

A METHODOLOGICAL FRAMEWORK TO EXPLORE  
LONG-TERM OPTIONS FOR LAND USE

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ABSTRACT

The Netherlands Scientific Council for Government Policy has developed a methodology that can be used to gather information on options for long-term developments in agriculture in relation to policy objectives. In this paper it is shown how quantitative relations between a number of self-contained technical development processes in agriculture, and socio-economic and environmental policy objectives can be modelled. This model can be used to demonstrate the influence of various policy preferences on future land use changes within the European Community.

A dynamic crop simulation model and a geographical information system that comprise soil characteristics, climatic conditions and crop properties have been used to calculate regional yield potentials for indicator crops. Next a linear programming model that contains several policy derived objective functions is applied to calculate optimal regional allocation of land use. Different sets of restrictions can be put to the objective functions. In this way a number of scenarios is created that reflect different



weights given to the policy goals.

In this paper the methodology is described and the potential as well as the flexibility of the approach is illustrated.

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INTRODUCTION

In 1988 the Netherlands Scientific Council for Government Policy started a research project to explore possible developments of the rural areas in the European Community (EC). The study provides scenarios that give information on the interactions between a number of more or less self-contained technical development processes in agriculture aimed at productivity gain, and several other 'non-agricultural-production' goals that are to be considered simultaneously. Hence, these scenarios will show the conflicts arising from increasing productivity, market saturation, uneven distribution of production within the EC and increasing concern for regional employment, environment and landscape. The scenarios are used to explore options that emerge when different priorities are given to the goals involved. By demonstrating the consequences of these priorities, valuable information can be gathered to evaluate strategic policy choices that must be dealt with in the current transformation of the Common Agricultural Policy of the EC. There is a clear need for a long term agricultural policy that takes account of major trends and unavoidable changes. Rabbinge and Van Latesteijn (1992) deal with these policy implications in more detail. This paper will focus on the methodological aspects of the study.

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To construct the scenarios a methodology is developed

EC) and their scientific basis is generally constrained to economic analysis. This presents us with the problem that is illustrated in figure 1. Research needs are concentrated at intermediate levels. How can we benefit from both the agronomists knowledge at the lower levels and the economists knowledge at the higher levels so as to bridge this gap?

A systems approach might be an answer to that question. Using engineers knowledge it is possible to construct a model representation of agriculture. Using economists knowledge it is possible to translate policy goals into quantified objective functions and integrate them in the model. With a model like this it is possible to assess the influence of policy objectives on agriculture and vice versa.

This is the approach adopted in our study. We neither investigate the reaction of farmers or plants to changing conditions, nor the effectiveness of policy instruments on agriculture. Instead we want to assess the flexibility of the agricultural system as a whole, given the fact that various goals are to be fulfilled within this single system. This gives us information on the possibilities within the agricultural system based on the properties of the system itself. It is explicitly not our intention to come up with more or less reliable predictions for the future of agriculture within the EC, but rather to explore the possibilities of the agricultural system. For tactical policy decisions concerning the use of instruments this will not be adequate, but for strategic policy planning purposes this type of analysis is indispensable.

that uses a systems approach to agriculture to describe possible future changes in land use. In the centre of the methodology a Linear Programming (LP) model is used in conjunction with a procedure called 'Interactive Multiple Goal Programming' (IMGP). A LP-model is generally used to optimize a single objective function. The IMGP procedure makes it possible to optimize a set of objective functions in an iterative process. This reveals the trade-offs between different goals that are modelled by the objective functions.

The IMGP procedure was used by the Council in earlier studies on techno-economic development on a national scale (Netherlands Scientific Council for Government Policy 1983 ; 1987) and is discussed in detail by Veeneklaas (1990). The present study differs from these earlier studies not only because the topic is quite different, but also because in this case the construction of a useful LP-model requires pre-processing a lot of data.

This paper describes the general features of the methodology.

