THE FUTURE
OF THE LAND
MOBILISING AND INTEGRATING KNOWLEDGE FOR LAND USE OPTIONS

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Chapter 4 Resource Use Analysis in Agriculture: A Struggle for Interdisciplinarity
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Resource Use Analysis in Agriculture: A Struggle for Interdisciplinarity

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INTRODUCTION

Referring to the law of diminishing returns, it is often taken for granted that the large increases in crop yield since 1945 in the industrialised world and since 1970 in a large part of the developing world require a much more than proportional use of resources. This would imply diminishing returns, when yields per hectare over time are correlated with, for instance, nitrogen use per hectare. However, it appears (De Wit, 1991, 1992a,b) that the returns to increased fertiliser application are at least equally high in the upper range as in the lower range. This does not mean that the famous law of diminishing returns does not hold, but that any decreasing return has been compensated by increased efficiency as a consequence of other technical changes in the production process.

Neither in agronomic research nor in agro-economic research has much work been done on the relation between resource use and technological change. As a consequence, policy measures may be taken that, despite good intentions, contribute little to the efficient use of resources and the control of pollution, they may be even counterproductive. This justifies a further analysis of production principles, with special emphasis on the efficiency of resource use.

PRODUCTION FUNCTIONS

Much agronomic research before the Second World War was directed towards the search for laws governing the relation between the input of so-called production factors and the yield of crops. This research on production functions has been replaced by research on the physical, chemical and biological processes that govern the growth of crops.
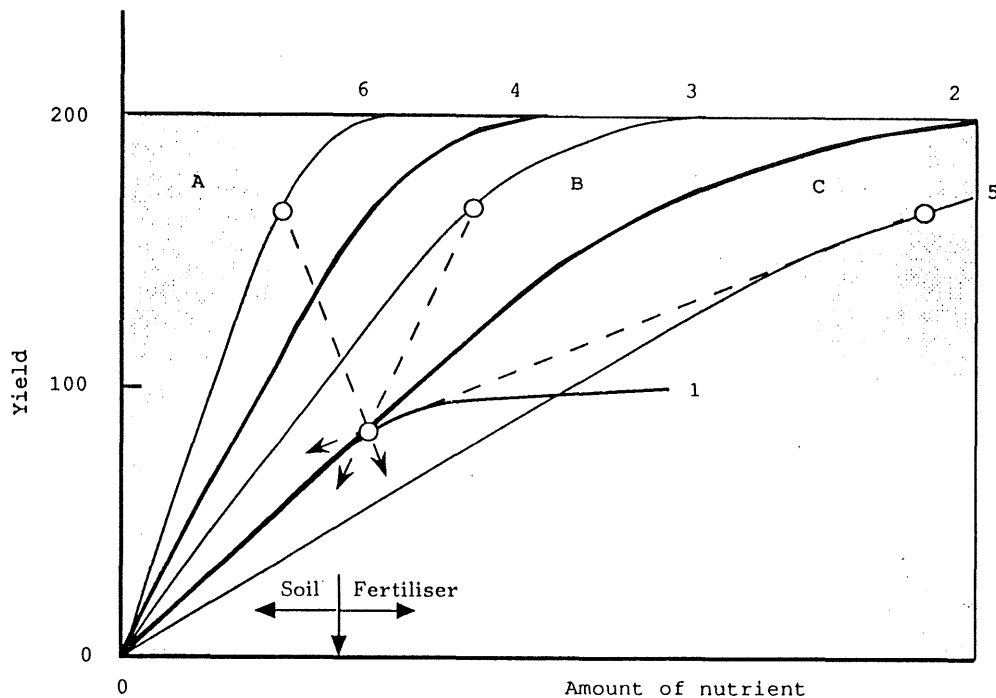
Figure 4.1 Schematic presentation of three classical yield response laws. Curves 1 and 2: Von Liebig's law of the minimum; curves 1 and 3: Liebscher's law of the optimum; curves 1 and 4: Mitscherlich's law of constant activity

However, the interest of agro-economists in production functions remained, so that gradually a situation has developed in which economists ask questions that cannot be answered by agronomists and agronomists give answers to questions not asked by economists.

Perhaps that stalemate can be broken by resuming where the agronomic discussion was left off some 50 years ago. For this purpose three production laws formulated in the century following the introduction of industrial fertiliser are schematically presented in Figure 4.1. Here the amount of a nutrient in the soil is given along the horizontal axis and the yield along the vertical axis. As is usual in this type of analysis, the available amount of nutrient in the soil and from sources like rain are expressed as an equivalent amount of nutrient applied as fertilizer. Both amounts are arbitrarily distinguished here by the vertical arrow at the horizontal axis. All curves reflect the well-known phenomenon of decreasing marginal returns with increasing amounts of nutrients. In the region of liberal supply, two maximum yield levels are distinguished: a basic level at 100 and an enhanced level at 200. The difference is due to the availability of other production factors, like water, radiation or other nutrients.

