Linking Crop Rotation and Fertility Management by a Transition Matrix:

Spatial and Dynamic Aspects in Programming of Ecosystem Service

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Abstract

This paper deals with crop rotation as a method to pest control and soil fertility from an economic point of view. In the past farmers created complex rotations to benefit from processes like natural pest control, recycling of organics, pollination and water retention. Cropping orders utilizing small fields to accommodate long lists of crop sequences were a major feature of agriculture. Today we are faced with large fields and monoculture. Usually, attempts to recognize economic benefits from rotation through modelling are meagre because of complexity. We address the issue of complexity as well as spatial and dynamics aspects of long run benefits by suggesting feasible types of modelling crop rotations (dynamic optimization). A newly introduced transfer matrix shall delineate impacts of crop compositions in period t to fertility of land in t+1. Categorizing different states of nature (which have to be communicated in line with farmers' knowledge of externalities) it can be implemented into modern crop rotations.

Keywords: crop rotation modelling, spatially explicit and dynamic programming

1 Introduction

Modern agriculture has given priority to pest control and soil fertility management through chemical inputs. However farmers still have problems with pest control and declining soil fertility, particularly in monocultures, since pests (resistance to chemicals) and declining fertility (soil structure) can strongly decrease yields. As a consequence, increasing unit costs of production will most likely prevail in the future (see the danger of myopic behaviour: Pemsl, et al 2008). Many advocates caring for nature request the implementation of ecologically more sound land use practices. Problems with sustainable agriculture are intensively discussed (Ruttan 1993) and crop rotation is one important issue. In fact, problems have emerged in the context of soil fertility going beyond minerals or chemical pest control and resistance of species is another problem; also the concern for increasing biodiversity conservation is now a request in diminishing negative externalities (McIntyre et al., 2009). But there are not only problems in farming; the society, itself, sees major problem of biodiversity loss from converting traditional cultural landscapes into production steppes (Thrupp 2000, Tscharntke et al. 2005). Some authors (Fiedler et al. 2008, Lindborg et al. 2008) think if the demand for nature conservation in cultural landscapes is not given priority (which is actually an environmental service of multi-functional agriculture for the society), problems of sustainability for the society will persist. But again the sector itself faces frequent problems (Aizen et al. 2008, Gallai et al. 2009) of land fertility. To a growing extent, farmers face problems with diminishing eco-system services (fertility) as private goods (input) which reduces individual income (i.e. output, Sandhu et al. 2008). In this context two strains emerge: (1) What are the real costs of alternatives (natural pest control) and chemical control (external). What is the scope of fertility control by rotations? This issue is exaggerated by increasing prices for chemicals. In Germany, for instance, since 20 years the costs of combating pest and maintaining soil fertility with chemical substances were relatively stable, but now it seems that costs are picking up as part of global energy price increases (see BMVEL 2008). (2) Due to processes like appearance of resistances against chemicals the affectivity of chemical substance seems to decline (Pretty and Waibel, 2004). Real costs are changing and eco-system services return.

However, directed towards monocultures and uniform landscapes by economies of scale concerns, specialization thrive and use of chemicals as strategy and as change in the knowledge system (McIntyre et al., 2009), farmers seem to be no longer willing to maintain land productivity through "natural" measures, rotations. They rather apply more and more pesticides, artificial fertilizer, and other technical measures to keep their land fertile. Though some scientists (Regev et al 1976) spoke very early of a public good character of pest problems and a downward spiral as well as myopic behaviour, not much work is done on the topic of long run cost comparison between traditional and modern modes. And a question is: Is there really an alternative? Yes, one way to maintain fertility and combat pests was to deal with crop rotation which was normally embedded in cultural traditions (Bachthaler, 1979, Könnecke, 1967, Parker, 1915). They were part of farm routines followed as collective knowledge and action. But, due to modern inputs complex rotations seem to become obsolete because rationality changed. As a result of needs to economize on profitable crops, less profitable crops were dropped in rotations and fields increased because of limited elements in rotations, big machinery, etc. In contrast, from an ecological point it seems sound to integrate many crops in rotations. However today farmers will tell ecologists, they make less money with ecologically sound rotations. There is a tendency to reduce complexity of rotations and even to introduce mono-cropping. This tendency has strong implications on the ecology and also appearance of landscapes which provide ecosystem services. They become uniform. In fertile areas, for example, pastures have been strongly reduced, though they were part of traditional rotations. Modern farms are composed of large fields and use few, highly profitable crops (wheat, rape seed, etc.). This trend is recently exaggerated by biogas production from maize. Mono-cropped maize fields are expanding; they are already dominant landscape features in some areas.