#### WHY SYSTEMS APPROACH

The ongoing productivity rise in agriculture in the EC causes a series of reactions, that lead to problems at EC level. At the level of individual plants and crops agronomic research has brought understanding of the processes involved in this productivity rise. However, policy decisions are taken at much higher levels of aggregation (region, country,

concept of 'best technical means' can be used to obtain such types of land use, i.e. agriculture is defined according to the results that are obtained in plant testing stations and experimental farms at this moment. These forerunners are used as a reference for future developments. In that way the results of the model calculations are consistent across all countries. Three levels of analysis were necessary to construct the GOAL model. They are discussed in the next paragraph.

#### LEVELS OF ANALYSIS

##### Crop level

In figure 2 the inputs and outputs for the analysis at the individual crop level are visualised. Plant properties, soil properties and climate properties determine the potential crop yield at a given location. To calculate this potential crop yield two steps are necessary. First the suitability of the soil for a certain crop is assessed to exclude all units where that crop can not be grown (e.g. wheat on steep slopes and maize on clay soils). This can be denoted as a qualitative land evaluation. Second, by means of a simulation model, potential yields are calculated for the suitable areas. This can be denoted as a quantitative land evaluation (Van Lanen 1990).

The qualitative land evaluation of the EC is accomplished through the use of a Geographical Information System (GIS) (Van Diepen et al 1990). The evaluation is executed at the

## GENERAL OUTLINE OF THE METHODOLOGY

The core of the methodology is formed by a model of (agricultural) land use in the EC which we have baptized 'GOAL' (= General Optimal Allocation of Land Use). The model can choose from a limitative set of types of land use to meet an exogenously defined demand for agricultural and forestry products. A number of policy goals that stem from official reports by the EC are coupled to types of land use in the form of objective functions, e.g. maximization of yield per hectare, minimization of regional unemployment in land based agriculture and minimization of the use of pesticides. Distinct policy views can be fed into the model by assigning different preferences to the objectives. Within the GOAL model this is done by restricting the objective functions to a certain domain, e.g.: the total labour force can not be less than 6 million man year. In this way scenarios can be constructed that show the effects of policy priorities, e.g.: to maintain the labour force the model will have to select types of land use with a relatively high input of labour.

The types of land use that the model can choose from are defined in quantitative terms. Because we want to explore possible long term options, current agricultural practise should not be used as a reference, because it reflects the capabilities and regional differences of this moment, not those of the future. It can be seen that in all areas of the EC agriculture is showing considerable technical and managerial progress. Therefore we must define types of land use that are envisaged over a longer period of time. The

no irrigation is applied. This is referred to as water limited yield. In the irrigated situation there are no limitations to crop growth other than those impeded by climate and soil conditions and properties of the crop. In that case the model simulation gives an indication of the maximum attainable yield at a given location. This is referred to as potential yield.

The validation of a simulation model of this type is somewhat problematic. The simulations are not meant to model actual situations, but give information on production potentials. One way of testing the model is comparing the simulation results with yields that were observed in experimental field situations. This has been done in this study. The assumption made is that in these experimental field situations the production potentials are (nearly) reached by applying state-of-the-art techniques. Although this is not a true validation it is a pragmatic approach to test the simulation model for extreme outcomes.

In figure 4 the results of the simulations for wheat are given. The simulations are executed at the level of LEUs but the results are averaged at the level of NUTS-1 regions (a classification into broad administrative regions used by Eurostat, the statistical bureau of the EC). If the water limited yield is compared to the actual yield (data of 1986) some conclusions can be drawn. For a number of northern regions the possible rise in yield per unit area appears to be small. This indicates that the limits of soil productivity in these regions are near. In most other regions the simulated

level of Land Evaluation Units (LEUs), a combination of soil and climate conditions that is considered to be homogeneous. For the EC some 22.000 units are necessary to cover the total area. By looking at factors like steepness, salinity, and stoniness of the soil the suitability for mechanised farming is assessed. In figure 3 the total areas suitable for grass, cereals and root crops per EC member state are given. The differences between the member states are obvious. Most of Denmark's area can be used for all three crops, whereas the larger part of Greece is not suitable for arable cropping. In each country the suitable area for grass production exceeds that for cereals, and that for root crops is still smaller.