The law of the minimum, attributed to Von Liebig (1840, 1855), implies that the yield of a crop is proportional to the availability of the production factor that is most limiting.

This law is schematically presented in Figure 4.1 by curves 1 and 2 with a maximum of 100 and 200, respectively. Characteristic for this law is that curves with different maximum yields have the same initial slope and thus coincide in the region where the nutrient presented along the horizontal axis is yield-limiting.

Liebscher (1895), however, did not observe such constant initial slopes in many experiments with the nutrients N, P and K. It appeared instead that the production factor that was in minimum supply contributed more to yield, the closer other production factors were to their technical optimum. This law of the optimum of Liebscher is presented by curves 1 and 3 in Figure 4.1. The difference with the law of the minimum is that the initial slope of the curves increases with increasing maximum yields. According to Liebscher, this law holds either when maximum yields are higher due to increasing supply of other nutrients, or to increased availability of water, better soil tillage, better weather or better pH of the soil.

As a special case of Liebscher's law, Mitscherlich (1924) assumed that the amount of nutrient in soil and fertiliser needed to reach a certain fraction of the maximum yield for a given production situation, is independent of the level of this maximum and the production factors that determine it. This heroic assumption of 'constant activity' is schematically presented in Figure 4.1 by curves 1 and 4. In this special case the initial slope of the curve is proportional to its maximum yield.

Van Der Paauw (1938) used these three functions for the classification of yield responses, as in Figure 4.1. He distinguished three regions of response, A, B and C, separated by the production functions of Mitscherlich (curve 4) and Von Liebig (curve 2). In region C the increase in yield is less than according to the law of Von Liebig: curve 5 is an example. The broken line that joins points of the same relative yield on curves 1 and 5 intersects with the horizontal axis to the left of the origin. Accordingly, the need for the nutrient that is in minimum supply increases both in absolute and relative terms under improved growing conditions. The efficiency of nutrient use or the nutrient productivity (defined as the slope of the relation between yield and nutrient in soil and fertiliser) is therefore lower, the higher the maximum. Such dismal responses are soil-chemically and plant-physiologically unlikely and examples have not been found.

In region A the responses are more favourable than according to the law of Mitscherlich: curve 6 is an example. Here, the slope of the broken line joining points with the same relative yield is now reversed, so that the need for the nutrient decreases both in relative and absolute terms under improved growing conditions. A most striking example of such a benign response (Van Der Paauw, 1938; De Wit, 1992a,b) is that crops growing under otherwise better conditions can stand a lower pH much better and therefore need less lime.

Region B at last is the domain of the optimum law of Liebscher. Here, the broken line that joins points of the same relative yield on curves 1 and 3 intersects with the horizontal axis to the right of the origin. This reflects that indeed the absolute need for a nutrient that is in minimum supply increases under improved growing conditions, but the relative need decreases: more nutrient is needed when expressed per unit of area (kg/ha), but less when expressed per unit yield (kg/kg). The marginal return at a given nutrient application increases therefore with increasing maximum yield, but the increase is less than proportional. Van der Paauw (1938) found, as did Liebscher 40 years earlier,
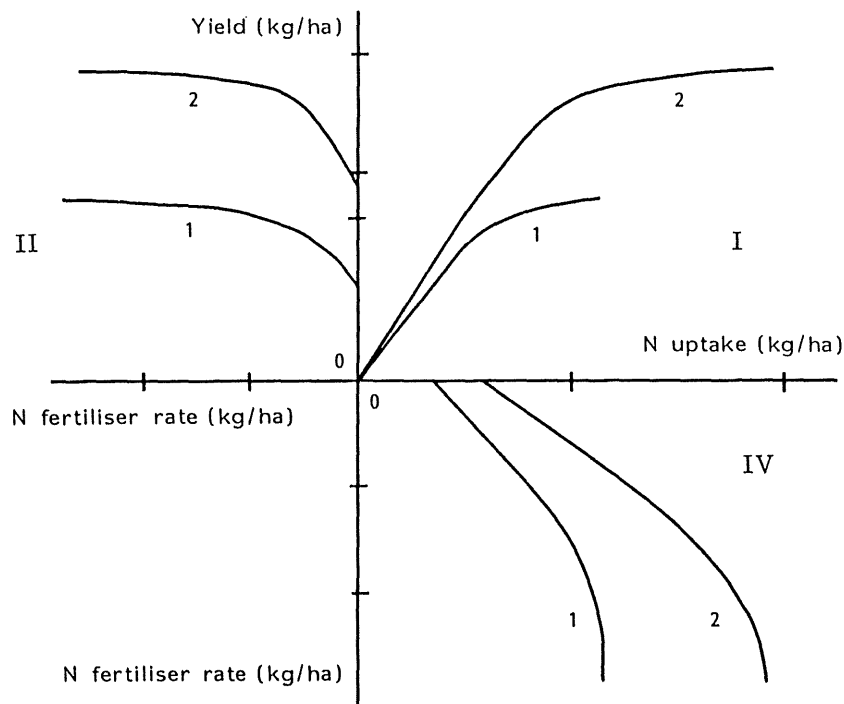
Figure 4.2 Three-quadrant diagram (De Wit, 1953) in which the relation between fertiliser rate and seed yield (quadrant II) is split up into the relation between fertiliser rate and uptake in seed and straw (quadrant IV) and between this uptake and seed yield (quadrant I)

that for experiments with more than one nutrient, by far the most production functions are located in region B, sometimes over the border in region A, but never in region C.