For farmers it does not seem to pay off to care for long lasting soil fertility and natural pest control through crop rotation and landscape management. Rather, due to the overwhelming pressure of economies of scale and short term thinking, they start to strongly discount benefits of rotation. The (ir)-rationality of such behaviour is evident. Farmers expect that the pesticide industry offers new substances to deal with pests occurring with mono-cropping. They seem to have lost experiences and knowledge on the positive impacts of diversified crop rotations. At the same time farmers face growing problems with resistances, new pests and declining eco-system services like pollination, ground water formation, natural soil fertility, etc.; note these services are traditionally based on landscape functions (foremost diversity). A major problem in this respect is that the modelling and programming of rotations is quite complex.

It is the objective of this paper to show how it may be possible to appreciate advantages of long run rotations better. By suggesting advanced modelling concepts of rotations we think one can increase awareness of long run effects of declining natural fertility and conduct better cost-benefit analyses. The question is how a potential drop in fertility can be linked to economic planning of crops, space and rotation. For an agronomist the interesting issue is how deficits in farm planning methods (programming: specifically in regard to optimizing rotations) determine behaviour. Then, how can things change, if one can accommodate the effects better? We will show that there are deficits in current planning methods and suggest a new concept (method) for temporal optimization of land use at farm and landscape levels. The method includes a transition matrix depicting degradation and pre-fabricated rotations as references.

In this context our paper will address the question, how modelling, as an instrument, can be used so long term rotations become more appropriate in portraying short- and long-term effects of crop use. It should work in a time frame of dynamic programming. Hereby we want to address sustainability, spatial appearance, and eco-system services from farmers` points. A further aim is to present a new dynamic optimization approach including rotation and spatial design of landscapes. The paper is organized along a problem statement, a review on state of art, methodological problems and solutions; and it gives an outline of work to be done.

2 State of the art

The issue of programming optimal land use as an instrument for crop rotation has not been very intensively studied over the last decades. El-Nazer and McCarl (1986) worked with yield regressions implemented in LPs. Detlefsen (2004) suggests to work with network analysis and

Klein, Haneveld and Stegeman (2004) studied crop successions as constraints. They used an algorithm which most likely will not be used by farmers due to its complexity. Rotation is the basis for decision trees (on the one side) and becomes very complex. On the other side empirical research seem to confirm that narrow rotations suit current aims of maximizing profits best; even no long run concerns exist (anymore), mostly, because farmers believe today that new pesticide types will help them to combat pest in future. By chemical inputs, zero tillage, etc., benefits of rotations are marginal (Lütke Entrup et al., 2006). So it is understandable that in practice, farmers minimize rotations. Threshold analysis (Lundkvist, 1997) is used as role of thumb. Weed control should no longer be based on successions of crops. Some decision support models are based on economics of weed depression (Wilkerson, et al. 2002), but the economics in terms of a full integration is limited. So no wonder that rotation is outdated, but ecosystem service functions may not be really reflected. A full integration of crop models and economic models in a bio-economic approach for practical applications is still missing.

3 Transition matrices in eco-system dynamics and links to farm productivity

We suggest a measure to detect a potential decline in soil fertility due to narrow crop rotations (in extreme mono-cropping) based on a transition matrix (Buss, 2006). A transition matrix sets up a temporal link between yield potentials today and cropping patterns of a past. Using a transition matrix we can establish a dynamic programming approach in bio-economic modelling. For instance, if rotation choices put too much emphasize on single crops, there is a potential decline in yields of crops next year. For practical reasons, the inclusion of the matrix enables the delineation of negative externalities in programming techniques using software like GAMS (Domptail et al. 2008). GAMS enables dynamic modelling by taking discrete, annual steps and transferring results from one period to the next as optimization. In Diagram 1 the main principle is outlined. The modelling should work with "planned" areas for crops at time t which are given as a percentage of farm size (spatial aspects will be tackled soon) and at t+1. Hereby categories of land quality are distinguished and deliver constraints to farming in periods. This means that land for farming is split into different fertility categories appreciable by farmers. Farmers face quality "states" of their land (as mix) being the consequence of farming in the past. "States" are characterized by discrete fertility categories, for instance "very fertile, …, fertile, poor, …, very poor". In categories yields are different, and the assumption is that farmers' knowledge is based on assigning quality categories. By the land quality categories one can simplify matters. Then, the focus is on land related activities changing land composition. Past land use activities give, as percentage of land use, options in future. Planned areas in period (t+1) must fit into the inheritance categories of land quality.

