compensate for the no-tillage effects on wheat output, and only a 5 percent decrease in the average yield would occur. In the case of soybean, the reduced tillage effects, combined with a 24 percent decrease in nitrogen usage would determine a 12 percent reduction in the average yield. As in the previous case, sugarbeet tillage system and nitrogen usage would not be affected by any means, but the negative effects of the no-tillage system of preceding wheat in the rotation would affect its yield, which would be reduced by 4 percent.

Relative to the pre-reform equilibrium, labor requirement would drop by 10 percent and, as before, family labor would never result a binding constraint in the operations of the farm.

The possibility for the farmer to maintain his traditional production plans after the implementation of the MacSharry reform is also a matter of interest. This situation is illustrated in Table 3.7.

Clearly, should the farmer insist on his traditional farm plans and tillage techniques, the level of farm profit would be reduced even further and, in case sugarbeet were excluded from the rotation, it would almost drop to zero. Also, the greater reduction in profitability would determine a further sharp decrease in the value of land, whose shadow price now reduces to just 40 percent of its original value.

Table 3.7 Post-MacSharry results: a comparison between the optimum farm plan (OFP) and some traditional farm plans (TFP)[a] for a *professional* producer

Model Variables	OFP	TFP1	TFP2	TFP3	TFP4	TFP5
Obj. Value (000 L/ha)	512.64	324.04	202.01	432.55	247.12	55.56
Land λ (000 L/ha)	502.20	290.50	290.50	290.50	290.50	290.50
Labor λ (000 L/ha)	0.00	0.00	0.00	0.00	0.00	0.00
Crop Yield (t/ha):						
wheat	5.95	6.29	6.23	6.39	6.27	6.39
sugarbeet	52.34	54.54	54.54	54.54	54.54	
soybean	3.84	4.33		4.33		4.33
corn			8.38		7.54	
Nitrogen Usage (kg/ha):						
wheat	180.00	150.00	150.00	150.00	150.00	150.00
sugarbeet	150.00	150.00	150.00	150.00	150.00	
soybean	38.00	50.00		50.00		50.00
corn			300.00		300.00	
Tillage System:						
wheat	NT	RT	RT	RT	RT	RT
sugarbeet	TT	TT	TT	TT	TT	
soybean	RT	TT		TT		TT
corn			TT		TT	

[a] The following TPP have been considered:
TPP1 = 4-year RT wheat-TT sugarbeet-RT wheat-TT soybean,
TPP2 = 4-year RT wheat-TT sugarbeet-RT wheat-TT corn,
TPP3 = 3-year RT wheat-TT sugarbeet-TT soybean,
TPP4 = 3-year RT wheat-TT sugarbeet-TT corn,
TPP5 = 2-year RT wheat-TT soybean.

The *small* producer

As previously explained, *small* producers are granted an optional special regime under the MacSharry plan. The effects of the policy reforms on a *small* producer are evaluated on the 20-hectare production unit resulting from the division of the representative farm chosen in this study. For reasons given above, it is to be assumed that the 20 hectare-unit production costs do not differ from those of the full-size farm and that the result from this analysis can be extended to a large number of similar enterprises in the area of interest.

For the post-reform period, the optimal solution incorporates the different provisions of the special regime granted to *small* producers. Results are given in Table 3.8, 3.9 and 3.10. Not surprisingly, the optimum farm plan is different from the *professional* producer case. The best plan involves a continuous two-year alternation of NT wheat and TT

Table 3.8 Post-MacSharry Model results: the optimum farm plan for a *small* producer

Crop Rotation Activities	Total Arable Land Share
WH3SU1	0.33
WH3SO2	0.165
SU1WH3	0.33
SO2WH3	0.165

Table 3.9 Post-MacSharry results: a comparison between the optimum farm plans before and after the reform; the *small* producer case

Model Variables	Pre-reform Optimum Farm Plan	Post-reform Optimum Farm Plan
Obj. Value (000 L/ha)	829.58	467.27
Land λ (000 L/ha)	661.16	349.80
Labor λ (000 L/ha)	0.00	0.00
Crop Yield (t/ha):		
wheat	6.61	5.89[a]
sugarbeet	54.54	52.34
soybean	3.91	4.01
Nitrogen Usage (kg/ha):		
wheat	180.00	180.00
sugarbeet	150.00	150.00
soybean	85.00	41.00
Tillage System:		
wheat	RT	NT
sugarbeet	TT	TT
soybean	RT	RT

[a] Average yield of activities WH3SU1 and WH3SO2.