The quantitative land evaluation is accomplished through the use of the WOFOST crop growth simulation model (Van Keulen and Wolf 1986). For the areas that are suitable the water-limited and potential yields of winter wheat, maize, sugarbeet, potato, and grass are assessed. The simulation model uses as its inputs: technical information on regional soil (such as water holding capacity) and climate properties and relevant properties of the crop (such as phenological development, light interception, assimilation, respiration, partitioning of dry-matter increase over plant organs and transpiration).

Two degrees of water availability are distinguished: rainfed and irrigated. In the rainfed situation maximum yields can be limited by the availability of water at any point during the growing season. In that case the model simulation gives an indication of the attainable yields when

These systems are not commonly used yet, but they might be put into practise within the coming decades. This element in the analysis is crucial yet open to debate due to the subjective choices that are involved. To enable the discussion at this point a full report of all the necessary choices has been published (De Koning et al 1992).

The following guidelines are used to arrive at an expert judgement on best technical means. It is assumed that cropping systems with excessive input of labour are excluded. This means that all cropping systems are mechanized (e.g.: no manual weed control).

For a given level of production (the water limited and potential production levels) the minimal input of resources can be assessed. The theoretical background of this optimization is dealt with extensively by De Wit (1992) . He describes this optimum as the situation where each variable production resource is minimized to such a level that all other production resources are used to their maximum. This defines the technical optimum for that particular production situation and will be used as a reference.

To arrive at an economic optimum some substitution of agrochemicals by labour and/or capital is permitted. Expert knowledge is used to define cropping systems that are both economically and agronomically acceptable. We call this set of systems Yield Oriented Agriculture (YOA).

Another deviation from the technical optimum is obtained when more account is taken of environmental hazards related to agriculture. This implies that less environmentally hazardous

water limited yields are much higher (up to 6 t ha<sup>-1</sup> dry matter) than the actual yields. In those regions soil productivity can still increase, even without irrigation.

In most regions the potential production is much higher. Even in the humid, well developed northern regions irrigation can raise the yield potential by 1 - 2 t ha<sup>-1</sup>. It can be concluded from figure 4 that the difference of what is actually produced and what can be produced according to the simulations is considerable in most of the regions within the EC, especially in the southern regions.

The water-limited and potential yields are used as input at the next level of analysis.

#### Cropping system level

If one wants to find out land use possibilities in the future, information on individual crops will not be sufficient. All crops are grown in a cropping system that defines all inputs and outputs. Moreover, in most cases monocropping does not provide sustainable agriculture and only a limited number of crop combinations can be used in practical cropping systems. Therefore potential yields of indicator crops are translated into cropping systems that comprise a certain rotation scheme, certain management decisions and a certain use of inputs. In figure 5 the inputs and outputs at this level of analysis are given. It is striking that at this level the only viable method is expert judgement. From his experience, both in practise and in experiments, the expert can deduce input and output coefficients of cropping systems.

to indicate a desired priority between goals and the levels to which these goals should be fulfilled. The views have been chosen so as to represent a maximum difference between options. They must be regarded as extremes, and their differences give an indication of maximum policy influence.

We distinguish:

- a - free trade and free market;
- b - regional employment;
- c - nature conservation;
- d - environment friendly.

The policy views are expressed in the GOAL model by setting different restrictions to the objective functions and by varying the demand. A few examples can illustrate this.

In the free trade and free market view the costs of agricultural production are minimized and no other restrictions are put to the objectives. Moreover, free trade implies that import and export is allowed, so the demand for agriculture produce from within the EC is modified according to expectations regarding new market balances. The model will now choose the most cost-efficient types of land use and allocate them in the most productive regions.