FURTHER ANALYSES

De Wit (1991, 1992b) analysed, on the one hand, the yield response of grain species to nitrogen as affected by the use of other fertilisers, choice of variety, supply of water, and control of diseases and, on the other hand, the effect of improved growing conditions on the efficiency of water use and the incidence of pests, diseases and weeds. Therefore, it suffices here to summarise the results.

By using above-ground nitrogen uptake as an intermediate between fertiliser rate and yield (Figure 4.2), the relation between both (quadrant II) could be split up into the relation between fertiliser rate and total uptake in seed and straw (quadrant IV) and the relation between this total uptake and yield (quadrant I). It was then found that both relations often respond to improved growing conditions according to Liebscher, as illustrated by the position of curves 2 with respect to curves 1. The improvement of the initial slope of the relation between uptake and yield is for grain species mainly due to the use of new varieties with a higher grain/straw ratio. The slope of the relation between uptake

and fertiliser rate is referred to as the recovery of the fertiliser. This recovery often increases under improved growing conditions because the root system is more extensive and longer active and losses are reduced. For the same reason and due to improved mineralisation (Middelkoop et al., 1993), the uptake from the unfertilised soil may also be higher with improved growing conditions.

Improved growing conditions also lead to an appreciably higher efficiency of water use due to an extended soil cover and a more extensive and active root system, resulting in reduced losses by soil surface evaporation and leaching. The amount of water transpired per unit dry matter produced is far less influenced by growing conditions. In dry regions, water use exhibits a threshold value before the crop grows at all, so that water use efficiency is at first practically zero, but increases consistently with further improvement in water supply.

In more humid regions, water supply as such may be guaranteed, so that amelioration measures are directed towards optimising the temporal and spatial availability of water and air during the whole growth period and across the whole field. A fundamental difference exists with the optimisation of inputs, e.g. fertiliser. The inputs are freely available on the market, so that their prices are independent of their use. However, the closer the situation is approached where water and air are in optimal supply throughout time and space, the more the control of water supply becomes an infrastructural problem that requires more expensive solutions. Investments in better management then become a public concern and the ultimate yield level reflects the attitude of society to such investments.

Under improved growing conditions many crops become more susceptible to obligate, parasitic fungal leaf diseases and insect pests, such as mildew, rusts, aphids and plant hoppers, and require intensified control at high yields. Crops are, however, at the same time less sensitive for parasitic and often soil-borne diseases that attack plants when they are weak and under stress. Examples are *Fusaria* and *Verticillium* species and nematodes: under favourable growing conditions, yield reduction due to these diseases is relatively less severe and their control requires less efforts.

For weeds, crop 'look alikes' exist, with development and requirements similar to the crop they are associated with. Examples are red rice and *Echinochloa* species in rice. They may not even be recognised at transplanting and are in general more competitive under favourable growing conditions, especially if modern, short and less leafy varieties are used. The effort to control such species increases therefore with increasing yields. On the other hand, under less favourable conditions, some weed species always exist that are more tolerant and perform relatively better than the crop, whatever the cause of its sub-optimal growth. Thus a crop under sub-optimal conditions is always invaded by weeds that are adapted to the situation and that claim their share of resources. The control of such 'weeds of opportunity' requires less effort under more favourable conditions.

Consequently, there are some pests, diseases and weeds that require less effort to control under favourable growing conditions and others that require more effort. Overall, the use of biocides in kilograms of active ingredient per hectare has a large fixed component, so that their productivity expressed in kilogram yield per kilogram active material is likely to increase with increasing yields. This is confirmed by a statistical

comparison of four regions in Europe: in the new Flevo Polders in the Netherlands, by far the most active material is used per unit surface, but at the same time productivity of its use is the highest (Jansma and Van Keulen, 1992).

Apart from the use of optional yield-increasing and yield-protecting production factors, certain activities are conditional for agriculture at any yield level and require the input of labour, capital and energy. Their requirements are partly area-related (e.g. plowing, harrowing and sowing) and partly yield-related (e.g. transport and drying of harvested products). Harvest activities themselves occupy intermediate positions. All in all, at increasing levels of production the use of labour, capital and energy increases per unit surface, but decreases per unit product.

