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# Integrating Agricultural Research and Development*

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## Introduction

It may be seen as a positive development that at least for the world as a whole production is keeping up with population growth and that there are no compelling reasons why this should not be so for years to come. The problem is not so much one of potential but of equity among consumers and producers and of meeting current demand without sacrifycing the heritage of future generations.

On one end of the spectrum there are the problems of affluence in Western Europa and the USA. There, the farmers operate in an economic environment that stimulates to produce more and more from each hectare of land and from each hour of labour, resulting by now in overproduction, pollution and loss of environmental diversity. On the other end of the spectrum are the problems of poverty of many African farmers who cannot afford industrial means of production so that the needs of an increasing population forces over-exploitation of the resource base leading to soil erosion, exhaustion of nutrients and destruction of fragile ecologies.

Such trends threaten the sustainability of agriculture and therefore it is a main purpose of production ecology to contribute to the development of an agriculture that meets the increasing demands for agricultural products, while enhancing its supporting resource base and avoiding environmental degradation. A powerfool tool to this end is the simulation of crop and farming systems in computer models that are rich in mathematical relationships and feedback loops that reflect fundamental growth processes and environmental interactions and are used in combination with dynamic linear programming techniques.

## 1. An early example of systems analyses in agriculture

It may come as a surprise that the idea of such dynamic modelling of agricultural systems is much older than the electronic computer. This approach may be traced back to the first quarter of the 19th century to a pupil of *Thaer: Carl von Wulffen* (11, 12, 16). He showed that the problem of soil fertility could be better understood by studying in detail the input-output dynamics of the farm, as a whole. It is the first example of a careful system analysis in agriculture which was made long before the term was invented.

*Von Wulffen* assumed that the soil contains a certain amount of „Reichtum" and that the yield in any year is equal to this „Reichtum" multiplied by the „Thätigkeit" of the soil, ranging from about 0.1 to 0.3. Without addition of nutrients, the „Reichtum" in the next year is then the „Reichtum" in the current year minus the current yield, so that the yield changes with time according to a negative exponential function. This continues untill the „Beharrungspunkt" of the crop rotation is reached, where the depletion of „Reichtum" by the crops equals the addition of „Reichtum" by manuring and weathering. On this basis, von *Wulffen* formulated and quantified a dynamic linear program for a farm with all its arable fields and pastures, but he lacked the optimizing algorithms to make full use of ist.

The „Reichtum" was expressed as a yield total stored in the soil and not in the clumsy humus-degrees of *Thaer*. A further innovation was to express the amount of manure not in the usual cartloads, but in terms of the amount of crop products, consumed by the herd of animals that produced it. This enabled to characterize each combination of soil and manure by its „Gattung". This „Gattung" was per definition one, in situations where the fertility of a field could be maintained at its original level by feeding the whole of its yield to a herd and returning all the produced manure to the field. Since losses were unavoidable, it appeared that in general more manure was needed to maintain the fertility, so that the „Gattung" was as a rule smaller than one.

The merit of his approach was that he analysed the system in such a way that the necessary database could be built up by experimentation and by careful bookkeeping of the inputs and outputs of each field and of the farm as a whole. This theory of *von Wulffen* stimulated many „Landjunker" to keep detailed farm records. Typical equilibrium yields appeared to be of the order of 1000 kg grain equivalents per hectare arable land.

Contrary to the grossly mistaken opinions of *von Liebig* (4), it was already convincingly proven in 1856 by *Wolff* (12) in his small brochure „Die Erschöpfung des Bodens durch die Kultur" that under normal agricultural practices the exhaustion of the soil was mainly due to lack of available nitrogen. This enabled interpretation of the „Reichtum" as the size of the available nitrogen pool in the soil, the „Gattung" as the fraction of nitrogen that is recirculated and the „Thätigkeit" as the efficiency of mining the nitrogen pool of the soil.

## 2. Towards more open agricultural systems

Even 175 years after its conception, *von Wulffen's* dynamic linear model is still suitable to describe the dilemma that are faced by third world farmers that have to manage without the benefit of external inputs.

The main problem in such closed systems is to recirculate as many nutrients as possible. However, the „Gattung" is always smaller than one, so that maintainance the yield level of the arable land requires additional inputs. In shifting cultivation, these are accumulated during the fallow period, whereas in mixed farming systems part of the land is grazed to produce manure. In this way yields of 1000 kg grain equivalents per ha may be obtained, as in Europe in *von Wulffen's* time. However, the population in most regions is increasing rapidly, so that more land is brought under cultivation and less land remains to maintain its fertility. The farmer may then try to increase the „Thätigkeit" by for instance using more often cassava to mine the soil more thoroughly. But this reduces the „Beharrungspunkt" still further, so that the cultivation of other crops is not worth the effort any more. Although the output for the region as a whole is increased for some time, it becomes impossible to maintain the yields per unit surface at such a level that it justifies the labour that is required to work the land. Or as the saying goes: rich fathers make poor children.

More innovative interventions, like the use of mycorhizza or good rooting varieties may improve the „Gattung" to some extent, but also lead to a more efficient mining of the soil. The predictable result of the latter is that after some years the yields will decline again but with the difference that they are more difficult to maintain. Phosphate fertilisation of nitrogen deficient soils is another example. Higher phosphate availability increases here the yield only to the extent that more nitrogen is taken up. Therefore its effect declines in course of time, but this may very well go unnoticed because of the short duration of research contracts.

Fortunately, phosphate fertilisation facilitates also the cultivation of leguminous crops in the rotation, but that may require the introduction of new varieties or species with their associated Rhizobium bacteria or innovative husbandry practices like the use of alleys with leguminous perennials or the use of fodder banks. By then the traditional, closed farming systems are well under way in their transition to more open systems that require external inputs in the form of research and extension, genetic material, mineral and nitrogen fertilizers and biocides.

Rapid urbanisation is another reason for the development of open farming systems. To satisfy the increasing urban demand, the remaining farmers have to produce increasing amounts of agricultural products over and above their own needs. This is only possible if the industrial sectors of the economy provide means of production for this purpose and if the terms of trade for the agricultural sector vis-a-vis the non-agricultural sectors are such that sufficient incentives are created for the farmer.

For this reason many of the agricultural development activities should be directed towards a further linkage of the agricultural and industrial sectors of the economy. In the final analysis, this is a political and socio-economic problem. However, it can only be solved if the technical constraints and possibilities are understood with such detail that it is possible to investigate to what extent the funds of techniques that are regionally applicable can meet the demands that are put upon it.

## 3. An interactive analysis

A promising methodology to explore feasible development options for a region is the technique of interactive multiple linear goal programming (10). The core of the input-output matrix of such programs is the fund of potential techniques of the region, as will be discussed later.

This particular dynamic linear programming technique simulates the problem of the policy maker of meeting various conflicting technical, social economic and environmental goals as satisfactorily as possible. The term interactive expresses here the notion that the linear program is executed in a number of iteration cycles. In the first iteration cycle each goal is maximized (or minimized) on its own. It can then be concluded that for each of the goals no better value can be obtained than calculated in this iteration and that it is not necessary to accept a value less favourable than the minimum goal restrictions that are generated. The initial freedom of choice is determined in this way, but the Utopia were all goals reach their maximum value simultaneously does not exist.