In the environment friendly view again the costs of agricultural production are minimized, but here strict limitations are put to the objective functions that represent the use of fertilizers and pesticides. Next to that the demand for agricultural produce is fitted to self-sufficiency. The model will now choose for types of land use that agree with the imposed restrictions.

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inputs (such as pesticides and fertilizers) are used, even if this means a slight decrease in yield. Here again the criteria are still rather subjective. We call this set of systems Environment Oriented Agriculture (EOA).

A third deviation from the technical optimum is driven by land use concerns. Under all circumstances it can be foreseen that the agricultural area within the EC will diminish. This can be detrimental to the maintenance of the countryside in some regions. So a set of cropping systems can be defined that deviates from the technical optimum and that is characterized by a relatively low soil productivity. We call this set of systems Land use Oriented Agriculture (LOA).

The cropping systems defined for YOA, EOA and LOA are all available to the GOAL model that is used at the next level.

#### Land use level

At the level of land use possibilities for the EC all information is brought together. Requirements for various goals related to land use together with alternative cropping systems and a demand for agricultural produce are fed into the GOAL model to generate scenarios of different options for land use at the level of NUTS-1 regions within the EC. This is illustrated in figure 6.

An IMGP procedure is used to optimize a set of objective functions that is incorporated in the model. In this procedure restrictions are put to the objective functions to model preferences in policy goals. Four policy views are used

directions in which the system can be developed.

#### CONCLUSION

With the methodological framework described in this paper we have been able to produce scenarios that, given a set of policy goals, describe optimal land use across the EC. These scenarios bridge the gap that was mentioned at the beginning of this paper. Bio-technical and agronomic knowledge together with economic knowledge have been used in a systems approach to agriculture. This synergy of disciplines adds value to the approach. Although the methodology serves a specific aim it can be applied in other situations as well, especially in those situations where integration of bio-technical 'engineers knowledge' and economic 'politicians knowledge' is wanted.

The study does not provide a blueprint for agricultural policy. Instead it presents a set of scenarios that explore possibilities of land based agriculture in the EC. For strategic policy planning this approach can be very useful.

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With these data the model creates different scenarios for land use. Policy-makers can now see how their priorities will affect land use and how the effects are distributed over the EC.

However, some requirements cannot be moulded into the rigid outlines of the model. Therefore spatially differentiated claims and demands for nature conservation and development have been assembled in a map (Jongman R, Bischoff N, Dept of Physical Planning and Rural Development, Wageningen University, pers. comm.). This map is matched with the scenarios (=regional allocation of types of land use) to identify potential problematic areas with respect to competing land use.

The study ends with two types of recommendations about the policy requirements that can be derived from the scenarios. First the scenarios, although very different in regional allocation of land use, show common results such as a dramatic decrease of agricultural area from  $140 \times 10^6$  ha down to as little as  $40 \times 10^6$  ha, and a 50% decrease in labour in land based agriculture. These results can be looked upon as inevitable and governments might want to mitigate some of the effects. Second the individual scenarios are all extremes and as such not to be pursued, but they indicate directions that might be stimulated with the aid of policy instruments. Here the existing regulatory system of laws, guidelines and subsidies is assessed for its effectiveness on a general level and recommendations are provided with regards to new

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Netherlands Scientific Council for Government Policy (1987)

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Fig. 5 Level II: theoretical cropping systems are defined based on expert judgement. The input consists of the calculated potential yields of indicator crops and information on cultivation methods, farm management, rotation schemes etc. The selection of cropping systems is guided by the principle of "best technical means", i.e. all inputs are used in an efficient way.

Fig. 6 Level III: land use alternatives are calculated using a linear programming model. The model finds an optimal solution to the problem of fulfilling the European demand for agricultural produce while at the same time contributing to the different land use related goals that are incorporated in the model. This can be achieved by choosing between the different cropping systems and locate them in the most appropriate region. The choice is influenced by alternative policy views on developments in agriculture.