Table 3.10 Post-MacSharry results: a comparison between the optimum farm plan (OFP) and some traditional farm plans (TFP)[a] for a *small* producer

Model Variables	OFP	TFP1	TFP2	TFP3	TFP4	TFP5
Obj. Value (000 L/ha)	467.27	257.38	174.20	325.60	184.26	-99.77
Land λ (000 L/ha)	349.80	228.87	228.87	228.87	228.87	228.87
Labor λ (000 L/ha)	0.00	0.00	0.00	0.00	0.00	0.00
Crop Yield (t/ha):						
wheat	5.89	6.29	6.23	6.39	6.27	6.39
sugarbeet	52.34	54.54	54.54	54.54	54.54	
soybean	4.01	4.33		4.33		4.33
corn			8.38		7.54	
Nitrogen Usage (kg/ha):						
wheat	180.00	150.00	150.00	150.00	150.00	150.00
sugarbeet	150.00	150.00	150.00	150.00	150.00	
soybean	41.00	50.00		50.00		50.00
corn			300.00		300.00	
Tillage System:						
wheat	NT	RT	RT	RT	RT	RT
sugarbeet	TT	TT	TT	TT	TT	
soybean	RT	TT		TT		TT
corn			TT		TT	

[a] The following TPP have been considered:
TPP1 = 4-year RT wheat-TT sugarbeet-RT wheat-TT soybean,
TPP2 = 4-year RT wheat-TT sugarbeet-RT wheat-TT corn,
TPP3 = 3-year RT wheat-TT sugarbeet-TT soybean,
TPP4 = 3-year RT wheat-TT sugarbeet-TT corn,
TPP5 = 2-year RT wheat-TT soybean.

sugarbeet on two-third of the arable land and, contemporarily, a continuous two-year rotation of NT wheat and RT soybean on the remaining farm land. This is not a very satisfactory result since, as previously specified, farmers tend to avoid two-year rotations of sugarbeet for parasites problems and lower product quality.

The model was then re-run imposing an additional constraint on the sugarbeet farm area and a new solution was obtained. This second-best optimum farm plan resulted identical to the *professional* producer case, with a continuous three-year rotation including NT wheat, followed by TT sugarbeet and RT soybean, and then starting with NT wheat again. But in this second case, a sharp decrease in the objective value relative to the first-best solution (minus 10 percent) was observed. Thus, to adopt the optimum farm plan the *small* producer would need to introduce substantial modifications in the tillage systems and in the traditional rotation patterns.

Compared with the *professional* producer case, the reduction of farm profit relative to the pre-reform optimal solution is even more severe and the continuation of the traditional production plans might even lead to consistent losses, in case sugarbeet were excluded from the rotation.

Relative to the pre-reform situation, 8 percent less labor is required in farm operations, a smaller reduction than in the *professional* producer case. The 0 value of its shadow price shows that the labor of the farmer and his family is never a binding constraint in the production activities of the farm considered.

Again, the adoption of the optimum farm plan entails different nitrogen fertilization and crop yield levels. Compared with the traditional solutions, output levels are reduced for all crops. A 20 percent increase in nitrogen application partly compensates for the no-tillage effects on wheat output, and a 7 percent decrease in the average yield occurs. In the case of soybean, tillage is reduced but the smaller decrease in nitrogen usage limits the yield reduction for the *small* producer to only 7 percent. Sugarbeet tillage system and nitrogen usage are still not affected but, as in the previous case, its yield is reduced by 4 percent for the negative effects of the reduced tillage of the preceding crop in the rotation.

Thus, based on the results of this analysis, the effects of the introduction of the MacSharry plan on an Italian representative grain farm located in the south part of the Po Valley can be summarized as follows:

1. Unambiguously, the farmer will be worse-off. Relative to the pre-reform situation, a 20-30 percent reduction in farm profits should be expected for the *professional* producer, while under the *small* producer regime, the deterioration in the level of farm profits is likely to

be even greater.

2. The continuation of the traditional production plans in lieu of the optimum farm plan would lead to further reductions in profits or even to net losses, depending on the crops in rotation and the tillage systems adopted by the farmer.
3. In order to limit the profit losses, several changes in the traditional production practices need to be introduced. In particular, a reduction in wheat and soybean tillage system, an increase in nitrogen usage for wheat and a decrease for soybean are most likely to be expected.
4. The overall effect of these changes on crop yields should result only moderate. The extent of this reduction depends on several factors, e.g., nitrogen usage, crop tillage system and preceding crop tillage system. In particular, the reduction in wheat and soybean yield should not exceed 10 and 12 percent, respectively, while in the case of sugarbeet this reduction should result even lower.
5. Sugarbeet should remain the high-revenue crop in the rotation, while in no case corn should enter the optimum farm plan.
6. Reduced profits are likely to determine a sharp decrease in land values. Relative to the optimal solution for the

period preceding the reform, the shadow price of land for the optimum farm plan in the post-reform period would be reduced, as an effect of the policy changes, by one-fourth for the *professional* producer and by more than 50 percent for the *small* producers.

7. As a consequence of the reduction of the number of field operations, labor requirements should be also consistently diminished.

Sensitivity Analysis

In the words of Paris (1991), sensitivity analysis is the analysis of the way the optimal solution is sensitive to changes in any original coefficients.

One assumption in mathematical programming is that all the coefficients of the model are known constants. Actually, the coefficient values used in the model normally are just estimates based on a prediction of future conditions. But as it is pointed out in Liu (1991), the data utilized to obtain these estimates often are rather crude or nonexistent.