Hence, variable production factors and more or less fixed activities have to be distinguished. For variable production factors the law of Liebscher has general validity, so that with increasing yields their need expressed per unit surface may increase, but expressed per unit product it decreases. Or formulated otherwise, the marginal productivity of resources that are limiting increases with improvement in growing conditions. Marginal productivities do not exist for fixed activities, but their productivity increases with increasing yields by definition.

RETURNS TO SCALE AND SUBSTITUTION

Instead of increasing the supply of one production factor, the supply of a number of production factors may be increased concurrently, such as nitrogen, phosphorus and potassium in a composite fertiliser. It is often assumed by agricultural economists that in such situations the law of diminishing marginal returns is also valid (Dillon and Anderson, 1990), which is then referred to as the phenomenon of decreasing returns to scale of the production per unit area. However, this cannot be the case if the optimum law of Liebscher has general validity.

To prove this, two production factors p_1 and p_2 are considered. According to the law of constant activity of Mitscherlich and at low input levels, yield is proportional to the input of each of the production factors when varied on its own. Hence, it is proportional to the product $p_1 \times p_2$ and increases initially in a quadratic fashion when both are varied concurrently. This increase levels off again at high inputs, as shown in Figure 4.3 for a situation where the yield response to both production factors is supposed to be identical. The combined response is therefore S-shaped and thus the more pronounced, the larger the number of production factors involved.

According to the law of the minimum of Von Liebig, one or the other production factor is limiting, depending on the ratio in which both are applied. Hence, the yield response to combined application remains linear until a limit, dictated by a third production factor, is reached. The optimum law of Liebscher assumes an intermediate position: at increased supply of two production factors the initial yield increase is less than quadratic but more than proportional. Hence, across the whole yield range, there are first increasing returns to scale which gradually change into decreasing returns to scale when the maximum yield is approached, and the S-shape is more pronounced the larger the number of production factors involved and the more the law of Liebscher approaches that of Mitscherlich.
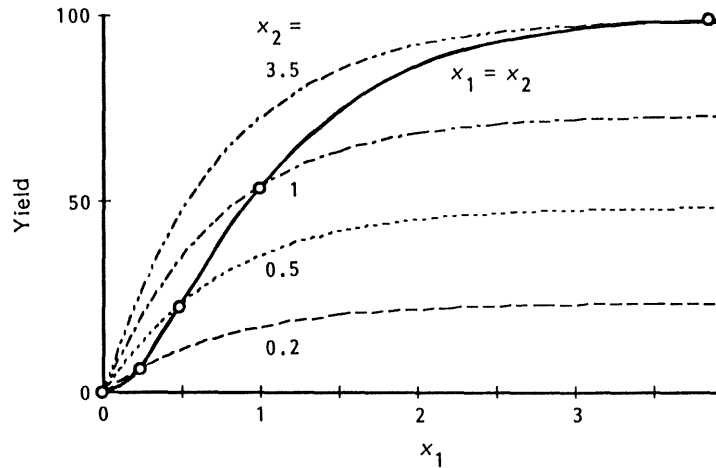
Figure 4.3   Returns to scale $(x_1 = x_2)$, as constructed for a situation where the yield responses for two inputs are the same

Many production factors have unique physiological functions: solar radiation cannot substitute for lack of water and nitrogen not for lack of phosphorus. Such absence of substitutability is reflected in the law of the minimum of Von Liebig. However, according to the law of Liebscher, there is always a possibility for partial substitution, as in Figure 4.1, where in the yield range of 0 to 100 the same yield can be attained with less of the nutrient, when growing conditions are more favourable. Therefore, agricultural economists (Dillon and Anderson, 1990) like to use flexible mathematical expressions for production functions:

$$Y = F(X_1, X_2, \ldots)$$

with the only restriction that they are so smooth that they can be differentiated twice and inputs and outputs are homogeneous, as for instance yield for Y and nitrogen and phosphorus fertiliser rates for X_1 and X_2. The economic optimum is then defined as that combination of inputs that maximises the difference:

$$W = p_y Y - (p_1 X_1 + p_2 X_2)$$

which is found by solving:

$$(dY/dX_1)p_y = p_1 \quad \text{and} \quad (dY/dX_2)p_y = p_2$$

with p_y being the price of the yield, and p_1 and p_2 the prices of the fertilisers. As the position of the maximum and hence the fertiliser rates depend on the price ratios, there is no technical optimal of applying fertilisers.

Nitrogen (X_1) and phosphorus (X_2) in such equations are substitutable in the range where the same yield increase can be obtained by applying either only P or only N.