Now more satisfactory solutions from the point of the policy maker may be obtained in subsequent iteration cycles in tightening one of the goal restrictions and repeating the maximisation for the other goals. At least one of the new maxima is then lower then before. The choice of the goal restrictions that are tightened in successive rounds and the degree to which, reflect the specific interests of the policy maker and ultimately forces him in a situation where he is unable to improve on one of his goals without sacrificing on others. Policy makers with different views and different constituents are forced in this way into their own solution corner to face the problems of their own making.

Technically, the analysis results in consistent feasible development paths and translates the goals into combinations of production techniques that are necessary to achieve them, the physical needs for means of production and investments, the qualification of the labour force and so on, as will be clarified later.

The input-output matrix of the linear program is quantified in physical terms and covers in principle the whole spectrum of possible crop and animal production techniques for the region. Since many of these may still be in the pipeline, the overall framework of the matrix is generated by a judicious application of crop growth models and animal production models under the regional agro-ecological conditions.

## 4. Crop growth model

A major part of the system-analytical research that is undertaken in Wageningen at the Department of Theoretical Production Ecology, the Centre for Agro-Biological Research and the Centre for World Food Studies in Wageningen (3, 6) is geared to the development of programs to simulate crop growth. The primary objective is to calculate the possible crop and pasture yields under constraints of climate, crops and soils at various levels of land amelioration and to determine consecutively minimum input requirements to achieve these yields. For this purpose various production situations are distinguished in such a way that the results of computations in one situation can be used as a starting point in another.

In the analyses, a distinction is made between three types of factors that affect the production. These are factors that are beyond the control of the farmer and determine the potential production like radiation, temperature and intrinsic crop properties, factors by means of which the growth of the crop can be modified like water, minerals and nitrogen and factors that reduce the yield like weeds, pests and diseases.

## 4.1 Potential production

To calculate the potential level of production, it is assumed that yield reducing factors are absent and water, minerals and nitrogen are in optimal supply in the physical sense. Consequently, the yield is determined by crop properties and the radiation and temperature regime throughout the growing season. Although potential yields may not be an ultimate goal of development, these yields are a necessary reference against which achievements can be measured.

Potential production is calculated by means of a simulation program that is based on a thorough analysis of assimilation, respiration and transpiration and of distribution processes in crops. In combination with crop calendars that specify the time of sowing, emergence, flowering and ripening it is possible to calculate the daily evapo-transpiration and crop growth throughout the season and the potential yields of the main crops in a region. This yield differs of course considerably between crops and locations on earth.

With respect to variations in growth, it has been found that the growth rate of closed crop surfaces varies between 150 and 350 kg dry matter per hectare per day, depending on radiation, temperature and crop species (17).

The total production depends not only on this rate but also on the length of the closed canopy period. An absolute topper is sugarcane which may yield over 100.000 kg dry matter per hectare by combining growth rates of over 300 kg/ha/day with a growing period of a year. A good maize crop may grow 100 days at this high rate and end up with 40.000 kg dry matter or 20.000 kg of shelled maize grains/ha. Small grains also may have a closed crop surface for 100 days, but their potential growth rate is only about 200 kg/ha so that their final yield is 20.000 kg dry matter or 12.000 kg grains per hectare (3, 15).

These calculated potentials were at first met with considerable scepticism, but they have been confirmed experimentally for the main crops in a number of instances. Of course, there are less suitable weather conditions where the potential production is considerably lower, but the purpose of these calculations is precisely to identify such differences as a first step to guide research and development planning.

## 4.2 Water

At the next level or production the water supply may not be optimal, but it is still assumed that weeds, pests and diseases are absent and that minerals and nitrogen are in optimal supply. Apart from some supplementary irrigation, the moisture situation of the crop depends in this situation on rainfall and drainage.

The physical properties of the soil, the morphology of the land and the climatic conditions are crucial for the outcome in these situations. The water balance is calculated throughout the growing season to identify periods that crop growth is reduced by shortage or excess of water (3).

By means of these results, workability of the land can also be estimated for different technology levels: by hand, animals or machines. This is crucial information for the analysis of the consequences of substituting labour by machinery. The constraints in this production situation can be modified to a large extent by flood control, land levelling, terracing and drainage and irrigation. The extent of such amelioration measures are worked out for different mechanisation levels on basis of the amount and distance soil masses have to be moved. The simulation models are designed in such a way that the effects on yield and workability of such measures can be quantified.

Suitable and less suitable soils differ not so much in the potential production that may be ultimately reached, but in the efforts that are needed for their amelioration. These are prohibitive for a major part of the earth surface, but nevertheless the production potential of the earth is very large indeed, compared with needs for years to come (1).

## 4.3 Fertilizers

Subsequently it is estimated how much plant nutrients have to be applied to achieve the calculated yields at the chosen amelioration level. Models are being developed for the main nutrients. Especially nitrogen deserves attention, because of the large quantities that are needed earch year, its mobility and its origin from biological fixation or out of the factory. The approach of *von Wulffen* can still be recognized in the models that are being developed to simulate the nitrogen balance under various conditions. Provided that these are used in conjunction with experimental results, they provide valuable information regarding the agricultural and environmental fate of this nutrient.

It appears that in case of rice about 15 kg N has to be taken up by the crop for each 1000 kg of grains that are produced. However, the yearly uptake of nitrogen is not more than about 10 kg/ha in most agricultural systems without external inputs. It is often this limited N supply that limits the yield to less than 1000 kg of grain per ha. However, if the reclamation level is suited for a yield of 5000 kg per ha, about 75 kg/ha of nitrogen has to be taken up by the crop. Then, 65 kg/ha of nitrogen has to be supplied by fertilizer, either directly or indirectly out of applications in previous years. Under favourable conditions, the direct and indirect recovery of industrial nitrogen fertilizer may be so high, that only 100 kg/ha/year of nitrogen has to be applied to maintain these uptake rates. However, the recovery is often much lower because of improper control of the water or application of improper amounts at improper times in improper ways (2).

Thus these mineral and nitrogen models estimate the soil supply and generate the sufficient and necessary amounts of fertilizers that are needed to achive the yields that are possible at the amelioration level under consideration. Each of the nutrients has its specific effect, so that deficiencies of some elements cannot be replaced by supplying more of other elements.

## 4.4 Weeds, pests and diseases

The actual yields may be considerably lower than the yields that are calculated in the various production situations because of the yield-reducing effects of weeds, pests and diseases.

Weeds compete always for light, but they are particularly damaging in traditional farming systems because they compete there also for nutrients. By linking competition models and crop growth models it is possible to analyse and quantify the damage by weeds and the effects of weed control measures (9, 14). The damage by weeds is especially large under low yielding conditions because of lack of competitive ability of the crop. Weed control is therefore a never ending concern in traditional agricultural systems. This is the more so because weeding with hand-tools is very labour intensive. It may require more than 200 hours per hectare and often has to be done repeatedly. This excessive labour requirement limits the area of land that can be cultivated in traditional farming systems with long fallows. Therefore the area of land under cultivation can often be drastically increased by the use of herbicides, but this is just another example of more efficient mining with its predictable temporary effect.