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## CAPTIONS

Fig. 1 Levels of scale and research needs. Technical information is usually available on plant and crop levels, whilst policy information is needed at regional, national and supra-national level. A systems approach can be used to bridge the gap between these different levels.

Fig. 2 Level I: potential yields of indicator crops are calculated using a crop growth simulation model. Inputs are soil and climate properties and relevant properties of the plant such as phenological development, light interception, assimilation, respiration, partition of dry-matter increase over plant organs and transpiration.

Fig. 3 Percentage of area per EC member state suited for grass, cereal and root crop production.

Fig. 4 Calculated water limited and potential yield of wheat in the NUTS-1 regions of the EC obtained with the WOFOST crop simulation model. The difference of water limited and actual yield gives an indication of the maximum gain in soil productivity under rainfed conditions. Actual yields are based on data of 1986. The difference between potential and water limited gives an indication of the gain in soil productivity due to irrigation.

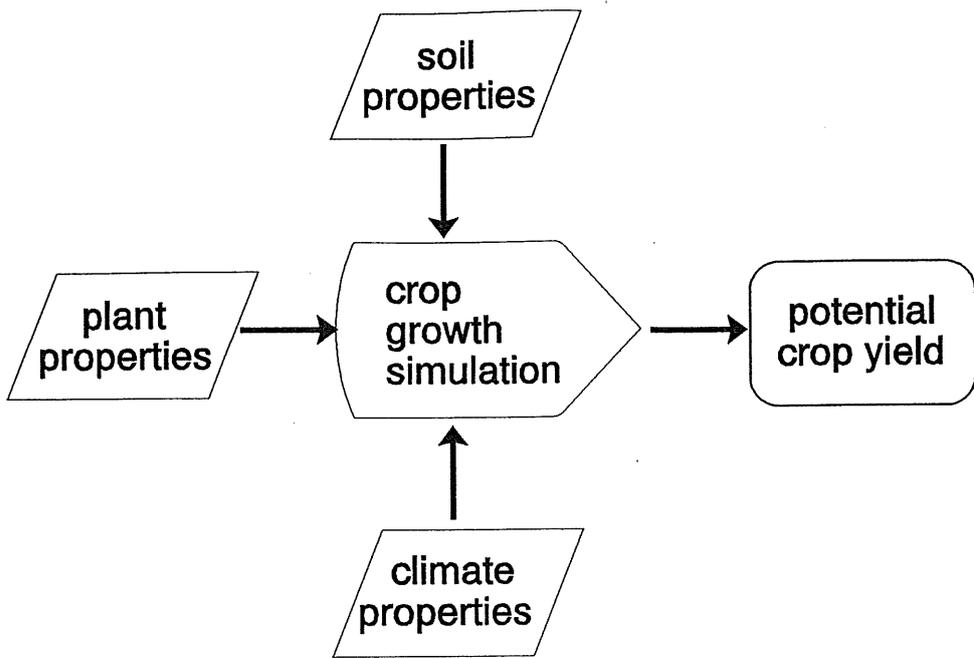


Fig. 2 Mark van Lotterstein

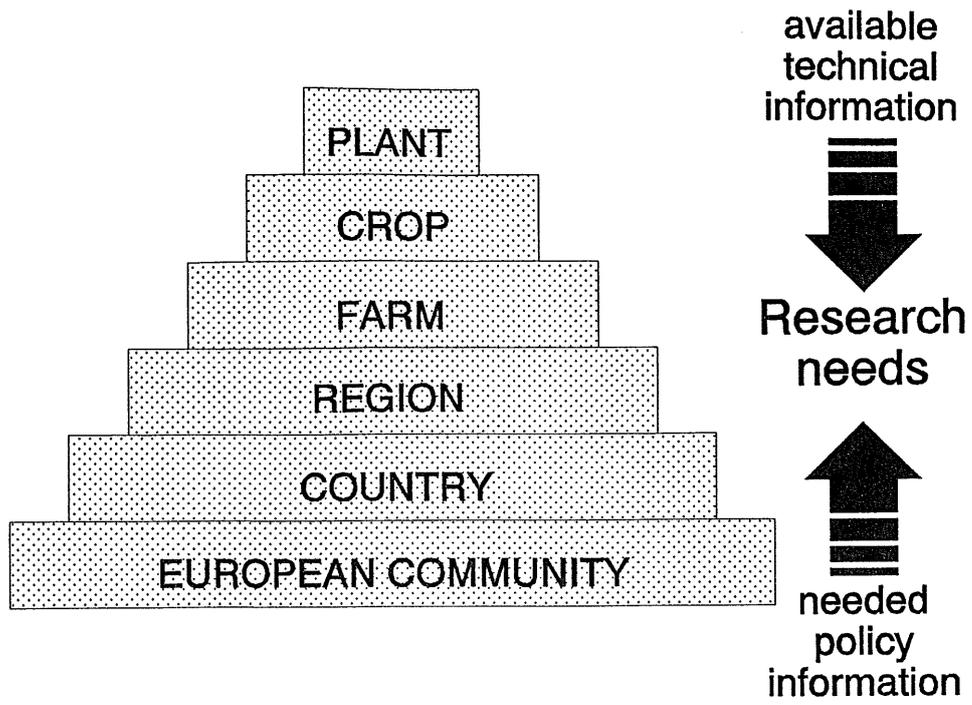


Fig 1 Werk van Loesdijk

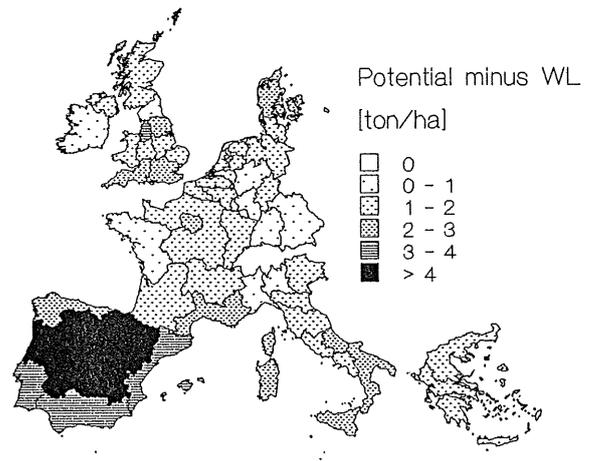
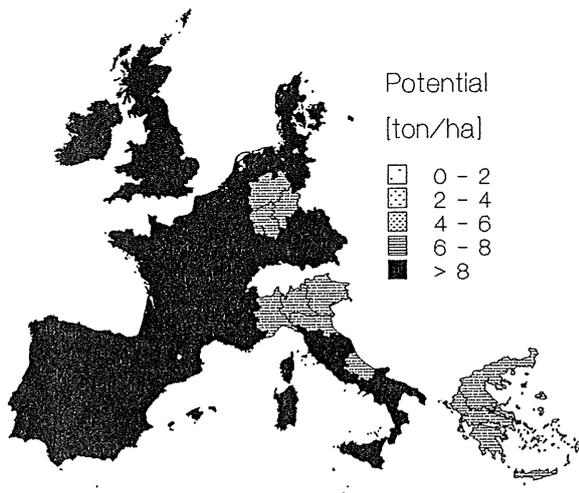
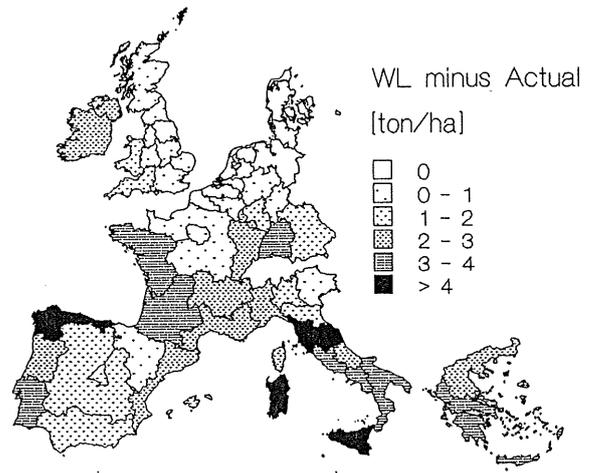
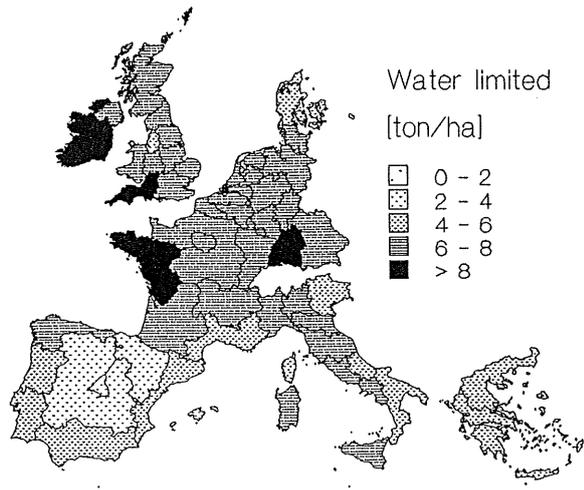