For these reasons, it is important to perform sensitivity analysis to investigate the effect on the optimal solution provided by a change in some of the model coefficients. Usually, some coefficients can be assigned any reasonable value without affecting the optimality of the solution. However, there may be also coefficients with likely alternative values yielding a new optimal solution. The basic objective of sensitivity analysis, therefore, is to identify those particular sensitive coefficients and select a solution that performs well for most of their likely values. An optimal solution is, in fact, optimal only with respect to the specific model being used to represent the real problem, and this solution becomes a reliable guide for action only after it has been verified as performing well for other reasonable representations of the problem as well (Liu, 1991).

In the present study, most of the parameters of the model are set as a result of policy decisions; the main objective of sensitivity analysis is to understand the full implications and all the potential consequences of these changes. In particular, the influence of nitrogen and output prices and of the level of the support payments on the optimal solution need to be investigated. These factors, as well as the effects of changing the set-aside requirements, are examined in a series of sensitivity analyses.

Wheat, corn and soybean prices

As previously noted, most of the studies on the effects of the liberalization of EC agriculture forecast lower EC production and export sales and, consequently, an increase in world prices.

As it was emphasized in an earlier section, the MacSharry reform introduces a new degree of correlation between EC and world prices. Thus, it is to be expected that future fluctuations in international prices might lead to EC market prices adjustments.

In this study, the equilibrium price for the stabilized market condition following the MacSharry reform has been assumed at the new intervention level in the case of wheat and corn, at the world reference price set by the EC Commission for soybean and at the previous pre-reform level for sugarbeet, since no provision for a reform of the sugar sector is contained in the plan.

Thus, the consequences of a possible rise in world prices need to be investigated, under the assumption that rising international prices can be reflected in higher EC market prices. In particular, sensitivity analysis is utilized to evaluated the effects of increased prices of wheat, corn and soybean on farm profitability, tillage practices and production level.

Results are presented in Table 3.11. As prices and farm profit increase, the *professional* and the *small* producer always adopt equal production plans. Soybean nitrogen usage and yields increase, while no change occurs for wheat or sugarbeet. Should prices rise by 30 percent or more, a strong incentive for higher production would be introduced, the optimal farm plan would return to its pre-reform equilibrium

Table 3.11 Sensitivity results for an increase in the market prices of wheat, corn and soybean: effects on the optimum farm plan for a *professional* producer (PP) and a *small* producer (SP)

	Price Increase		
	10%	20%	30%
PP:			
rotation	-	-	Δ[a]
Π/ha	573.51	634.47	713.78
wheat yield	5.95	5.95	6.61
sugarbeet yield	52.34	52.34	54.54
soybean yield	3.85	3.86	3.87
wheat N usage	180.00	180.00	180.00
sugarbeet N usage	150.00	150.00	150.00
soybean N usage	44.93	50.64	55.87
SP:			
rotation	Δ[b]	Δ[b]	Δ[a]
Π/ha	499.54	571.27	643.08
wheat yield	5.95	5.95	6.61
sugarbeet yield	52.34	52.34	54.54
soybean yield	3.85	3.86	3.87
wheat N usage	180.00	180.00	180.00
sugarbeet N usage	150.00	150.00	150.00
soybean N usage	44.93	50.64	55.87

[a] Three-year RT wheat-TT sugarbeet-RT soybean.
[b] Three-year NT wheat-TT sugarbeet-RT soybean.

and so would crops nitrogen usage and yield levels: the effects of the MacSharry plan would be completely eliminated.

Sugarbeet price

In the light of the price reductions introduced with the new CAP reform, the assumption of a constant sugar price does not seem to hold. In fact, following the reform of its arable crops sectors, the EC Commission is planning to review its sugar regime in connection with proposals on the future of the existing regime which expires at the end of 1993 (Green Europe, 1991). Given the current EC sugar overproduction, a decrease in the price of sugarbeet within the next few months is to be expected.

Using sensitivity analysis, the effects of a reduction in the price of sugarbeet on the optimal farm plan of the representative producer is investigated.

A summary of the results is shown in Table 3.12. The optimum farm plan seems quite stable for a moderate change in the price of sugarbeet. But following a 20 percent price decline, sugarbeet is completely eliminated from the optimal rotations. Also, it is to be noticed that for the *professional* producer wheat and sugarbeet tend to be associated in production and a sufficient decline in sugarbeet price would eliminate both crops from the optimal solution. Hence, the development in the EC sugar policy seems to be important in

Table 3.12 Sensitivity results for a decrease in the market price of sugarbeet: effects on the optimum farm plan for a *professional* producer (PP) and a *small* producer (SP)

		Price Decrease	
	10%	20%	30%
PP:			
rotation	-	Δ[a]	Δ[a]
Π/ha	383.36	292.90	292.90
WH yield	5.95		
SU yield	52.34		
SO yield	3.84	3.05	3.05
WH N usage	180.00		
SU N usage	150.00		
SO N usage	38.64	0.00	0.00
SP:			
rotation	-	Δ[b]	Δ[b]
Π/ha	338.00	123.16	123.16
WH yield	5.89	5.95	5.95
SU yield	52.34		
SO yield	4.01	4.01	4.01
WH N usage	180.00	180.00	180.00
SU N usage	150.00		
SO N usage	41.40	41.40	41.40

[a] Continuous NT soybean.