The relative damage of diseases may work out otherwise. In traditional systems where nitrogen is often the main limiting factor, this element is taken up in the early part of the growing season. It is translocated from the vegetative organs to the seeds or other storage organs at later stages. This process of translocation accelerates leaf senescence and because leaves can only die once, the so called ripening diseases are not likely to be as disastrous as in high yielding situations. This is different for diseases that manifest themselves in an early stage, like those that can be controlled by disinfection of seeds (8).

By combining crop growth models with epidemiological models of weeds, pests and diseases, the understanding of their mutual interactions with crop growth is increasing rapidly. This supports the development of integrated methods for pests, disease and weed management that are geared towards a minimum use of biocides. Such schemes have been developed and used for wheat in the Netherlands since the middle of the seventies and that is an important reason why the number of sprayings is only 2.5 on the average compared with 7 in North West Germany and 8.5 in England (7).

### 4.5 The environment

Dynamic crop production models can only be solved by means of numerical integration because they contain many non-linear relations and dependencies on environmental forcing functions. This puts considerable demands on the geographical data base of weather, soil and land-form. In regions where the weather varies considerably from year to year it is necessary to have access to daily data over a number of years.

However, much of this information is often lost in the stastistical handling of the raw data, so that weather simulators may be needed as a last resort. Likewise too much information on spatial heterogeneity (5) may be lost in the process of soil classification and mapping and this the more so because map units are not especially made to meet the demands of production simulation models. Therefore much is to be said for data base systems that give ready access to the untampered data of the original pedons. Access to original weather and soil data enables to do the calculations first and then the averageing. The other way around — first averageing then calculating — may have been necessary not so long ago, but with the widespread availability of computers there is no excuse to continue to do so (19).

## 5. Exploring options for development in a semi-arid environement

The purpose of the exercise that is presented in this paper is to explore to what extent the fund of techniques that can be envisaged in a region can meet the demands that may be made upon it by stake holders in development. This interactive multiple goal programming is further illustrated by considering some semi-arid regions with a Mediterranean climate that is characterized by dry summers, erratic and rather low rainfall in winter and spatial heterogeneity (20).

### 5.1 The fund of techniques

The fund of existing and vizualized techniques in a region form the core of the interactive multiple goal program. Crop growth models are used in conjunction with statistical data, field experiments and the general body of knowledge of farmers, extension workers and local experts to generate this fund of techniques (20).

The techniques to grow wheat and barley in these semi-arid regions range from extensive grain/fallow systems via run-off/run-on systems to highly intensive systems, where the water supply is ensured in most years by the collection fo rainfall water behind dams or in cisterns. The output is straw and grain for animals or grain for human consumption. The diversity may be enhanced by the cultivation of drought or saline resistent fruit trees like olives, figs and dates and of leguminous forages for animal husbandry systems.

These systems range in their turn from nomadic grazing with the sheep at pasture year round to systems with intensively managed pastures and to feedlot operations that obtain their lambs from more extensive systems and make considerable use of imported concentrates. The output of these systems is mainly milk, meat or both and of course manure which may be partly collected and used in arable farming or otherwise be dumped in the nearest ravine. The crop growth models for such situations have been also verified for grasses and legumes and may be used to simulate forage quantity and quality throughout the season under a spectrum of treatments.

Comprehensive physiologically based animal production models are not readily available and therefore animal husbandry activities are defined in a target oriented way. This means that the yield is defined first and the requirements to achieve these are derived from this.

In that way a fund of techniques is defined covering a wide range of activities that may be used in a sustainable fashion. Apparently this fund of existing and envisaged techniques may encompass hundreds of techniques.

### 5.2 Constraints

As has been said, the fund of techniques forms the framework of a dynamic linear program that in addition characterizes a region by area of soil types, farming population, initial endowments and degree of openess. Farming systems constraints are formulated in terms of crop rotation demands and other limits on land use. In case of full isolation all inputs, output and constraints are expressed in physical terms because they cannot be traded across the border.

Most agricultural sectors in North Africa and the Middle East are open in the sense that the meat and grain is mainly sold outside the region and concentrates, fertilizers, machinery, fencing and building materials are imported and outside labour may be hired and fired. The economic environment is then defined by attaching prices to the goods and services that are tradable across the border ot the agricultural sector in the region. To avoid the misleading notion that trees may grow up into the blue sky, the credit facilities have to be limited by for instance commercial interest rates and the obligation to repay within the time horizon that is considered.

It is the purpose to assess the technical possibilities. Therefore social-economic constraints, like ownership of the means of production, land titles, gender specific labour qualities or traditional economic behavioural patterns are not taken into account at first. Forced quantification of these aspects would block the perspectives for development at a too early stage. Of course, they may be introduced stepwise later on. For example, in semi-arid regions, integrated arable farming and animal husbandry systems may very well turn out to be optimal, but development in that direction may be in practice blocked by lack of interaction between different ethnic groups. This apartheid may then be introduced in the analyses as a goal to be minimized in order to quantify its cost in terms of the other goals that are pursued.

**5.3 Goals**

Development aid may be taken into account, but then as a goal which is to be minimized by donor agencies without jeopardizing the development goals that are pursued. In the Middle East this does not appear to be the case because the rapidly increasing urban demand leads to a comfortable price ratio between lamb meat and concentrates.

Another goal that may be considered is minimizing the use of imported concentrates, because of its drain on foreign exchange or the environmental hazards of its use in intensive animal husbandry systems. Environmental concern may also lead to minimizing fertilizer use or maximizing the area under extensive systems of primary and secondary production.

The total employment may be another goal to be maximized, but then a distinction has to be made between the farmers that have no alternative employment possibilities and migrant labour. Keeping the number of farmers low and allowing unrestricted hiring and firing of migrant labour may be a goal of the farmers themselves, but maximizing the number of farmers without creating unemployment, while maintaining a minimum income may be the goal of a settlement agency.

Maximizing consumable income, is obviously a goal of the farmers, but also of the government because it broadens the tax-base. Generation of income and employment is also a concern for the environmentalist, because it may be otherwise too difficult to maintain the environmental integrity of the region.

Important physical goals, that may serve sustainability, are investments in soil conservation, in water-harvesting systems or in olive orchards. In case of full isolation all consumption goals are also formulated in physical terms like the amount of grain, meat, milk and fruit.

## 5.4 The interactive procedure

The interactive procedure is illustrated for a region of 50.000 hectare of which half is suitable for arable farming and more intensive pasture and the other half can be used as fenced or unfenced rangeland and which has 400 farm families to begin with. The optimisations are performed for a period of 15 years so that the employment over the whole time horizon has to be at least 6000 person-years. Considering the cost of hired labour, the minimum income of the farmers should be at least 50 million dollars.

The possibilities of the interactive multiple goal linear programming technique can be utilized to its best advantage, if the initial number of goals is set at a high number. In that way a high degree of flexibility is achieved and the options for technically feasible development paths are kept as open as possible.