However, if phosphorus is applied, not only yield increases, but the nitrogen reserve in the soil decreases due to increased uptake in the harvested material. Similarly, if nitrogen is applied, the stock of phosphorus in the soil decreases. There are more changes, but this suffices to show that there is not only one homogeneous output (i.e. the yield), but also at least one inhomogeneous output (i.e. a change in soil fertility). Hence, simple mathematics to determine optimal fertiliser rates are not applicable. Also the results are not very meaningful, because situations where only one nutrient is applied are always unsustainable. Similarly, optimal yields are only by coincidence sustainable, because agro-ecological sustainability is defined in natural science terms only, and optimal yields are also defined in economic terms.

If the reasonable demand of agro-ecological sustainability is imposed, yields can in general only be maintained by fertilising in such a way that the uptake of one nutrient is matched by the uptake of others. Moreover, if yield is improved by, for instance, improved water supply, better varieties or better disease control, increased nutrient uptake is required. Consequently, agronomic production factors are more complementary than substitutable in sustainable agriculture. This does not imply that the law of Von Liebig holds and that there are no positive returns to scale, but that input combinations are only sustainable in a restricted range. Other combinations overuse some inputs and are exhaustive for other inputs. The relevant question is then, not what are the marginal returns to increased fertiliser application under otherwise constant conditions, but what fertiliser rates are needed to realise a given target yield in such a way that the fertility of the soil is brought to or maintained at its corresponding equilibrium level.

To answer such questions, elementary dynamic simulation models are available for nitrogen and phosphorus (Wolf et al., 1987, 1989) that require as main input the results of fertiliser experiments, where in addition to yield, uptake of the nutrient under consideration is also determined. An example of the results is given in Figure 4.4. The target uptake of nitrogen is given as an *independent* variable along the horizontal axis and the nitrogen fertilisation that is necessary to sustain this uptake as a *dependent* variable along the vertical axis. Compared with Figures 4.1 and 4.2, the axes in Figure 4.4 are switched. Higher target uptakes also require other improved growing conditions, but these are taken for granted here and are not considered further. Taking wheat as an example, an uptake of 25 kg of N in straw and seed suffices to produce 1000 kg of seed under any growing conditions, without falling into the traps of luxury consumption and under-fertilisation (De Wit, 1992a,b). Further, the law of Liebscher is reflected in the assumption that the recovery of inorganic fertiliser is 0.3 for target uptakes below 15 kg N/ha and increases linearly to 0.6 for target uptakes of above 150 kg N/ha. The recovery of nitrogen from other sources is set at two-thirds of these values and the background supply by, for instance, rain is 60 kg N/ha per year. This latter value has been taken so high for illustrative purposes.

The bold curve 2 in Figure 4.4 presents the equilibrium fertiliser rates needed to sustain the target uptakes. Transient processes are accounted for in the models, but are not considered further here, apart from observing that such equilibrium values are, for all practical purposes, reached in a period of 5–10 years. The marginal productivity of the N fertiliser is defined in this context as the increase in target uptake per unit increase
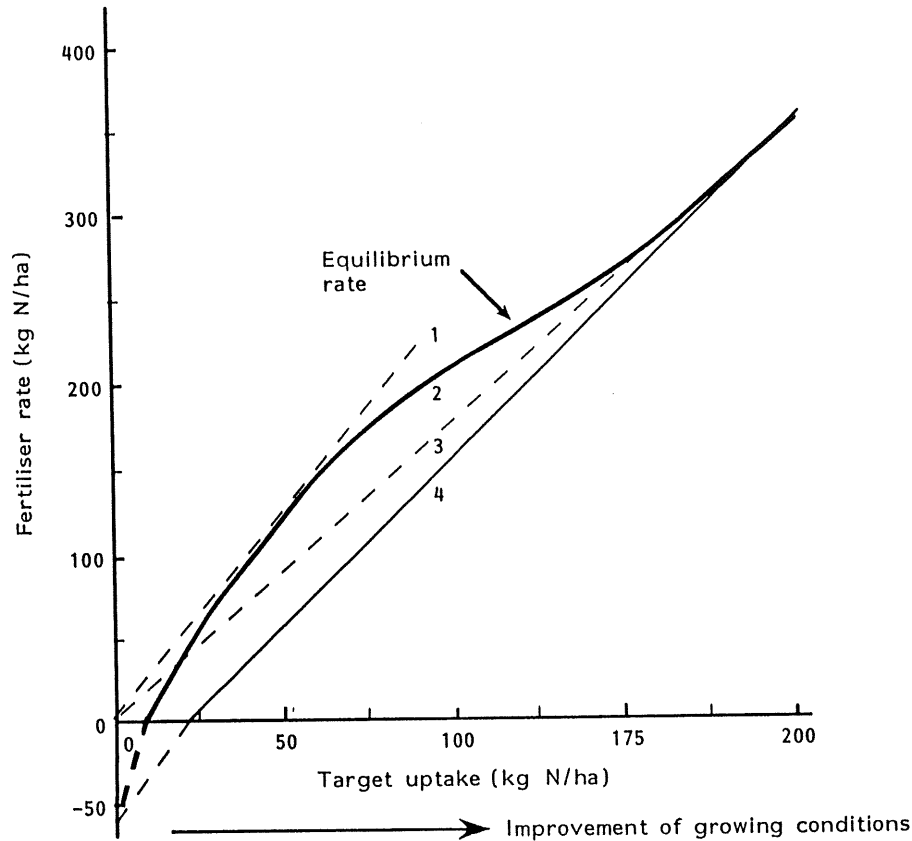
Figure 4.4   Relation between target nitrogen uptake and the nitrogen fertilisation that is necessary in the equilibrium situation to sustain this uptake in case of concurrent improvement of other growing conditions