Diagram 1: Scheme for Transition Matrix

$$\begin{bmatrix} land - quality - category - 1_{t+1} \\ land - quality - category - 2_{t+1} \\ land - quality - category - 3_{t+1} \\ \dots \end{bmatrix} = \begin{bmatrix} \pi_{11} & \dots & \dots \\ & \dots & \\ & & \pi_{33} \\ \dots & & \end{bmatrix} \begin{bmatrix} wheat - area_{t} \\ barley - area_{t} \\ grassland_{t} \\ \dots \end{bmatrix}$$

Yields and gross margins of land quality categories are varying systematically. This does not mean that observed yields are going down, if monocultures prevail; it means that eventually more fertilizer is used and underlying natural fertility declined. In programming alternative management options, practices can be assigned as discrete choices with separate gross margins (such as wheat with 30, 40, or 50 dt/ha, etc.). If more and more land is in a low quality category, for example, farmers face limited choices in natural fertility of land and have to use more chemicals to maintain yields increasing costs or yields decline. A corresponding choice for production alternatives is given in Diagram 2; for clarification. In this structure the highest yields are only reached from land in category "1". In category 2 we see lower "natural" yields

and choices for crops within this category. Note, on the right side choice potentials are collected. A necessity is to change practices, eventually also for advancements of better quality in future, or less land in category "best" is available. Apparently, the analysis is made more complex if we include a possibility to substitute natural fertility and use of chemicals.
The matrix depiction in Diagram 1 and 2 is a substitute for differential equations in dynamic resource economics. It works with a land classification (discrete) which is perceivable by farmers. It anticipates local knowledge on transitions; alternatively it can be derived from ecological modelling. As tests showed in a context of pasture use (Domptail et al., 2008) applying an ecological modelling to derive a transition matrix is feasible. Using minimal mathematics and simple calculi, or working with tableaus, the matrix approach can be used in arable land.

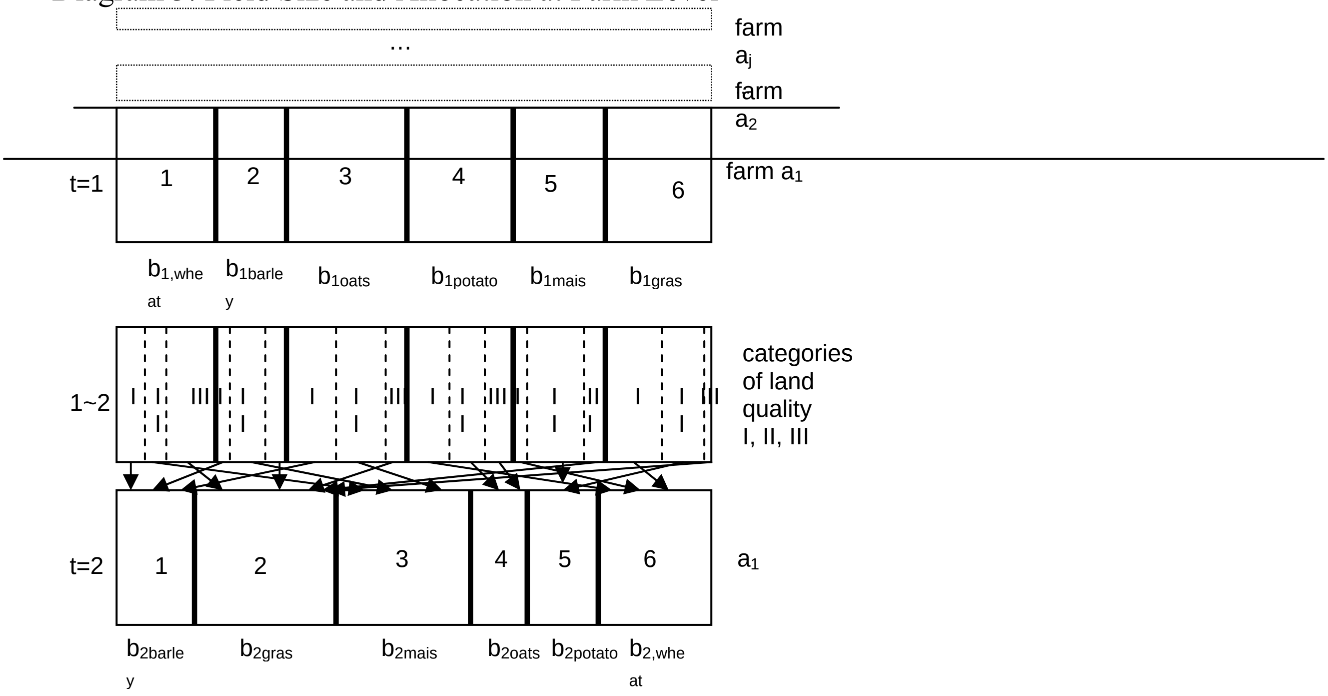
Diagram 2: Qualified Scheme for Transition

$$\begin{bmatrix} 1 & 1 & 1 & 0 & 0 & 0 \\ & & & 1 & 1 & 1 \\ & & & & & \cdots \\ & & & & & \\ & & & & & \end{bmatrix} \begin{bmatrix} wheat-yield-1_{t+1} \\ barley-yield-1_{t+1} \\ grass-yield-1_{t+1} \\ wheat-yield-2_{t+1} \\ barley-yield-2_{t+1} \\ grass-yield-2_{t+1} \\ \ldots \end{bmatrix} \le \begin{bmatrix} land-quality-category-1_{t+1} \\ land-quality-category-2_{t+1} \\ land-quality-category-3_{t+1} \\ \ldots \end{bmatrix}$$