However, for illustrative purposes the number of goals treated in this paper has to be restricted to only three. These are consumable income, employment and area under extensive systems. The first iteration cycle determines the initial freedom of choice. In the three diagrams of Figure 1 it is seen that this freedom is bounded by 50 and 197 million dollar for the consumable income, by 6000 and 19200 person-years for employment and by 100 and 742 thousand hectare for extensive systems over the whole time horizon of 15 years. In the next iteration cycles, the views of the society for the conservation of the landscape are served. This society would like to reserve at least 80 percent of the area for extensive systems. Hence, in the second iteration the minimum restriction for this goal was set at 600.000 ha, whereas the other goals were maximized again in turn. The diagrams show that this reduces the freedom of choice for the other goals considerably. Subsequent calculations showed that a minimum restriction of 12.500 person-years on the goal for employment would still allow a doubling of the number of farmers over the time horizon of 15 years. This may be considered a good bargaining position in the debate with the settlement agency. In the third iteration cycle, the maximum consumable income was found to be 135 million dollars. This appeared to be per farmer two times the wages of a hired hand, and was therefore considered a good bargaining position with the farmers association.

However, this association could remark that this so-called consumable income is income before taxes and has to compensate also the entrepeneural risks of farming and that 10 percent of the area reserved for extensive systems would do. Their interactive exercise may end up in a situation where the number of farmers remained the same but their income was two times higher and a considerable portion of the labour was provided by migrant labour that could be easily hired and fired.

The settlement agency may come to the conclusion that it would be possible to increase the number of farmers with a factor of three, while maintaining the consumable income at two and a half times the wage of hired labour and the area under extensive systems at fifteen percent.

## 5.5 Follow up

At the end, the three parties may forge a compromize and formulate a common request to the government research council to analyse its technical, social, economic and policy consequences.

Such a further analyses showed that 25 percent of the range land would remain unfenced and in extensive use by the sturdy Awassi fat-tail breed and that for income generation the region would rely to a considerably extent on feed-lot operations with the more prolific but also more disease prone Finncross breed. Although it was not taken up as an explicit goal, it was found that the drain on foreign exchange by the import of concentrates was rather modest, because of the cultivation of high quality home grown forage. This may suit the government very well.

It is remarked that this development path would require more research on legumes and the disease problems of Finn-cross and less research on the Merino breeds and that the data on manure conservation need confirmation because they were derived from experience in temperate climates. Some further exercises with the model showed that research on fig orchards systems could pay off handesomely, but that the existing research program on date palms is better shelved.

The extension service may stress that the rapid expansion of feedlot operations requires considerable training, improved credit facilities and a good market organisation, whereas an university sociologist may observe that future settlers are likely to be cattle farmers who would not touch sheep with a ten feet pole.

Obviously, this story is carried a little too far, but this is done in the firm belief that the time has come for innovative ways to integrate agricultural research and development that may inspire planners and policy makers and are a challenge for interdisciplinary research.

## Summary

Simulation models that reflect fundamental growth processes are used in combination with dynamic linear program techniques to investigate to what extent the fund of agricultural techniques that are regionally available can meet the demands of stake holders in development.

The crop growth simulation models distinguish various production situations in such a way that the results of the computations in one situation can be used as a starting point in others. Animal husbandry activities are defined in a target oriented way, such that the yields are defined first and the requirements to achieve these are derived from this.

Together with data on the physical, social and economic environment the simulation models are used to generate the input-output matrices and constraints of a dynamic linear program. This program is used in an interactive mutliple goal mode, in such a way that stake holders with different interests are guided to their own solution space that they become aware of the trade-offs between their own conflicting goals and aspirations.

The approach is further clarified by considering the prospects for agricultural development in a semi-arid region with special emphasis on sheep husbandry.

## Zusammenfassung

Simulationsmodelle, die grundlegende Wachstumsprozesse widerspiegeln, werden in Kombination mit dynamischen, linearen Programmierungstechniken benutzt, um zu untersuchen, in welchem Ausmaß der Fundus an regional verfügbaren landwirtschaftlichen Produktionstechniken den Ansprüchen der an der Entwicklung Beteiligten gerecht wird.

In Simulationsmodellen für das Pflanzenwachstum werden verschiedene Produktionssituationen in der Weise unterschieden, daß das Ergebnis der Berechnung einer Situation als Ausgangspunkt für andere verwendet werden kann. Aktivitäten der Tierhaltung werden in einer zielorientierten Weise definiert, so daß zuerst die Leistungen definiert werden und dann die zur Erreichung dieser Leistungen notwendigen Ansprüche davon abgeleitet werden.

Zusammen mit Daten über die physische, soziale und ökonomische Umwelt werden die Simulationsmodelle benutzt, um die Input-Output-Matrizen und Begrenzungen eines dynamischen linearen Programms zu generieren. Dieses Programm wird im Rahmen eines interaktiven Ansatzes mit multiplen Zielen so verwendet, daß die Beteiligten, die unterschiedliche Interessen verfolgen, so in ihren eigenen Lösungsraum geleitet werden, daß sie sich der „trade-offs" zwischen ihren eigenen konfligierenden Zielen und Erwartungen bewußt werden.

Vorgestellt wird dieser Ansatz am Beispiel der Möglichkeiten für die landwirtschaftliche Entwicklung in einer semi-ariden Region mit besonderem Schwerpunkt in der Schafhaltung.

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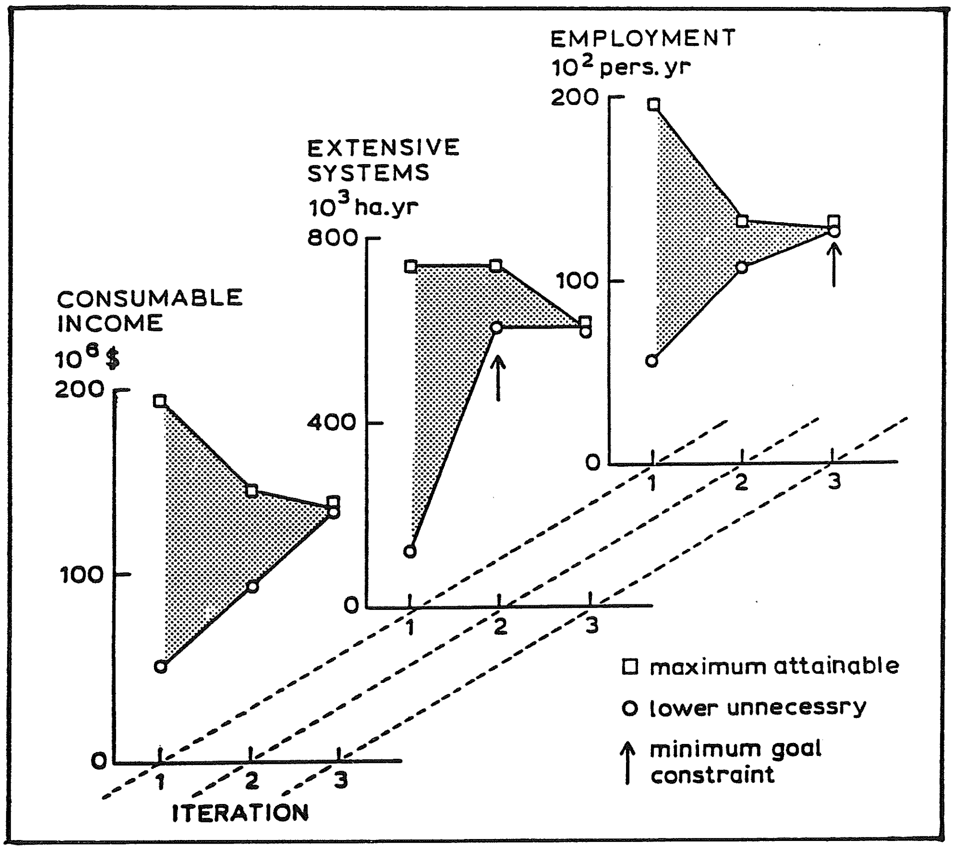
**Figure 1:** A graphical presentation of the iterative procedure. There are three goals and therefore also three graphs and three iteration cycles that comprize each three iterations. At the first iteration cycle the maximum attainable values (squares) for the three goals are determined. No minimum goals constraints are set, but it appears that it is unnecessary to aim at goals that are less ambitious than indicated by the open dots. At the second iteration cycle, a minimum goal constraint is set for the extensive systems (arrow). This reduces the range for the other goals. At the third iteration cycle the minimum goal constraint of employment (arrow) is set very close to its maximum attainable level. This appears to remove any slack out of the other two goals. At this stage on goal can only be improved at the expense of another.