in equilibrium fertiliser rate and its productivity as the ratio of target uptake and fertiliser rate. The marginal productivity increases over a wide range of target uptakes. The productivity, however, is at its lowest at a target uptake of about 50 kg N/ha, where curve 1 touches curve 2. At higher target uptakes, the productivity increases until a maximum is reached at the point where curve 3 touches curve 2. At lower target uptakes the productivity increases rapidly to infinite because the background supply allows sustainable uptakes without any fertiliser at all. At less illustrative but more realistic background supplies of about 10 kg N/ha per year, yields are so low that to make cultivation of a crop worthwhile, it is always necessary to apply inorganic or organic fertiliser, to grow green manures or to use fallow periods. The point of contact of curves 1 and 2 is then so close to the origin that the productivity of the fertiliser increases with increasing target uptakes over practically the whole range.

   Curve 2 reflects equilibrium situations, so that the amount of nitrogen that is not taken up by the crop is lost by leaching and denitrification. Since at lower target uptakes,

the amount of fertiliser needed for their realisation is relatively larger, the losses are also relatively larger. For response functions according to Von Liebig, recovery of fertiliser N does not increase with increased target uptake. Curve 2 is then a straight line and the relative losses are independent of the target uptake. This conclusion of constant or decreasing relative losses with increasing absolute losses seems contradictory to the common experience in nitrogen fertiliser experiments. However, these represent a completely different situation where the fertiliser rate is varied under otherwise the same conditions. It is then self-evident that finally the crop is over-fertilised, so that both absolute and relative losses increase with increasing rates of fertilisation. Undue emphasis on this trivial result diverts attention from the more sensible question of what fertiliser rates are needed to reach target uptakes as determined by the availability of other production factors and what are then the associated losses.

Curve 4 is approached if nitrogen is in minimum supply, while the other production factors are maintained at levels necessary for high target uptakes and thus sustain high recoveries of nitrogen. Then, fertiliser productivity at lower rates exceeds that for curve 2 and the distance between both curves could be considered the maximum substitution possibility between nitrogen fertilisation and all other variable production factors. However, curve 4 implies under-fertilisation with nitrogen or over-fertilisation with other nutrients and does not reflect a sustainable situation.

Nevertheless, many substitution possibilities remain in sustainable agriculture, but much more so at the management level than at the agronomic level. Many activities that are conditional for agriculture at any yield level, like plowing and seedbed preparation, can be executed with much labour and little capital and energy, or the other way round. Weed control is always necessary, but can be done with ecological (i.e. dense planting) or mechanical means or by herbicides. And if an ecotax on nitrogen is introduced, a more efficient application method may be developed, but the uptake that is necessary to achieve the target yield will remain the same.

SOME RAMIFICATIONS

In agriculture, one agronomic measure to improve growing conditions leads to others in a heuristic process of trial and error and based on limited and sometimes flawed knowledge of the production system. The analysis suggests that the law of Liebscher has general validity, so that this heuristic process occurs in an environment where returns to scale of yield follow an S-shaped curve. Therefore, it will be rewarding to examine a wide yield range for increasing returns to aggregate supplies of two or more production factors. For this purpose one should systematically consider whether each resource is used in such a way that other resources are used most efficiently.

Increasing returns to aggregate supplies reflect that agriculture is more difficult the more control is restricted, as is the case with a sub-optimal supply of resources. This not only leads to low yields per unit area but also to inefficient use of all other resources. In other words, the increase in production per unit area and in the efficiency of resource use are closely interlinked. Comparison of food grain production in the Punjab in the pre-green revolution period of 1962–1965 and the post-green revolution period of

1970–1973 indeed confirms that both yield and the productivity of all inputs increased (Bhalla et al., 1984).

In agro-ecologically sustainable situations, the reserves of nitrogen and minerals in the soil build up to their equilibrium level for the yield that is aimed at and the damage by pests, diseases and weeds does not systematically increase with time. As shown, the substitution possibilities at the agronomic level are then considerably less than in the usual field experiments. It is then less complicated, as mentioned above, to identify the minimal production factors and activities necessary to achieve a given target yield than to determine production functions that give yield as a function of all possible input combinations, disregarding their sustainability.