Fig. 4. Difference in potential and water-limited crop yield in Europe

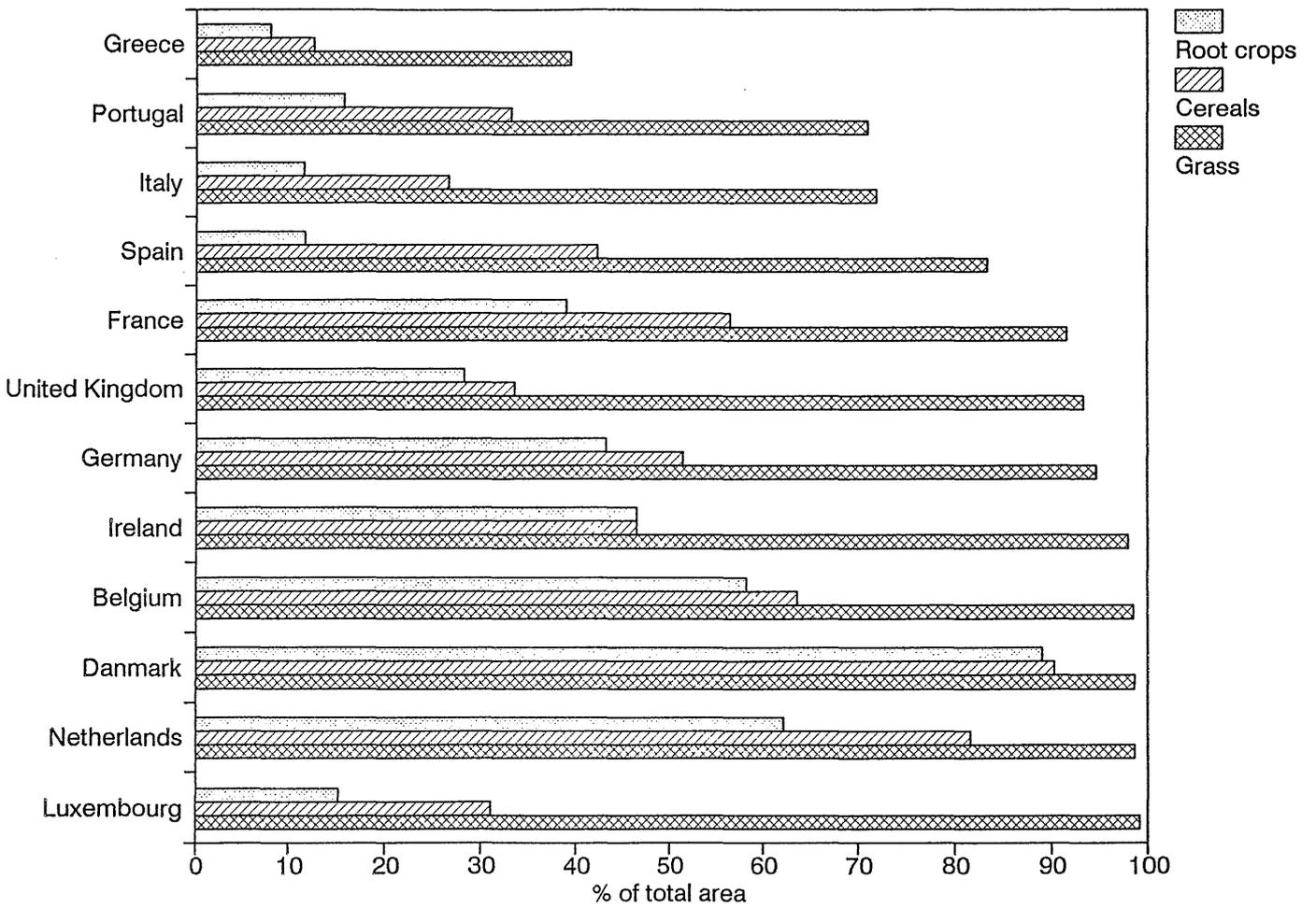