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# Integrating Agricultural Research and Development*

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## Introduction

It may be seen as a positive development that at least for the world as a whole production is keeping up with population growth and that there are no compelling reasons why this should not be so for years to come. The problem is not so much one of potential but of equity among consumers and producers and of meeting current demand without sacrifycing the heritage of future generations.

On one end of the spectrum there are the problems of affluence in Western Europa and the USA. There, the farmers operate in an economic environment that stimulates to produce more and more from each hectare of land and from each hour of labour, resulting by now in overproduction, pollution and loss of environmental diversity. On the other end of the spectrum are the problems of poverty of many African farmers who cannot afford industrial means of production so that the needs of an increasing population forces over-exploitation of the resource base leading to soil erosion, exhaustion of nutrients and destruction of fragile ecologies.

Such trends threaten the sustainability of agriculture and therefore it is a main purpose of production ecology to contribute to the development of an agriculture that meets the increasing demands for agricultural products, while enhancing its supporting resource base and avoiding environmental degradation. A powerfool tool to this end is the simulation of crop and farming systems in computer models that are rich in mathematical relationships and feedback loops that reflect fundamental growth processes and environmental interactions and are used in combination with dynamic linear programming techniques.

## 1. An early example of systems analyses in agriculture

It may come as a surprise that the idea of such dynamic modelling of agricultural systems is much older than the electronic computer. This approach may be traced back to the first quarter of the 19th century to a pupil of *Thaer: Carl von Wulffen* (11, 12, 16). He showed that the problem of soil fertility could be better understood by studying in detail the input-output dynamics of the farm, as a whole. It is the first example of a careful system analysis in agriculture which was made long before the term was invented.

*Von Wulffen* assumed that the soil contains a certain amount of „Reichtum" and that the yield in any year is equal to this „Reichtum" multiplied by the „Thätigkeit" of the soil, ranging from about 0.1 to 0.3. Without addition of nutrients, the „Reichtum" in the next year is then the „Reichtum" in the current year minus the current yield, so that the yield changes with time according to a negative exponential function. This continues untill the „Beharrungspunkt" of the crop rotation is reached, where the depletion of „Reichtum" by the crops equals the addition of „Reichtum" by manuring and weathering. On this basis, von *Wulffen* formulated and quantified a dynamic linear program for a farm with all its arable fields and pastures, but he lacked the optimizing algorithms to make full use of ist.

The „Reichtum" was expressed as a yield total stored in the soil and not in the clumsy humus-degrees of *Thaer*. A further innovation was to express the amount of manure not in the usual cartloads, but in terms of the amount of crop products, consumed by the herd of animals that produced it. This enabled to characterize each combination of soil and manure by its „Gattung". This „Gattung" was per definition one, in situations where the fertility of a field could be maintained at its original level by feeding the whole of its yield to a herd and returning all the produced manure to the field. Since losses were unavoidable, it appeared that in general more manure was needed to maintain the fertility, so that the „Gattung" was as a rule smaller than one.

The merit of his approach was that he analysed the system in such a way that the necessary database could be built up by experimentation and by careful bookkeeping of the inputs and outputs of each field and of the farm as a whole. This theory of *von Wulffen* stimulated many „Landjunker" to keep detailed farm records. Typical equilibrium yields appeared to be of the order of 1000 kg grain equivalents per hectare arable land.

Contrary to the grossly mistaken opinions of *von Liebig* (4), it was already convincingly proven in 1856 by *Wolff* (12) in his small brochure „Die Erschöpfung des Bodens durch die Kultur" that under normal agricultural practices the exhaustion of the soil was mainly due to lack of available nitrogen. This enabled interpretation of the „Reichtum" as the size of the available nitrogen pool in the soil, the „Gattung" as the fraction of nitrogen that is recirculated and the „Thätigkeit" as the efficiency of mining the nitrogen pool of the soil.

## 2. Towards more open agricultural systems

Even 175 years after its conception, *von Wulffen's* dynamic linear model is still suitable to describe the dilemma that are faced by third world farmers that have to manage without the benefit of external inputs.

The main problem in such closed systems is to recirculate as many nutrients as possible. However, the „Gattung" is always smaller than one, so that maintainance the yield level of the arable land requires additional inputs. In shifting cultivation, these are accumulated during the fallow period, whereas in mixed farming systems part of the land is grazed to produce manure. In this way yields of 1000 kg grain equivalents per ha may be obtained, as in Europe in *von Wulffen's* time. However, the population in most regions is increasing rapidly, so that more land is brought under cultivation and less land remains to maintain its fertility. The farmer may then try to increase the „Thätigkeit" by for instance using more often cassava to mine the soil more thoroughly. But this reduces the „Beharrungspunkt" still further, so that the cultivation of other crops is not worth the effort any more. Although the output for the region as a whole is increased for some time, it becomes impossible to maintain the yields per unit surface at such a level that it justifies the labour that is required to work the land. Or as the saying goes: rich fathers make poor children.

More innovative interventions, like the use of mycorhizza or good rooting varieties may improve the „Gattung" to some extent, but also lead to a more efficient mining of the soil. The predictable result of the latter is that after some years the yields will decline again but with the difference that they are more difficult to maintain. Phosphate fertilisation of nitrogen deficient soils is another example. Higher phosphate availability increases here the yield only to the extent that more nitrogen is taken up. Therefore its effect declines in course of time, but this may very well go unnoticed because of the short duration of research contracts.

Fortunately, phosphate fertilisation facilitates also the cultivation of leguminous crops in the rotation, but that may require the introduction of new varieties or species with their associated Rhizobium bacteria or innovative husbandry practices like the use of alleys with leguminous perennials or the use of fodder banks. By then the traditional, closed farming systems are well under way in their transition to more open systems that require external inputs in the form of research and extension, genetic material, mineral and nitrogen fertilizers and biocides.