4 Field location and allocation in dynamic programming of rotations

As the next step a cluster of fields with different states of fertility must be outlined. Fields are farm and landscape structures conducive for rotations. Farm land is a spatial unit. For modelling we have to stylize the situation. In modelling the crucial thing is to initialize current fields, but also to give flexibility. A compromise is stylization (as example a polder). We assume a rectangular form of fields and size: $a_i \cdot b_j$ (Diagram 3). Under such conditions land area and size is portrayed by b_j (note a_i is fixed). Fields are programmed by b_j stretch (a_i is constant).

Diagram 3: Field Size and Allocation at Farm Level



A farm (size related) or cluster of fields has a certain length $\Sigma\, b_j = B$. In this distance we have to fit parcels (plots, fields) in rotation which means a constraint in programming. A way of doing so is introducing different categories of yields and types of crops as part of a rotation (see above). In Diagram 3 we illustrate three different categories (I,II, II). Also in the Diagram we illustrate that the allocation can change from period 1 to 2. As preferred crops, like wheat, generally require "best" land, we sequentially allocated land to wheat land in "I" (best, this will be done in programming by a computer, here it is for demonstration). After the transition between periods programming has re-produced a new distribution of land quality. In a computer model activities (as allocation) for each year are chosen according to long run profits (discounted profits) prevailing over a planning horizon of thirty years, or even more.

Hence, in such conceptual outline to formulate programming, we have to categorize b_j further as $b_{j,q,t}$ (i.e. crop, quality, time). As augmented choice on crops, quality categories, "q", become involved, which represent different classes of "natural" productivity of land in time t. For example, wheat yields can be, as said: "best, good, medium, bad and low"; in terms of activities they are categorized in fixed yields. The advantage is that farm planning can be associated with categories, requiring a minimal knowledge system on degradation; further on categories require different technologies to answer degradation. With deteriorated yields farmers have to use more inputs due to pests and non-recovery of soils, nutrient depletion, etc.

Such type of modelling can now be combined with different technology coefficients in programming to depict the quality category change options. Quality categories become temporal constraints (see above). They are plan-able and foreseeable for farmers. As a consequence the availability of land in different quality categories changes (planed) over time. Vice versa, by actions in the past, farmers can improve land through rotation. Temporal constraints show the availability of land in t and in different productivity categories as subject to the use (choice) of rotations (see below). The categories (size in b) indicate different declines in productivity, need of inputs, and come up with different gross margins. For instance, eventually in category III wheat will perform worse than rye (see below for the "choice of rotation" and depiction).

5 Anticipation of results in rotation design from agronomists

To be able to introduce knowledge on potential rotations into the previously explained modelling (soil quality, spatial, time, etc.; i.e. to specify alternatives in rotation) a foundation of alternatives as discrete choices is required. Two aspects prevail: agronomists' concepts on "designing" rotation alternatives and the programming techniques (modes). Crops can be distinguished according to their stand in a rotation (in Diagram 4 a complex rotation is given first and simplex second). A rotation might start with wheat after wheat "WW" or wheat after rape seed "RW". Technically it would mean to add a fourth dimension "r" in $b_{c,j,q,r,t}$, which is the type of rotation. Sequences in rotations are fixed by experts (knowledge of scientist). Theoretically the production, "size of b", at a plot can now be identified by the five dimensions: crop, location (field), quality, rotation, time (and ev. as farm number). Normally linear programming has no spatially oriented algorithm to assign crops to fields, but by numbering fields we can construct a substitute (as a ranking like in time and in space; actually in GAMS a ranked numbering of field is possible). In programming by a selection process for most profitable alternatives we use all dimensions (not used options are put by a computer to zero; in numerical solutions it means many b's of zeros are possible). Selection means that only one quality, rotation, and location opportunity becomes selected, for instance by if-else-statements.