[b] Two-year NT wheat-RT soybean.

the future of wheat production in this area. Conversely, in the *small* producer case wheat production does not seem to be influenced by the price of sugarbeet. The elimination of this crop would simply reduce the optimum farm plan to a two-year rotation of wheat and soybean, leaving all other things equal.

In analyzing these results, a word of caution is necessary. In this simulation no compensatory measures is provided for the price reduction of sugarbeet. But a wide variety of measures could be introduced to compensate farmers for their income losses. In such a case the response of the farmer to the hypothesized policy changes would be probably different to the one observed.

But no matter what the assumptions of the simulation model are, the results of this analysis underline the strong relationship between further extensions of the CAP reform process and the production decisions of the farmers. Should the current price support in the sugar sector be consistently reduced or eliminated, the impact on farm plans would certainly be profound.

Compensatory payments

In trying to forecast the effects of the MacSharry reform, a source of concern arises on the consequences of a possible increase in world prices on the level of income support granted to EC farmers.

As previously noticed, higher world prices could put an upward pressure on EC market prices; in this case, a decrease in EC outlays to farmers could be advocated, to curb renewed incentives for overproduction. This could be achieved, for example, with a reduction of acreage compensatory payments offsetting exactly the world price increase. In this case, the definition of the aid level to be paid to farmers would probably have to occur on an annual basis, depending on the magnitude of international and internal market prices.
In the MacSharry provisions, nothing is specified on this matter; hence, this possibility is not to be ruled out *a priori*.

Parametric analysis can be utilized to evaluate the consequences on farmers production plans of changes in the level of support caused by market price fluctuations. In particular, the effects of a simultaneous increase in the market price of wheat, corn and soybean and a progressive reduction in the existing level of the compensatory payments are evaluated for the representative farm. A decrease in the price of sugarbeet is also added to this hypothetical scenario. The variations in the prices and in the level of support are assumed equal.

The outcome of this scenario is summarized in Table 3.13. The optimum farm plan for the *professional* and the *small* producer results always the same and in all cases farm profit

Table 3.13 Sensitivity results for an increase in the market prices of wheat, corn and soybean, and a reduction in the market price of sugarbeet and in the level of compensatory payments: effects on the optimum farm plan for a *professional* producer (PP) and a *small* producer (SP)

	Variation		
	10%	20%	30%
PP:			
rotation	-	Δ^a	Δ^a
Π/ha	400.62	302.73	260.23
WH yield	5.95	5.95	5.95
SU yield	52.34		
SO yield	3.85	4.03	4.04
WH N usage	180.00	180.00	180.00
SU N usage	150.00		
SO N usage	44.95	53.36	58.58
SP:			
rotation	Δ^b	Δ^a	Δ^a
Π/ha	338.04	246.20	307.94
WH yield	5.95	5.95	5.95
SU yield	52.34		
SO yield	3.85	4.03	4.04
WH N usage	180.00	180.00	180.00
SU N usage	150.00		
SO N usage	44.95	53.36	58.58

[a] Two-year NT wheat-RT soybean.

[b] Three-year NT wheat-TT sugarbeet-RT soybean.

is reduced from the original level. A 20 percent increase in the prices of grains and a 20 percent reduction in sugar price and compensatory payments represents the critical point at which sugarbeet is eliminated and a two-year wheat-soybean rotation becomes the optimal solution. The optimal soybean nitrogen usage is progressively increased but the yield response is only moderate. Wheat is unaffected by the market changes and by the elimination of sugarbeet from the optimal rotation. In light of previous findings which linked wheat to sugarbeet together in the optimal solution, this might seem a contradictory result. The answer is probably to be found in the increased market price of wheat, which maintains this crop in the optimal solution even for a consistent reduction in the price of sugar and the elimination of sugarbeet from the rotation.

Rotational set-aside

One of the main features of the MacSharry reform is the 15 percent mandatory set-aside on cereals, oilseed and protein crops, as a pre-requisite for farmers to be eligible for income support. Under the provisions of the new plan, this minimum set-aside requirement can be increased in case overproduction occurs, to maintain the equilibrium between supply and demand and avoid the accumulation of new surpluses at intervention. Thus, an increase in the mandatory acreage reduction is to be expected, at least for the market adjustment period following the introduction of the reform.

Sensitivity analysis is then useful to investigate the consequences of a progressive increase in the rotational set-aside requirement on the production plans of the farmer.