Activities like seedbed preparation, sowing and harvesting hardly require more effort at increasing target yield. This holds also for the application of micronutrients, for the use of lime to maintain an acceptable pH of the soil and for maintenance-breeding. Expressed in terms of active ingredient per hectare, biocides have a considerable fixed component, so that their needs increase relatively little with increasing target yield. Fertiliser requirements increase with increasing target yield, but above some minimum yield level the efficiency of their use increases as well. Water use efficiency increases also, but to create an optimal water supply and uniform growing conditions at the field level may require amelioration measures that demand a more than proportional effort with increasing target yield.

Formulated in economic terms, the productivity of the traditional fixed activities increases with increasing yields, while the marginal productivity of more variable yield-increasing and yield-protecting production factors remains high because of their complementarity. This implies that within a rather wide range, their input level is less dependent on their costs and their reward is less dependent on their scarcity, than for independent production factors (Van Dijk and Verkaik, 1989). Accordingly, within a wide margin, relative prices have little influence on their optimal mix (De Veer et al., 1992). As said before, substitution possibilities do exist but mainly at the management level and then mostly between labour, capital and energy.

THE FRONTIER OF MINIMUM COSTS OF PRODUCTION

So far in this discussion, prices have played a minor role and the considerations could be largely restricted to the technical level. This is different for the farmer, who requires acceptable financial returns for his/her work, without jeopardising the continuity of his/her enterprise. To elucidate the link between technical and economic considerations, the relation between production and costs over the whole range from extensive to intensive farming, is schematically presented in Figure 4.5, as inspired by the work of Holt (1987, 1988). The production target, expressed in ECU/ha (European currency unit) for a full rotation is given along the horizontal axis, with higher production targets representing more intensive production systems. The curve in the graph is the frontier of minimum production costs. It represents the costs that have to be met to reach the production target on the horizontal axis in an agro-ecologically sustainable way. Many possibilities exist to do worse, but none to do better. Sustainability implies here that the quality and fertility of the soil, the damage level of pests, diseases and weeds, and the capital
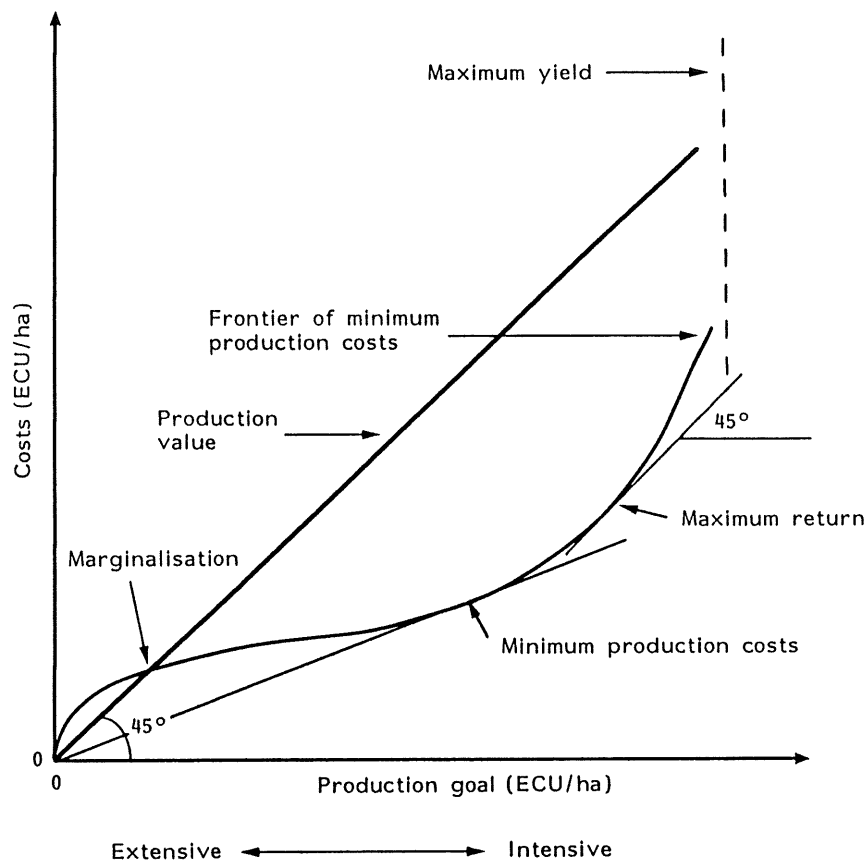
Figure 4.5 Minimum cost of production in dependence of production targets of farming systems. Source: Holt (1988)

stock do not deteriorate systematically in the course of time and is therefore not restricted to a certain production level.