Our compromise is further that information from crop science is used to specify rotation alternatives for pre-selection. The practicability of farm management may impose additional constraints, such as labour constraints for certain crops. A first step is that information on practical crop rotations are depicted as crop sequencing. For example in Diagram 5a such an "ideal rotation" of biologically oriented agronomists is given as a "prescription" of sequencing crops. It implies that, for example, a plot "1" has to follow a sequence: wheat, barley, potato, rye, cow peas, maize, oats, alfa-alfa, livestock with legumes, rape seed: w-b-p-r-c-m-o-a-l-s, if this rotation is chosen. Then plot "2" follows with one year lack and plot "3" with two years, etc. (steps of rotation: Diagram 4). Under this condition the spatiality of the farm is designed along the necessary number of plots as indicated by the number of steps in a rotation. So we most likely get small fields. Technically, by summation of rotation options we guarantee that no other system or sequence is selected. Flexibility lies in the size of the plot.

Diagram 4: Rotation and its periodicity

a: complex

Field/ Period	1	2	3	4	5	6	7	8	9	10 … 30
1	W	L	L	A						S
2	B	W	L	L						
3	P	B	W	L						
	R	P	B	W						
	C				W					
	O					W				
	M						W			
	A							W		
	L								W	
	S									W

b: simple

Field/	1	2
	W	S
	W	S
	R	S
	…	

with W: wheat, B: barley, P: Potatoes, R: rye, cow peas, O: oats, M: Maize, A: alfa alfa, L: legumes, S: rape seed

But, other sequences are possible; they are fictional in the computer who makes the choice in programming. They are optional and the programming shall select rotations, in time at a threshold year. The rotation systems can be changed if it is opportune. Simulations must be longer than just one sequence. The rotation systems are depending on the recommendation of agronomists and given for one run or sequence; for example of 12 years at a maximum. But then they can be swapped if we extend the time frame and look for replications (even more than 60 years which means 5 sequences); as usually used in dynamic programming the lifespan of a decision can be extended. In Diagram 5 we see alternatives on plot "1" (1a, 1b, ..., 1h). The flexibility, built in, comes with the choice of alternatives; though choices are discretionary, they can be anticipative.

The need for soil fertility should increase complexity of rotations and open the way for longer rotations. Pest pressure, seasonality of labour, etc. are elements constituting the different options and choices on rotation. Also special crops in the particular rotation system as well as eventual modern technologies to off-set disadvantages from narrow rotation can be explicitly modelled. However, the alternatives must be discrete. Pesticides and mineral fertilizer are complementary in narrow rotations and substitute commitments to ecologically sound rotations. In the activity spectrum more chemical inputs appear for narrow rotations. Even maize in mono-culture can be an alternative (1h). It is exactly here, where the dispute between proponents of modernization and proponents of sustainable agriculture lays, and people clash in grey zones of not testing alternatives. For our purpose of getting a spatial representation it is sufficient to have benchmark rotations. To get simple and treatable structures we propose to use "bloc" combined of 12 years as "offer" and elements of "most suitable" crop rotation.

Within this framework of potential rotations and plot outlets the "design" of field composition includes a type of "supply" flexibility between rotations, i.e. as superficial activities in programming activities are to be created which suits the special type of rotations at discrete order. As optimization is based on five distinct dimensions, for practicability reasons the results are to be aggregated to actually a given fields. As an example: in period 3 a field 2 shall be mainly under livestock in rotation 1; hence it must take all corresponding activities given at this time and we get the area under livestock under land quality of category 5 as dominant. Different results are summarized in crop categories for a given slot following the choice of the relevant rotation as priority. The consequence is a reasonable flexibility; though still choice of "rotation system" is the dominant and temporary fixed one. For the moment it looks that such a practical procedure and the flexibility in dimensions can open an outline that fits farmers' choices based on knowledge. Making things sufficiently flexible needs a relaxation in the fixed rotation sequence. A compromise would be: allowing a split into a restrictive and a less restrictive treatment of combinations or traditional versus modern rotations.

Diagram 5: Alternatives in Rotation

Field/ Period	1a	1b	…	1g	1h	2a	2b	…2h	3…	4…	5…	6…	7…	8…	9…	10 … (alternatives)
Period	W	W	…	W	M	S	S	M	L	L	A					
2	B	W	…	W	M	W	W	M	S	L	L					
3	P	R	…	B	M	B	W	M	W	L						
4	R	M	…	B	M	P	B	M		W						
5	C	M	…	M	M			M			W					
6	O	W	…	M	M			M				W				
7	M	W	…	W	M			M					W			
8	A	R	…	W	M			M						W		
9	L	M	…	S	M			M							W	
10	S	S	…	S	M			M								W