Results are shown in Table 3.14. In this simulation only the effects on the production decisions of the *professional* farmer are considered, since under the current provisions no mandatory acreage reduction is required for a *small* producer; thus, only farmers participating to the *professional* regime should be affected by further limitations of the farm base area. Clearly, the optimum farm plan is quite stable to changes in the set-aside area. Increasing retirement of land from production would achieve nothing but a modest reduction in farm profits. Conversely, a 100 percent increase, hence a 30 percent acreage reduction requirement, would determine a change in the basis. But in this case, the original pre-reform production plan would, again, result optimal and the effects of the pre-MacSharry reform would be once more eliminated.

Evidently, as the acreage reduction constraint imposed on farmers gets more stringent, more intensive farming systems and higher yields become necessary to limit the revenue losses. Then, if the goal pursued with higher limitations on land is the reduction of production, the overall effect of such a measure might be limited.

Table 3.14 Sensitivity results for an increase in the rotational set-aside requirements: effects on the optimum farm plan for a *professional* producer

	Increase in set-aside requirements			
	25%	50%	75%	100%
PP:				
rotation	-	-	-	Δ[a]
Π/ha	505.37	498.10	490.83	498.91
WH yield	5.95	5.95	5.95	6.61
SU yield	52.34	52.34	52.34	54.54
SO yield	3.84	3.84	3.84	3.84
WH N usage	180.00	180.00	180.00	180.00
SU N usage	150.00	150.00	150.00	150.00
SO N usage	38.64	38.64	38.64	38.64

[a] Three-year RT wheat-TT sugarbeet-RT soybean.

Nitrogen price

The results obtained in the preceding sections seem to demonstrate that in most of the cases the effects of the MacSharry reform on crop yields are surprisingly low. In fact, increased nitrogen usage can compensate for the negative effects on yields of tillage reductions, introduced by the farmer to lower the cost of production and reduce his profit losses. If this is the case, it is evident that the cost of fertilizers is not, at the moment, a binding constraint on the operations of the farmer.

Under these assumptions, it is interesting to evaluate the effects of a change in the price of nitrogen on production plans and crop yields. The results of sensitivity analysis are presented in Table 3.15. If a substantial increase in the price of nitrogen should follow the policy changes introduced with the new reform, the impact on the farmer would be profound. Interestingly, the results are different for the two kinds of producers. Should the price of nitrogen increase over 100 percent relative to its initial value, the *professional* producer would maintain its traditional rotation, but no-tillage would be introduced for soybean; the fertilization levels would be consistently reduced for wheat and terminated for soybean.

Relative to the values in the optimum farm plan, for a 200 percent increase in the price of nitrogen the average yields for wheat and soybean would drop by 17 and 13 percent, respectively. The overall reduction in farm profits would also be substantial, almost 30 percent.

In the *small* producer case, soybean would be eliminated from the optimal rotation and one-third of the land would be left fallow. The reduction in farm profits would be even greater than in the *professional* producer case, almost 40 percent, but the smaller reduction in the fertilization level would result in a moderate effect on the average wheat yield, which decreases by just 5 percent from the original value.

From these results, some general considerations can be made. A low price of nitrogen is a strong incentive for intensive farming and high yields. Any policy aimed at a

Table 3.15 Sensitivity results for an increase in the price of nitrogen: effects on the optimum farm plan for a *professional* producer (PP) and a *small* producer(SP)

		Price Increase		
	50%	100%	150%	200%
PP:				
rotation	-	Δ[a]	Δ[a]	Δ[a]
Π/ha	478.14	363.03	405.82	376.18
WH yield	5.95	5.18	5.07	4.96
SU yield	52.34	52.34	52.34	52.34
SO yield	3.77	3.37	3.37	3.37
WH N usage	180.00	171.75	157.64	145.13
SU N usage	150.00	150.00	150.00	150.00
SO N usage	12.50	0.00	0.00	0.00
SP				
rotation	-	Δ[b]	Δ[b]	Δ[b]
Π/ha	422.05	340.25	323.60	291.25
WH yield	5.89	5.82	5.72	5.61
SU yield	52.34	52.34	52.34	52.34
SO yield	3.94			
WH N usage	180.00	178.24	164.67	152.71
SU N usage	150.00	150.00	150.00	150.00
SO N usage	14.20			

[a] Three-year NT wheat-TT sugarbeet-NT soybean.
[b] Three-year NT wheat-TT sugarbeet-fallow.

consistent reduction in the level of agricultural production might achieve only limited results, unless a strong incentive to cut production is introduced. This incentive could very well be an increase in the cost of fertilizers.

Shouldn't the MacSharry reform be successful in its attempt to drive down agricultural output, an increase in the price of nitrogen could be advocated. This solution would certainly lead to a reduced production level, but at a very high cost for farmers. In particular, a consistent reduction is most likely to be achieved in case the *professional* regime is opted for by the farmer, while in the case the *small* producer regime is chosen, the effects of a higher nitrogen price on crop yields would probably be only moderate.

CHAPTER IV.

SUMMARY AND CONCLUSIONS

This study focused on the reform of the agricultural policy of the European Economic Community. The consequences of the policy changes on a representative Italian grain farm were investigated by solving a mathematical optimization model, to assess the impact on crop yields, farming systems and acreage response.