Fig 2. Land use in Europe



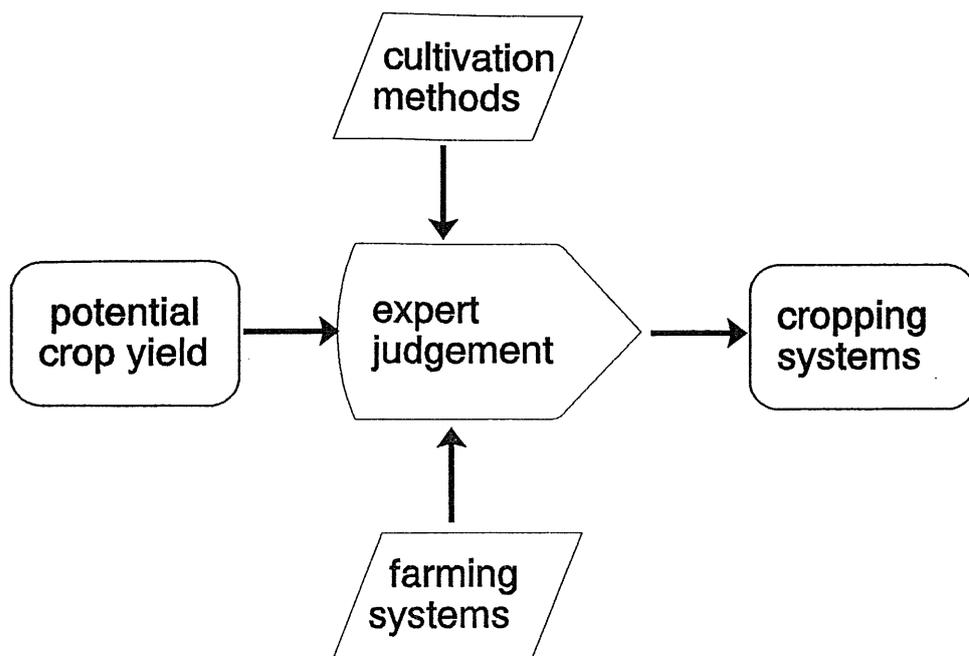


Fig 5 Werk van Lotesteijn