(1) For explanation: In field 1 (in Diagram5) we contrast the option 1a to 1h of predesigned rotations. For instance 1h means that the monoculture M, maize, has been chosen on field 1. 1g would have meant that 2 years of wheat are followed by 2 years of barley, etc.; but after the choice 1h the combinations are exclusive M. This means that in programming first a choice between types of rotations (1a to 1h) has to be made and then the field size is determined. Determining the size of the plot is the actual optimization. But choice and optimization can be programmed simultaneous, because one can use if-else-statements. The consecutive choice in time is a mixture of rotations, for instance after 12 years as threshold period, a new rotation is chosen because yields are good. The alternative is a split in the field size between rotations. In practical terms this is normally impossible. It would imply a fragmentation of fields. But a split (fragmentation) is unattractive due to economies of scale. To solve this problem with the logic applied in programming (using GAMS) the application of an "if-else" function is a possibility, i.e.: if a field 1a is larger than 1b, the computer takes the option (1a) for the whole plot size. (if–else in GAMS: The winner takes it all.) This is relevant, because in the modelling approach an inter-temporal implication is envisaged based on the land use in period 1 which is transferred in period 2. Via the transition matrix changes occur in land quality from this year to next year's crop. Note the predecessor crop in the rotation mode determines yield potentials and crop choices for the next period. The transfer between periods matters for future choices (crop choices, i.e. understanding soil mining crops vs. soil recovering crops).

(2) But we should not only restrict choice and let conservation prevail. A further issue in programming is that a switch between rotations (towards higher yielding crops) should be possible, but it inherits the risk of being inhibited due to maturing rehabilitation costs in the next periods, and this should reflect rehabilitation costs as shadow prices. However, the objective within the algorithm (discounted future profits) assures that only profitable regimes are presenting the total profitability (discounted), and are chosen, as if final capital restrictions exist.

(3) The implementation of the procedure in software programs is of relevance. An example: In programming, as mentioned the exclusion of an activity by the disposal of another can be achieved through assignments. In GAMS we can specify it as "if-else" statement on the basis of "greater (less) equal", and then let the model solve the problem which rotation is optimal. This can be extended to several transition matrices and their dynamic constraints. Specifical-

ly, in GAMS there is the option to create "if-else" statements for choices on which dynamic equations and constraints (matrices) prevail in terms of the transition matrix. It means to use thresholds and then we can "switch on or off" the relevant transition matrices and rotation. Rotation choices are represented by transition matrices. It means, in modelling farmers' decisions, investments in soil fertility, pesticides or modern technology change constraints. Passing thresholds opens options for less restrictive rotations in future; vice versa. Investments are separate activities. To adapt a new constraint function (for instance a narrow rotation instead of an old complex), investments are to be made to climb over an edge. The consequence will be an outcompeting of old by new rotation systems; done potentially, but not necessarily: i.e. if investments are cheap, farmers prefer narrow rotations; if not they opt for complex ones. Since we model a dynamic (constraint) system, a switch in strategy of farmers should be possible, but it has temporal effects. The matter of an underlying strategy can help to understand the importance of rotation choices threefold: (1) what matters, is the state of soil fertility and eco-system health, (2) as rotation planning it is embedded in dynamic programming (i.e. conditions to obtain good yields or gross margins, and minimize costs of pesticide); application controls are changing in time. (3) Investments through spraying or decontamination are decision variables, which could make a modern rotation (i.e. a simple) preferable.

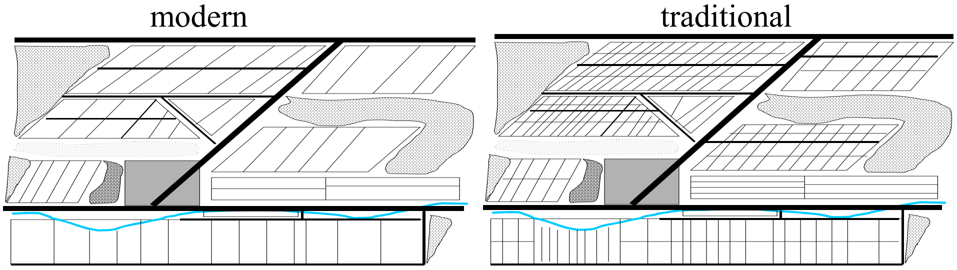
(4) For dynamic optimization the start and end conditions play a major role. Hence, we may start with a situation of depleted stocks of soil fertility. The consequence is a need to restore fertility by crop rotation. In this context we can use an index of soil fertility "I". It can be used to specify conditions under which a switch in rotations is relevant. Apparently, the size of the criteria index $I > s$ (threshold) is a matter of an open debate and subject to agronomist knowledge. In programming, at least for the last period, i.e. before the threshold is transgressed, we may suggest a fixing of the index as a sustainability criterion. Technically, the criterion of the threshold of the index, to be passed in order to pursue a simple rotation instead of a complex one, is normally exogenous. Why do we have to do so? Simple rotations give higher gross margins, because low yielding crops, pertinent for traditional crop rotations, are excluded. This should only be possible if the state of nature is good. On the other hand the threshold constitutes the eco-system behaviour as response to mono-cropping. Thus, the threshold is a critical value and it serves as an interface between the ecology and economy aspects of a farming system. The issue is that today the farmers should already anticipate deteriorations in crop rotations according to the transition matrix. In the given framework, either the traditional or modern rotation is applicable according to a threshold. It means, if a threshold, characterizing the eco-system as healthy, is passed the modern rotation is no longer applicable. This norm is given by a farmer's eco-system service request. In principle, for decision support and sensitivity analyses communications with farmers are necessary. The question is, whether the threshold is exogenous or endogenous to knowledge, i.e. up to decision making or not? From a point of view of endogenous decision making, exogeneity is questionable. Accordingly periodical decisions, which follow, should be known. At the moment envisaged decision makings rest on periodicity of rotations and sizes of land chosen for crops.