Unambiguously, under the new regime of low market prices, mandatory base acreage reductions and income support payments, the farmer will be worse-off than before, with an estimated 20-30 percent reduction in his profit level. Should the farmer opt for the special regime granted by the EC to the *small* producers, the profit reduction would result even more severe, since the benefits from the absence of limitations on the base acreage would be more than offset by the reduction in the level of support granted by the new EC policy.

A shift towards reduced tillage farming techniques is to be expected, since it is likely that the farmer will try to limit the cost of production by reducing the number of field operations.

Increasing nitrogen fertilization rates could partly compensate for the negative effect of minimum or no-tillage on the level of production, and consequently the overall reduction in yields should result only moderate. In particular, wheat yield should not decrease by more than 7-10 percent of its current average value.

The level of farm output should be influenced by the particular regime opted for by the farmer. In the *professional* producer case, the seasonal land retirement under the rotational set-aside program should strongly reinforce the effect of the reduction in yields and determine a consistent decrease in production. But for the *small* producer no acreage reduction is required and the low yield reductions should only result in a very moderate effect on the level of farm output.

Then, assuming that these findings can be extended to a large number of farm operations, the effect of the reform on regional, or even national, aggregate production is likely to be influenced by the type of producers present in the area of interest and their preferences for the support regime. Given the results of the simulation, in the area considered in this study, the south part of the Po Valley, the *professional* regime should be preferred by all producers. Hence, the effect of the reform on the level of aggregate production should be significative.

Sugarbeet will most likely remain the high revenue crop in the rotations, unless a reform in the EC sugar policy is introduced; in that case, the response of farmers will be influenced by the extent of the price reduction and the possible compensatory measures which could be introduced.

Land values are expected to fall, due to the lower farm profitability. The extent of the reduction seems to be influenced by several factors, such as the specific support regime opted for or the particular rotation chosen by farmers. On average, a 25-50 percent reduction in the value of farmland should be expected.

The result of the sensitivity analyses show the farmer response to changing policy conditions. For a substantial increase in the market price of cereals and soybean, as well as in the acreage reduction requirement, an incentive for more intensive production would be created and the effects of the MacSharry reform on crop yields and rotations would then be gradually eliminated. Also, a strong increase in the price of nitrogen appears to be a very effective solution for obtaining a consistent reduction in the level of production.

Finally, doubts can be cast on the appropriateness of the new policy reform for achieving the main goal of a reduced impact of agriculture on the environment. Should the results of this simulation well represent the response of farms to the new plan, it is clear that in this area such expectation could not be fully met. As previously noted, the adoption of minimum tillage practices by producers is most likely to be accompanied by an increase in the level of fertilization and chemical weed control, hence by a higher impact on the environment.

Maybe, an alternative approach could have been used to meet the MacSharry goals. For example, a drastic increase in the price of fertilizers could have been introduced. It appears more likely that under such a different scenario reduced production at a lower impact on the environment might have been achieved, sparing farmers the bureaucracy and the complexity of the new production rules, and the taxpayers the considerable burden of the MacSharry reform plan.

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APPENDIX

Table A.1 Rotational activities total direct costs (fertilizers excluded) ($Q_{is}^{\delta\epsilon}$), total imputed costs ($K_{is}^{\delta\epsilon}$) and rotational yield-correcting factors ($\alpha_{is}^{\delta\epsilon}$)

Rotational Activity	$Q_{is}^{\delta\epsilon}$	$K_{is}^{\delta\epsilon}$	$\alpha_{is}^{\delta\epsilon}$
WH2WH2	1,079,800	420,810	0.742
WH2WH3	1,079,800	420,810	0.652
WH2SU1	1,079,800	420,810	0.970
WH2SU2	1,079,800	420,810	0.960
WH2SU3	1,079,800	420,810	0.844
WH2SO1	1,079,800	420,810	1.000
WH2SO2	1,079,800	420,810	0.990
WH2SO3	1,079,800	420,810	0.870
WH2CO1	1,979,800	420,810	0.980
WH2CO2	1,079,800	420,810	0.970
WH2CO3	1,079,800	420,810	0.853
WH3WH2	825,800	404,300	0.742
WH3WH3	825,800	404,300	0.652
WH3SU1	825,800	404,300	0.970
WH3SU2	825,800	404,300	0.960
WH3SU3	825,800	404,300	0.844
WH3SO1	825,800	404,300	1.000
WH3SO2	825,800	404,300	0.990
WH3SO3	825,800	404,300	0.870
WH3CO1	1,000,800	415,675	0.980
WH3CO2	1,000,800	415,675	0.970
WH3CO3	1,000,800	415,675	0.853
SU1WH2	2,202,200	493,766	0.990
SU1WH3	2,202,200	493,766	0.950
SU1SO1	2,202,200	493,766	0.850
SU1SO2	2,202,200	493,766	0.841
SU1SO3	2,202,200	493,766	0.807
SU1CO1	2,202,200	493,766	0.840
SU1CO2	2,202,200	493,766	0.832
SU1CO3	2,202,200	493,766	0.798
SU2WH2	1,881,700	472,934	0.990
SU2WH3	1,881,700	472,934	0.950
SU2SO1	1,881,700	472,934	0.850
SU2SO2	1,881,700	472,934	0.841
SU2SO3	1,881,700	472,934	0.807
SU2CO1	1,881,700	472,934	0.840
SU2CO2	1,881,700	472,934	0.832
SU2CO3	1,881,700	472,934	0.798