Rapid urbanisation is another reason for the development of open farming systems. To satisfy the increasing urban demand, the remaining farmers have to produce increasing amounts of agricultural products over and above their own needs. This is only possible if the industrial sectors of the economy provide means of production for this purpose and if the terms of trade for the agricultural sector vis-a-vis the non-agricultural sectors are such that sufficient incentives are created for the farmer.

For this reason many of the agricultural development activities should be directed towards a further linkage of the agricultural and industrial sectors of the economy. In the final analysis, this is a political and socio-economic problem. However, it can only be solved if the technical constraints and possibilities are understood with such detail that it is possible to investigate to what extent the funds of techniques that are regionally applicable can meet the demands that are put upon it.

## 3. An interactive analysis

A promising methodology to explore feasible development options for a region is the technique of interactive multiple linear goal programming (10). The core of the input-output matrix of such programs is the fund of potential techniques of the region, as will be discussed later.

This particular dynamic linear programming technique simulates the problem of the policy maker of meeting various conflicting technical, social economic and environmental goals as satisfactorily as possible. The term interactive expresses here the notion that the linear program is executed in a number of iteration cycles. In the first iteration cycle each goal is maximized (or minimized) on its own. It can then be concluded that for each of the goals no better value can be obtained than calculated in this iteration and that it is not necessary to accept a value less favourable than the minimum goal restrictions that are generated. The initial freedom of choice is determined in this way, but the Utopia were all goals reach their maximum value simultaneously does not exist.

Now more satisfactory solutions from the point of the policy maker may be obtained in subsequent iteration cycles in tightening one of the goal restrictions and repeating the maximisation for the other goals. At least one of the new maxima is then lower then before. The choice of the goal restrictions that are tightened in successive rounds and the degree to which, reflect the specific interests of the policy maker and ultimately forces him in a situation where he is unable to improve on one of his goals without sacrificing on others. Policy makers with different views and different constituents are forced in this way into their own solution corner to face the problems of their own making.

Technically, the analysis results in consistent feasible development paths and translates the goals into combinations of production techniques that are necessary to achieve them, the physical needs for means of production and investments, the qualification of the labour force and so on, as will be clarified later.

The input-output matrix of the linear program is quantified in physical terms and covers in principle the whole spectrum of possible crop and animal production techniques for the region. Since many of these may still be in the pipeline, the overall framework of the matrix is generated by a judicious application of crop growth models and animal production models under the regional agro-ecological conditions.

## 4. Crop growth model

A major part of the system-analytical research that is undertaken in Wageningen at the Department of Theoretical Production Ecology, the Centre for Agro-Biological Research and the Centre for World Food Studies in Wageningen (3, 6) is geared to the development of programs to simulate crop growth. The primary objective is to calculate the possible crop and pasture yields under constraints of climate, crops and soils at various levels of land amelioration and to determine consecutively minimum input requirements to achieve these yields. For this purpose various production situations are distinguished in such a way that the results of computations in one situation can be used as a starting point in another.

In the analyses, a distinction is made between three types of factors that affect the production. These are factors that are beyond the control of the farmer and determine the potential production like radiation, temperature and intrinsic crop properties, factors by means of which the growth of the crop can be modified like water, minerals and nitrogen and factors that reduce the yield like weeds, pests and diseases.

## 4.1 Potential production

To calculate the potential level of production, it is assumed that yield reducing factors are absent and water, minerals and nitrogen are in optimal supply in the physical sense. Consequently, the yield is determined by crop properties and the radiation and temperature regime throughout the growing season. Although potential yields may not be an ultimate goal of development, these yields are a necessary reference against which achievements can be measured.

Potential production is calculated by means of a simulation program that is based on a thorough analysis of assimilation, respiration and transpiration and of distribution processes in crops. In combination with crop calendars that specify the time of sowing, emergence, flowering and ripening it is possible to calculate the daily evapo-transpiration and crop growth throughout the season and the potential yields of the main crops in a region. This yield differs of course considerably between crops and locations on earth.

With respect to variations in growth, it has been found that the growth rate of closed crop surfaces varies between 150 and 350 kg dry matter per hectare per day, depending on radiation, temperature and crop species (17).

The total production depends not only on this rate but also on the length of the closed canopy period. An absolute topper is sugarcane which may yield over 100.000 kg dry matter per hectare by combining growth rates of over 300 kg/ha/day with a growing period of a year. A good maize crop may grow 100 days at this high rate and end up with 40.000 kg dry matter or 20.000 kg of shelled maize grains/ha. Small grains also may have a closed crop surface for 100 days, but their potential growth rate is only about 200 kg/ha so that their final yield is 20.000 kg dry matter or 12.000 kg grains per hectare (3, 15).

These calculated potentials were at first met with considerable scepticism, but they have been confirmed experimentally for the main crops in a number of instances. Of course, there are less suitable weather conditions where the potential production is considerably lower, but the purpose of these calculations is precisely to identify such differences as a first step to guide research and development planning.

## 4.2 Water

At the next level or production the water supply may not be optimal, but it is still assumed that weeds, pests and diseases are absent and that minerals and nitrogen are in optimal supply. Apart from some supplementary irrigation, the moisture situation of the crop depends in this situation on rainfall and drainage.

The physical properties of the soil, the morphology of the land and the climatic conditions are crucial for the outcome in these situations. The water balance is calculated throughout the growing season to identify periods that crop growth is reduced by shortage or excess of water (3).

By means of these results, workability of the land can also be estimated for different technology levels: by hand, animals or machines. This is crucial information for the analysis of the consequences of substituting labour by machinery. The constraints in this production situation can be modified to a large extent by flood control, land levelling, terracing and drainage and irrigation. The extent of such amelioration measures are worked out for different mechanisation levels on basis of the amount and distance soil masses have to be moved. The simulation models are designed in such a way that the effects on yield and workability of such measures can be quantified.

Suitable and less suitable soils differ not so much in the potential production that may be ultimately reached, but in the efforts that are needed for their amelioration. These are prohibitive for a major part of the earth surface, but nevertheless the production potential of the earth is very large indeed, compared with needs for years to come (1).

### 4.3 Fertilizers

Subsequently it is estimated how much plant nutrients have to be applied to achieve the calculated yields at the chosen amelioration level. Models are being developed for the main nutrients. Especially nitrogen deserves attention, because of the large quantities that are needed earch year, its mobility and its origin from biological fixation or out of the factory. The approach of *von Wulffen* can still be recognized in the models that are being developed to simulate the nitrogen balance under various conditions. Provided that these are used in conjunction with experimental results, they provide valuable information regarding the agricultural and environmental fate of this nutrient.

It appears that in case of rice about 15 kg N has to be taken up by the crop for each 1000 kg of grains that are produced. However, the yearly uptake of nitrogen is not more than about 10 kg/ha in most agricultural systems without external inputs. It is often this limited N supply that limits the yield to less than 1000 kg of grain per ha. However, if the reclamation level is suited for a yield of 5000 kg per ha, about 75 kg/ha of nitrogen has to be taken up by the crop. Then, 65 kg/ha of nitrogen has to be supplied by fertilizer, either directly or indirectly out of applications in previous years. Under favourable conditions, the direct and indirect recovery of industrial nitrogen fertilizer may be so high, that only 100 kg/ha/year of nitrogen has to be applied to maintain these uptake rates. However, the recovery is often much lower because of improper control of the water or application of improper amounts at improper times in improper ways (2).