6 Empirical foundation, eco-system services and landscape

In case of small farms, the issue of crop rotation must be extended to landscapes, if eco-system services are addressed. To address the landscape issue we need a deeper thought on eco-system health and landscape design. For the ranking of land quality categories we could employ states of the eco-system at hamlet or parish level which are jointly farmed. Categorizing the productivity of land based on eco-system states in landscapes by experts is a method being highly successful in reducing complexity of eco-system analysis (Schneider, 2007, Domptail et al., 2008). Farmers and researchers can build assessments of rotation problems on this landscape analysis. The assessments should include a common understanding of classes or "states" of nature, associated with soil fertility, resistance decline, prevalent pests, and threats of further pest problems etc., as well as diminishing water and moisture problems which goes beyond farm level. If decently done and correctly anticipated (Domptail et al., 2008), the states contain quantitative and qualitative information on eco-system health at larger scale and underlying service provision, for instance of pollination and water retention which is above a farm level. Hence, the transition matrices can be extended to the landscape level. Hereby they change their characters from farm to system knowledge.

From the farmers´ point of view, reckoning the eco-systems´ service underlying farming systems, the decision on rotations contains a double hurdle: a control of negative effects on farm (1) and on landscape (2) level. At landscape level the dynamics and equilibrium between prey and predatory species in nature through designing rotations and landscapes must be understood. This seems to be a high aspiration. However, to support agronomist and farmers in designing rotations landscape analysis can help to employ ecological modelling, in particular by finding transition matrixes. Though ecological modelling is very complex, the advantage is that it can integrate landscape interactions and elements at a larger scale. Another advantage is that it can come up with classifications for states characterising ecosystem health (Domptail et al., 2008) at farm and system level. Traditional and local knowledge helps conceptualizing states. This enables projections of eco-system trajectories in order to fully explore rotation effects. A technique of receiving information might be a straightforward ecological modelling of rotation systems based on events. This helps to accommodate disturbances created by farming and effects can be demonstrated by simulating ecological consequences (Henderson et al., 2009). Rotations and their consequences for eco-systems can stabilize farming systems. But, what landscape and what farming are we heading for? Diagram 4 gives a comparison between traditional and modern landscapes. We can mediate between these two systems by creating a “surrogate” of diversity over time by rotations, and deliver services. An eco-system is more than rotation at farm level. Rotation experiments at farm level have to be embedded in landscape designs. Then we can observe what happens, if external effects between farms exist. Preliminary research shows that eco-system services depend on landscape diversity (Dauber et al., 2003). We have to extend the farm analysis to simulations with several farms also at the spatial level to fully explore rotation benefits.

Diagram 6: Farm and Landscape level



In principle we should become able to transfer cropping patterns of a current period given a number of farms at a collective level into an availability of land fertility classes in the following period. Notify that this implies a new matrix outline of cross effects and we should also implement improvements of productivity at a farming system level dependent on landscape elements such as hedges, buffer strips, etc. Rotations become interconnected to landscape elements. Further improvements, for instance by fallowing, clover and legume inclusion, etc. in the rotation can be implemented as an augmenting function of good land quality for the community. The management is land allocation at different quality level and beyond farms.

7 Discussion on management units

As a conclusion, we have to think about decision making on soil fertility and thresholds in a broader sense. Hereby appears the question about the unit of decision making. So far a representative farmer was making the decision. Is that correct? If we proceed with methodological individualism representative farmers optimize on behalf of the community. But, deliberations on rotation choice are a joint exercise between landscape ecologist, agronomists and farmers. It may start with results of a rotation optimization, assuming an average farm prevails in terms of size, and labour, etc. Adjustments can be expected in case of labour input and machinery, as the size of operation is concerned. As there is flexibility in the input choice, a predetermined product mix, given on average result from the rotation optimization, must be anticipated with different technologies. This choice should be expressed in an "economies of scale" section of the model, because this will especially determine the size of the farm.