Table A.1 (continued)

SU3WH2	1,466,700	445,959	0.990
SU3WH3	1,466,700	445,959	0.950
SU3SO1	1,466,700	445,959	0.850
SU3SO2	1,466,700	445,959	0.841
SU3SO3	1,466,700	445,959	0.807
SU3CO1	1,556,700	451,809	0.840
SU3CO2	1,556,700	451,809	0.832
SU3CO3	1,556,700	451,809	0.798
SO1WH2	1,429,000	443,508	0.990
SO1WH3	1,429,000	443,508	0.980
SO1SU1	1,429,000	443,508	0.940
SO1SU2	1,429,000	443,508	0.931
SO1SU3	1,429,000	443,508	0.921
SO1SO1	1,429,000	443,508	0.850
SO1SO2	1,429,000	443,508	0.841
SO1SO3	1,429,000	443,508	0.833
SO1CO1	1,429,000	443,508	0.950
SO1CO2	1,429,000	443,508	0.940
SO1CO3	1,249,000	443,508	0.931
SO2WH2	1,123,600	423,657	0.990
SO2WH3	1,123,600	423,657	0.980
SO2SU1	1,123,600	423,657	0.940
SO2SU2	1,123,600	423,657	0.931
SO2SU3	1,123,600	423,657	0.921
SO2SO1	1,123,600	423,657	0.850
SO2SO2	1,123,600	423,657	0.841
SO2SO3	1,123,600	423,657	0.833
SO2CO1	1,123,600	423,657	0.950
SO2CO2	1,123,600	423,657	0.940
SO2CO3	1,123,600	423,657	0.931
SO3WH2	950,000	412,373	0.990
SO3WH3	950,000	412,373	0.980
SO3SU1	950,000	412,373	0.940
SO3SU2	950,000	412,373	0.931
SO3SU3	950,000	412,373	0.921
SO3SO1	950,000	412,373	0.850
SO3SO2	950,000	412,373	0.841
SO3SO3	950,000	412,373	0.833
SO3CO1	1,100,000	422,123	0.950
SO3CO2	1,100,000	422,123	0.940
SO3CO3	1,100,000	422,123	0.931
CO1WH2	1,876,000	472,563	0.990
CO1WH3	1,876,000	472,563	0.980
CO1SU1	1,876,000	472,563	0.890
CO1SU2	1,876,000	472,563	0.881
CO1SU3	1,876,000	472,563	0.872
CO1SO1	1,876,000	472,563	0.900

Table A.1 (continued)

CO1SO2	1,876,000	472,563	0.891
CO1SO3	1,876,000	472,563	0.882
CO1CO1	1,876,000	472,563	0.850
CO1CO2	1,876,000	472,563	0.841
CO1CO3	1,876,000	472,563	0.833
CO2WH2	1,453,000	445,068	0.990
CO2WH3	1,453,000	445,068	0.980
CO2SU1	1,453,000	445,068	0.890
CO2SU2	1,453,000	445,068	0.881
CO2SU3	1,453,000	445,068	0.872
CO2SO1	1,453,000	445,068	0.900
CO2SO2	1,453,000	445,068	0.891
CO2SO3	1,453,000	445,068	0.882
CO2CO1	1,453,000	445,068	0.850
CO2CO2	1,453,000	445,068	0.841
CO2CO3	1,453,000	445,068	0.833
CO3WH2	1,240,000	431,223	0.990
CO3WH3	1,240,000	431,223	0.980
CO3SU1	1,240,000	431,223	0.890
CO3SU2	1,240,000	431,223	0.881
CO3SU3	1,240,000	431,223	0.872
CO3SO1	1,240,000	431,223	0.900
CO3SO2	1,240,000	431,223	0.891
CO3SO3	1,240,000	431,223	0.882
CO3CO1	1,240,000	431,223	0.850
CO3CO2	1,240,000	431,223	0.841
CO3CO3	1,240,000	431,223	0.833