The inverted S-shape of the frontier (Figure 4.5) reflects the results of the preceding analyses. In this presentation, the amelioration level is fixed, but all other costs, including those of capital goods, are considered variable. Further amelioration reduces the minimum costs to reach a certain target, and shifts the maximum attainable production to the right. The 45° line in the graph represents the gross production value when the production target is attained. Net return is the difference between gross production value and costs of production and is by definition equal to the entrepreneural reward plus the soil rent. It is assumed that prices are independent of the production target, to avoid unnecessary complexity. This implies that all labour is supposed to be hired on an hourly basis or that the farm size is adapted to the availability of labour in the farm household.

It requires a major effort to determine such a frontier of minimum production costs across the whole range from extensive to intensive farming, in spite of the limited

substitution possibilities at the agronomic level. Initial attempts should, therefore, be directed to production systems with a simple crop rotation as, for instance, only grain or only maize and soybeans and for the present level of mechanisation. But even the discussion on the basis of a schematic presentation remains enlightening.

Three characteristic points may be distinguished in the graph (Figure 4.5). The lowest costs per unit product are represented by the point of contact of the line through the origin and the frontier of minimum costs. This is also the point of highest ECU productivity. The increase in production and in the costs of production are the same at the point of contact of the minimum cost frontier and a line parallel to the gross production value. Here net return is at its maximum. This point is always to the right of the point of highest productivity if, as in this example, a range exists where net return is positive. Finally, the intersection of the line of gross production and the frontier of minimum production costs represents the point below which farming does not pay. It is emphasised that the point of highest efficiency in financial terms is not the point of highest efficiency of resource use. For some resources the latter may require more extensive production targets and for others more intensive production targets. This only shows up in a more detailed presentation of results.

It appears from agro-ecological surveys that in the greater part of the European Community (EC) a substantial gap exists between current production levels and the levels that could be reached at the present amelioration level, and that current production would be possible with a much more efficient use of resources (WRR, 1992). Farms are, therefore, not clustered around the point of maximum return in Figure 4.5, but scattered above the frontier of minimum costs and, hopefully, below the gross production line. There are many reasons for this, such as attachment to the established way of running the farm, lack of knowledge of the production situation and alternatives, imperfectly functioning markets for credit and for products and production resources not widely used in the region, and the time needed to acquire and apply new knowledge. Given this yield gap and the options to improve the productivity of the soil and other resources, it is in most regions of the EC economically attractive for the farmer to aim at higher net returns by setting higher production targets. The rate of intensification is then not so much dependent on prices, but on public and private activities of research and extension.

A continuing increase in production volume without much increase in demand leads sooner or later to reduced prices of agricultural products, even in the EC where agricultural policy struggles to control prices and production volumes. Such a reduction at otherwise the same price ratios may be presented in Figure 4.5 by a decrease in the slope of the line for the gross production value: the production target on the horizontal axis is then no longer formulated in current prices but in prices in some base year. With such a decreasing slope of the line for gross production, the point of marginalisation moves upward and the point of maximum return downward along the frontier of minimum production costs. The point of highest productivity is, however, independent of the price of agricultural products and remains in place. Hence, in a case where price reduction continues, a situation will be reached where the three points coincide. Agriculture becomes uneconomical if product prices decrease still further. The point of highest productivity may thus also be referred to as the vanishing point of agriculture.

Research that is aimed at continuity of agriculture should, therefore, not be centred around the more elusive point of maximum return, but around the more robust point of maximum productivity.

Well- and less-endowed regions in the EC are distinguished by the position of the frontier of minimum production costs: in less-endowed regions the maximum is lower, and the minimum costs—although to some extent compensated by lower wages—are higher. With decreasing prices the vanishing point of agriculture is, therefore, reached earlier the less endowed the region is. After some years of exhaustive exploitation and hardship, the land is abandoned or at best used for extensive grazing. Since the vanishing point of agriculture coincides with the point of highest ECU productivity, such changes do not occur along a pathway of gradual extensification. In regions of the EC where agriculture remains an economically attractive enterprise, yields continue to increase, so that there are in fact only two alternatives: completely terminating agricultural activities or continuing intensification (De Veer et al., 1992).

Preventing pollution is best served by the efficient use of external resources. This is also achieved by concentrating arable farming in well-endowed regions. However, there are a few caveats to consider. Although the use of resources per unit product is lower, such a concentration of agriculture also leads to a concentration of pollution, so that environmental standards may be threatened in regions where agriculture is concentrated. Moreover, the concentration of agriculture would make it impossible to mine large soil surfaces for plant nutrients as is done in extensive forms of agriculture and to exploit the possibilities of reducing the effects of pollution by dilution.

There are equity arguments for support of farmers in less-endowed regions and ecological and environmental reasons to maintain forms of agricultural land use in these regions. World-wide, geopolitical and environmental arguments exist to produce the food where the mouths are. Such goals will place heavy demands on the political process, because it requires not only national and international solidarity, but invariably leads to a less efficient use of production resources and unnecessarily exposes soils to the risks of agricultural use.

ACKNOWLEDGEMENTS

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