But then we have to expand beyond the farm level. The farm size is correlated with technology choice, rotation and landscape needs for ecosystem services: A dilemma! If the approach would stop at the farm level, we would not correctly address the farm and landscape connectivity. Thus, we have to extend the approach to the landscape level and calculate the implication from rotation decisions of several individual farmers on landscape appearance. For this a planner is necessary. The task is threefold: (1) It has to be explained how individual and collective decisions are compatible; (2) the issue of retrieving a quality index for the landscape must be discussed at landscape level; (3) a recursive implementation of the quality index as a measure to guide rotation decisions must be outlined; (4) to address questions of landscape organization and ecology, an explicit spatial programming of fields, farm size and rotation strategies (that goes beyond individual farms) is necessary. It means to synthesise several farms in one larger approach. However, this again requires a level of complexity which normally goes beyond simple modelling. A compromise is to stylize the spatial organization of farming at the landscape level (Diagram 6) and iterate farm behaviour with more complex rotation interactions. To emphasize: at the centre of this analysis stands the newly suggested transformation matrix for the landscape which shall translate a certain choice of cropping patterns in period "t" into ecological effects of a consecutive period "t+1" in a landscape. The ecological effects are decoded as a certain value of on-farm productivity change. The empirical foundation of the analysis can be provided by a productivity ranking, as well as by the determination of the pest danger in the predominant farming system of the landscape. The ranking is implemented by different states of the eco-system that are jointly elaborated.

Farmers and researchers can then base their management decisions on a modelled assessment of the crop rotation problem as a landscape problem. This is depicted by the planning of a "central authority". Our assessment is based on common (community) understanding of classes or "states" of the ecology in the whole landscape. We must assume that farmers, agronomists and scientists have a reasonable understanding of the outlined problem (i.e. traditional and local knowledge, conceptualized capacities to project eco-system trajectories, information on mechanisms in ecology, etc.). To achieve such understanding "states" can be used and the aim should be that the community plans the "states" in future. For instance, if soil fertility in the landscape declines, the model must be capable to project different states at landscape level (note they must not be equal to farms assessments), as well as show diminishing water, moisture and pest problems (from very good to very bad). From a point of view of landscape a custodian farmers become agents. However, this consideration of a simplified rotation plan at community level should follow underlying eco-system services; we hope that farmers´ view of possible alternative farming systems (categories at farm level) are changing. For this intention a characterization and valuation of the defined "best" rotation in a participatory way is important. The reason is some beneficial organisms eventually only occur (and with them positive externalities), if we introduce community oriented landscape elements (notability as elements of the rotation). Then, the ecological equilibrium can be regulated by designing landscapes and rotations simultaneously based on fields, farm size, fallow, etc.

8 Discussion, Limitations and Conclusions

We pointed out that the reduced capacity of eco-systems to assimilate disturbances created by current farming systems is a reason for reduced eco-system services and this requests better rotation choice. A reduced recognition of eco-system services by farmers is also amplified by the lack of appropriate planning methods. We suggested using a transition matrix and a concept of states and transition to alleviate these deficits as well as to do spatial planning. Apparently, the transition matrix is a substitute for differential equations in dynamic resource economics. We acknowledge that programming based on a transition matrix and qualitative states has its limitations in the capability to identify states and to get the matrixes. In programming the major choice to be made concerns decision variables of farmers in spatial land use. Since land use and rotation are the focus, farmers would never understand why they should program pest populations. Our approach is a compromise which accommodates farmers' and ecologists' knowledge, and seeks to develop a farmer oriented approach to rotation design.

Another issue is the consideration of the spatial connectivity of fields, crops and eco-system. We constructed a stylized landscape. The spatial problem is to be solved simultaneous as choice of crops and land quality. A discretionary variable has to be constructed that has the capacity to depict land use and quality variations simultaneously. A method to combine qualitative and quantitative information is to categorize choices and to introduce variations in yields along farms. The farms are given in a rectangular plot system, i.e. in a polder landscape as a reference for modelling choices of farmers. Only then rotations can be introduced as discrete problems, requiring the interaction of farmers, agronomists and landscape ecologists.

9 Summary

A traditional answer of farmers to address problems of soil fertility, pest control and eco-system services has been the use of crop rotations. Labour intensive rotations are normally linked to diverse and species rich cultural landscapes. Instead, in modern agriculture few crops, heavy machinery and economies of scale dominate. However, farmers face the loss of positive externalities of eco-system services. We addressed the issues by making suggestions for modelling crop rotations (through dynamic optimization models) and landscape analysis. A newly introduced transfer matrix shall delineate impacts of crop compositions in period "t" to natural fertility of farm land in "t+1". Further deliberations are made concerning the spatial organization, landscape and agronomic aspects of rotations. A joint modelling of these components is proposed, and it is shown how programming software can be used to model it.

10 Literature

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