Thus these mineral and nitrogen models estimate the soil supply and generate the sufficient and necessary amounts of fertilizers that are needed to achive the yields that are possible at the amelioration level under consideration. Each of the nutrients has its specific effect, so that deficiencies of some elements cannot be replaced by supplying more of other elements.

### 4.4 Weeds, pests and diseases

The actual yields may be considerably lower than the yields that are calculated in the various production situations because of the yield-reducing effects of weeds, pests and diseases.

Weeds compete always for light, but they are particularly damaging in traditional farming systems because they compete there also for nutrients. By linking competition models and crop growth models it is possible to analyse and quantify the damage by weeds and the effects of weed control measures (9, 14). The damage by weeds is especially large under low yielding conditions because of lack of competitive ability of the crop. Weed control is therefore a never ending concern in traditional agricultural systems. This is the more so because weeding with hand-tools is very labour intensive. It may require more than 200 hours per hectare and often has to be done repeatedly. This excessive labour requirement limits the area of land that can be cultivated in traditional farming systems with long fallows. Therefore the area of land under cultivation can often be drastically increased by the use of herbicides, but this is just another example of more efficient mining with its predictable temporary effect.

The relative damage of diseases may work out otherwise. In traditional systems where nitrogen is often the main limiting factor, this element is taken up in the early part of the growing season. It is translocated from the vegetative organs to the seeds or other storage organs at later stages. This process of translocation accelerates leaf senescence and because leaves can only die once, the so called ripening diseases are not likely to be as disastrous as in high yielding situations. This is different for diseases that manifest themselves in an early stage, like those that can be controlled by disinfection of seeds (8).

By combining crop growth models with epidemiological models of weeds, pests and diseases, the understanding of their mutual interactions with crop growth is increasing rapidly. This supports the development of integrated methods for pests, disease and weed management that are geared towards a minimum use of biocides. Such schemes have been developed and used for wheat in the Netherlands since the middle of the seventies and that is an important reason why the number of sprayings is only 2.5 on the average compared with 7 in North West Germany and 8.5 in England (7).

### 4.5 The environment

Dynamic crop production models can only be solved by means of numerical integration because they contain many non-linear relations and dependencies on environmental forcing functions. This puts considerable demands on the geographical data base of weather, soil and land-form. In regions where the weather varies considerably from year to year it is necessary to have access to daily data over a number of years.

However, much of this information is often lost in the stastistical handling of the raw data, so that weather simulators may be needed as a last resort. Likewise too much information on spatial heterogeneity (5) may be lost in the process of soil classification and mapping and this the more so because map units are not especially made to meet the demands of production simulation models. Therefore much is to be said for data base systems that give ready access to the untampered data of the original pedons. Access to original weather and soil data enables to do the calculations first and then the averageing. The other way around — first averageing then calculating — may have been necessary not so long ago, but with the widespread availability of computers there is no excuse to continue to do so (19).

## 5. Exploring options for development in a semi-arid environement

The purpose of the exercise that is presented in this paper is to explore to what extent the fund of techniques that can be envisaged in a region can meet the demands that may be made upon it by stake holders in development. This interactive multiple goal programming is further illustrated by considering some semi-arid regions with a Mediterranean climate that is characterized by dry summers, erratic and rather low rainfall in winter and spatial heterogeneity (20).

### 5.1 The fund of techniques

The fund of existing and vizualized techniques in a region form the core of the interactive multiple goal program. Crop growth models are used in conjunction with statistical data, field experiments and the general body of knowledge of farmers, extension workers and local experts to generate this fund of techniques (20).

The techniques to grow wheat and barley in these semi-arid regions range from extensive grain/fallow systems via run-off/run-on systems to highly intensive systems, where the water supply is ensured in most years by the collection fo rainfall water behind dams or in cisterns. The output is straw and grain for animals or grain for human consumption. The diversity may be enhanced by the cultivation of drought or saline resistent fruit trees like olives, figs and dates and of leguminous forages for animal husbandry systems.

These systems range in their turn from nomadic grazing with the sheep at pasture year round to systems with intensively managed pastures and to feedlot operations that obtain their lambs from more extensive systems and make considerable use of imported concentrates. The output of these systems is mainly milk, meat or both and of course manure which may be partly collected and used in arable farming or otherwise be dumped in the nearest ravine. The crop growth models for such situations have been also verified for grasses and legumes and may be used to simulate forage quantity and quality throughout the season under a spectrum of treatments.

Comprehensive physiologically based animal production models are not readily available and therefore animal husbandry activities are defined in a target oriented way. This means that the yield is defined first and the requirements to achieve these are derived from this.

In that way a fund of techniques is defined covering a wide range of activities that may be used in a sustainable fashion. Apparently this fund of existing and envisaged techniques may encompass hundreds of techniques.

### 5.2 Constraints

As has been said, the fund of techniques forms the framework of a dynamic linear program that in addition characterizes a region by area of soil types, farming population, initial endowments and degree of openess. Farming systems constraints are formulated in terms of crop rotation demands and other limits on land use. In case of full isolation all inputs, output and constraints are expressed in physical terms because they cannot be traded across the border.

Most agricultural sectors in North Africa and the Middle East are open in the sense that the meat and grain is mainly sold outside the region and concentrates, fertilizers, machinery, fencing and building materials are imported and outside labour may be hired and fired. The economic environment is then defined by attaching prices to the goods and services that are tradable across the border ot the agricultural sector in the region. To avoid the misleading notion that trees may grow up into the blue sky, the credit facilities have to be limited by for instance commercial interest rates and the obligation to repay within the time horizon that is considered.

It is the purpose to assess the technical possibilities. Therefore social-economic constraints, like ownership of the means of production, land titles, gender specific labour qualities or traditional economic behavioural patterns are not taken into account at first. Forced quantification of these aspects would block the perspectives for development at a too early stage. Of course, they may be introduced stepwise later on. For example, in semi-arid regions, integrated arable farming and animal husbandry systems may very well turn out to be optimal, but development in that direction may be in practice blocked by lack of interaction between different ethnic groups. This apartheid may then be introduced in the analyses as a goal to be minimized in order to quantify its cost in terms of the other goals that are pursued.

## 5.3 Goals

Development aid may be taken into account, but then as a goal which is to be minimized by donor agencies without jeopardizing the development goals that are pursued. In the Middle East this does not appear to be the case because the rapidly increasing urban demand leads to a comfortable price ratio between lamb meat and concentrates.

Another goal that may be considered is minimizing the use of imported concentrates, because of its drain on foreign exchange or the environmental hazards of its use in intensive animal husbandry systems. Environmental concern may also lead to minimizing fertilizer use or maximizing the area under extensive systems of primary and secondary production.

The total employment may be another goal to be maximized, but then a distinction has to be made between the farmers that have no alternative employment possibilities and migrant labour. Keeping the number of farmers low and allowing unrestricted hiring and firing of migrant labour may be a goal of the farmers themselves, but maximizing the number of farmers without creating unemployment, while maintaining a minimum income may be the goal of a settlement agency.