Table A.2 Labor requirements per hectare for the rotations

Activity	Spring	Summer	Fall
WH2WH2	7.5	9.6	5.5
WH2WH3	7.5	9.6	5.5
WH2SU1	7.5	4.0	11.1
WH2SU2	7.5	4.0	11.1
WH2SU3	7.5	4.0	11.1
WH2SO1	7.5	4.0	11.1
WH2SO2	7.5	4.0	11.1
WH2SO3	7.5	4.0	11.1
WH2CO1	7.5	4.0	11.1
WH2CO2	7.5	4.0	11.1
WH2CO3	7.5	4.0	11.1
WH3WH2	6.0	8.0	5.0
WH3WH3	6.0	8.0	5.0
WH3SU1	6.0	2.5	9.0
WH3SU2	6.0	2.5	9.0
WH3SU3	6.0	2.5	9.0
WH3SO1	6.0	2.5	9.0
WH3SO2	6.0	2.5	9.0
WH3SO3	6.0	2.5	9.0
WH3CO1	6.0	2.5	9.0
WH3CO2	6.0	2.5	9.0
WH3CO3	6.0	2.5	9.0
SU1WH2	12.0	16.5	8.0
SU1WH3	12.0	16.5	8.0
SU1SO1	12.0	12.8	21.7
SU1SO2	12.0	12.8	21.7
SU1SO3	12.0	12.8	21.7
SU1CO1	12.0	12.8	21.7
SU1CO2	12.0	12.8	21.7
SU1CO3	12.0	12.8	21.7
SU2WH2	10.0	9.0	16.5
SU2WH3	10.0	9.0	16.5
SU2SO1	10.0	5.5	18.5
SU2SO2	10.0	5.5	18.5
SU2SO3	10.0	5.5	18.5
SU2CO1	10.0	5.5	18.5
SU2CO2	10.0	5.5	18.5
SU2CO3	10.0	5.5	18.5
SU3WH2	9.0	8.0	15.0
SU3WH3	9.0	8.0	15.0
SU3SO1	9.0	8.5	16.5
SU3SO2	9.0	8.5	16.5
SU3SO3	9.0	8.5	16.5

Table A.2 (continued)

SU3CO1	9.0	8.5	16.5
SU3CO2	9.0	8.5	16.5
SU3CO3	9.0	8.5	16.5
SO1WH2	8.8	12.4	6.8
SO1WH3	8.8	12.4	6.8
SO1SU1	8.8	6.0	10.8
SO1SU2	8.8	6.0	10.8
SO1SU3	8.8	6.0	10.8
SO1SO1	8.8	6.0	10.8
SO1SO2	8.8	6.0	10.8
SO1SO3	8.8	6.0	10.8
SO1CO1	8.8	6.0	10.8
SO1CO2	8.8	6.0	10.8
SO1CO3	8.8	6.0	10.8
SO2WH2	8.0	11.0	6.0
SO2WH3	8.0	11.0	6.0
SO2SU1	7.5	5.5	10.0
SO2SU2	7.5	5.5	10.0
SO2SU3	7.5	5.5	10.0
SO2SO1	7.5	5.5	10.0
SO2SO2	7.5	5.5	10.0
SO2SO3	7.5	5.5	10.0
SO2CO1	7.5	5.5	10.0
SO2CO2	7.5	5.5	10.0
SO2CO3	7.5	5.5	10.0
SO3WH2	7.0	8.4	5.8
SO3WH3	7.0	8.4	5.8
SO3SU1	7.0	3.0	9.0
SO3SU2	7.0	3.0	9.0
SO3SU3	7.0	3.0	9.0
SO3SO1	7.0	3.0	9.0
SO3SO2	7.0	3.0	9.0
SO3SO3	7.0	3.0	9.0
SO3CO1	7.0	3.0	9.0
SO3CO2	7.0	3.0	9.0
SO3CO3	7.0	3.0	9.0
CO1WH2	8.8	9.4	8.4
CO1WH3	8.8	9.4	8.4
CO1SU1	8.8	6.0	11.8
CO1SU2	8.8	6.0	11.8
CO1SU3	8.8	6.0	11.8
CO1SO1	8.8	6.0	11.8
CO1SO2	8.8	6.0	11.8
CO1SO3	8.8	6.0	11.8
CO1CO1	8.8	6.0	11.8
CO1CO2	8.8	6.0	11.8

Table A.2 (continued)

CO1CO3	8.8	6.0	11.8
CO2WH2	7.0	6.4	7.0
CO2WH3	7.0	6.4	7.0
CO2SU1	7.3	4.0	9.3
CO2SU2	7.3	4.0	9.3
CO2SU3	7.3	4.0	9.3
CO2SO1	7.3	4.0	9.3
CO2SO2	7.3	4.0	9.3
CO2SO3	7.3	4.0	9.3
CO2CO1	7.3	4.0	9.3
CO2CO2	7.3	4.0	9.3
CO2CO3	7.3	4.0	9.3
CO3WH2	5.0	4.0	5.5
CO3WH3	5.0	4.0	5.5
CO3SU1	5.0	3.0	8.0
CO3SU2	5.0	3.0	8.0
CO3SU3	5.0	3.0	8.0
CO3SO1	5.0	3.0	8.0
CO3SO2	5.0	3.0	8.0
CO3SO3	5.0	3.0	8.0
CO3CO1	5.0	3.0	8.0
CO3CO2	5.0	3.0	8.0
CO3CO3	5.0	3.0	8.0