Maximizing consumable income, is obviously a goal of the farmers, but also of the government because it broadens the tax-base. Generation of income and employment is also a concern for the environmentalist, because it may be otherwise too difficult to maintain the environmental integrity of the region.

Important physical goals, that may serve sustainability, are investments in soil conservation, in water-harvesting systems or in olive orchards. In case of full isolation all consumption goals are also formulated in physical terms like the amount of grain, meat, milk and fruit.

## 5.4 The interactive procedure

The interactive procedure is illustrated for a region of 50.000 hectare of which half is suitable for arable farming and more intensive pasture and the other half can be used as fenced or unfenced rangeland and which has 400 farm families to begin with. The optimisations are performed for a period of 15 years so that the employment over the whole time horizon has to be at least 6000 person-years. Considering the cost of hired labour, the minimum income of the farmers should be at least 50 million dollars.

The possibilities of the interactive multiple goal linear programming technique can be utilized to its best advantage, if the initial number of goals is set at a high number. In that way a high degree of flexibility is achieved and the options for technically feasible development paths are kept as open as possible.

However, for illustrative purposes the number of goals treated in this paper has to be restricted to only three. These are consumable income, employment and area under extensive systems. The first iteration cycle determines the initial freedom of choice. In the three diagrams of Figure 1 it is seen that this freedom is bounded by 50 and 197 million dollar for the consumable income, by 6000 and 19200 person-years for employment and by 100 and 742 thousand hectare for extensive systems over the whole time horizon of 15 years. In the next iteration cycles, the views of the society for the conservation of the landscape are served. This society would like to reserve at least 80 percent of the area for extensive systems. Hence, in the second iteration the minimum restriction for this goal was set at 600.000 ha, whereas the other goals were maximized again in turn. The diagrams show that this reduces the freedom of choice for the other goals considerably. Subsequent calculations showed that a minimum restriction of 12.500 person-years on the goal for employment would still allow a doubling of the number of farmers over the time horizon of 15 years. This may be considered a good bargaining position in the debate with the settlement agency. In the third iteration cycle, the maximum consumable income was found to be 135 million dollars. This appeared to be per farmer two times the wages of a hired hand, and was therefore considered a good bargaining position with the farmers association.

However, this association could remark that this so-called consumable income is income before taxes and has to compensate also the entrepeneural risks of farming and that 10 percent of the area reserved for extensive systems would do. Their interactive exercise may end up in a situation where the number of farmers remained the same but their income was two times higher and a considerable portion of the labour was provided by migrant labour that could be easily hired and fired.

The settlement agency may come to the conclusion that it would be possible to increase the number of farmers with a factor of three, while maintaining the consumable income at two and a half times the wage of hired labour and the area under extensive systems at fifteen percent.

## 5.5 Follow up

At the end, the three parties may forge a compromize and formulate a common request to the government research council to analyse its technical, social, economic and policy consequences.

Such a further analyses showed that 25 percent of the range land would remain unfenced and in extensive use by the sturdy Awassi fat-tail breed and that for income generation the region would rely to a considerably extent on feed-lot operations with the more prolific but also more disease prone Finncross breed. Although it was not taken up as an explicit goal, it was found that the drain on foreign exchange by the import of concentrates was rather modest, because of the cultivation of high quality home grown forage. This may suit the government very well.

It is remarked that this development path would require more research on legumes and the disease problems of Finn-cross and less research on the Merino breeds and that the data on manure conservation need confirmation because they were derived from experience in temperate climates. Some further exercises with the model showed that research on fig orchards systems could pay off handesomely, but that the existing research program on date palms is better shelved.

The extension service may stress that the rapid expansion of feedlot operations requires considerable training, improved credit facilities and a good market organisation, whereas an university sociologist may observe that future settlers are likely to be cattle farmers who would not touch sheep with a ten feet pole.

Obviously, this story is carried a little too far, but this is done in the firm belief that the time has come for innovative ways to integrate agricultural research and development that may inspire planners and policy makers and are a challenge for interdisciplinary research.

## Summary

Simulation models that reflect fundamental growth processes are used in combination with dynamic linear program techniques to investigate to what extent the fund of agricultural techniques that are regionally available can meet the demands of stake holders in development.

The crop growth simulation models distinguish various production situations in such a way that the results of the computations in one situation can be used as a starting point in others. Animal husbandry activities are defined in a target oriented way, such that the yields are defined first and the requirements to achieve these are derived from this.

Together with data on the physical, social and economic environment the simulation models are used to generate the input-output matrices and constraints of a dynamic linear program. This program is used in an interactive mutliple goal mode, in such a way that stake holders with different interests are guided to their own solution space that they become aware of the trade-offs between their own conflicting goals and aspirations.

The approach is further clarified by considering the prospects for agricultural development in a semi-arid region with special emphasis on sheep husbandry.

## Zusammenfassung

Simulationsmodelle, die grundlegende Wachstumsprozesse widerspiegeln, werden in Kombination mit dynamischen, linearen Programmierungstechniken benutzt, um zu untersuchen, in welchem Ausmaß der Fundus an regional verfügbaren landwirtschaftlichen Produktionstechniken den Ansprüchen der an der Entwicklung Beteiligten gerecht wird.

In Simulationsmodellen für das Pflanzenwachstum werden verschiedene Produktionssituationen in der Weise unterschieden, daß das Ergebnis der Berechnung einer Situation als Ausgangspunkt für andere verwendet werden kann. Aktivitäten der Tierhaltung werden in einer zielorientierten Weise definiert, so daß zuerst die Leistungen definiert werden und dann die zur Erreichung dieser Leistungen notwendigen Ansprüche davon abgeleitet werden.

Zusammen mit Daten über die physische, soziale und ökonomische Umwelt werden die Simulationsmodelle benutzt, um die Input-Output-Matrizen und Begrenzungen eines dynamischen linearen Programms zu generieren. Dieses Programm wird im Rahmen eines interaktiven Ansatzes mit multiplen Zielen so verwendet, daß die Beteiligten, die unterschiedliche Interessen verfolgen, so in ihren eigenen Lösungsraum geleitet werden, daß sie sich der „trade-offs" zwischen ihren eigenen konfligierenden Zielen und Erwartungen bewußt werden.

Vorgestellt wird dieser Ansatz am Beispiel der Möglichkeiten für die landwirtschaftliche Entwicklung in einer semi-ariden Region mit besonderem Schwerpunkt in der Schafhaltung.

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Figure 1: A graphical presentation of the iterative procedure. There are three goals and therefore also three graphs and three iteration cycles that comprize each three iterations. At the first iteration cycle the maximum attainable values (squares) for the three goals are determined. No minimum goals constraints are set, but it appears that it is unnecessary to aim at goals that are less ambitious than indicated by the open dots. At the second iteration cycle, a minimum goal constraint is set for the extensive systems (arrow). This reduces the range for the other goals. At the third iteration cycle the minimum goal constraint of employment (arrow) is set very close to its maximum attainable level. This appears to remove any slack out of the other two goals. At this stage on goal can only be improved at the expense of another.