16 Bridging the Gap between Environmentally Acceptable and Agronomically Desirable Nutrient Supply

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16.1 INTRODUCTION

Present-day agriculture is faced with gaps between what is theoretically possible and what is achievable in practice (the *yield* gap), and between what is achievable and what is environmentally desirable or permitted (in part, the nutrient *efficiency* gap). In a larger context, there is a third gap between what agriculture can produce and what a large part of the world population can afford to consume (the *consumption* gap). Bridging these three gaps is a major challenge at the brink of the new century.

Enormous progress has been made, particularly in the second part of the twentieth century, in closing the yield gap and bringing agricultural productivity (on a per hectare basis) closer to the theoretical maxima. At the same time, by substituting fossil fuel energy for labour, and by increased use of chemical inputs, productivity per unit of labour has also increased dramatically. Since the Second World War, the success of agriculture in boosting the economies and the standard of living of many nations is indisputable. Agriculture now accounts for about 5% of per capita income in the Netherlands and, during recent years, several agricultural products consistently have been among the 10 most important exports (Centraal Bureau voor de Statistiek, 1993). European nations as a whole are net exporters of food, despite a substantial increase in population during the last 50 years.

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Table 16.3. Yields from the Dutch programme on Soil Ecology of Arable Farming Systems for the period 1988-91 (Reproduced by permission from van Faassen & Lebbink, 1994)

	%C[1] Soil	*%N[1] Soil*	*Winter wheat[2]*	*Potatoes[3]*	*Spring barley[2]*	*Sugarbeet[4]*	*% of CONVB*
CONV-A[5]	1.59	0.14	6.7 (0.7)[6]	60.1 (6.6)	5.0 (0.5)	14.3 (4.4)	103
CONV-B[5]	1.28	0.10	6.7 (0.8)	57.4 (7.5)	5.3 (0.6)	14.5 (1.6)	100
INT-A[5]	1.59	0.14	5.6 (0.8)	58.4 (7.1)	4.8 (0.7)	12.9 (1.2)	97
INT-B[5]	1.33	0.11	5.6 (0.8)	50.6 (9.1)	4.7 (0.6)	13.3 (1.2)	88

[1] Mean 1981–84 0–25 cm.
[2] Grain dry matter (t/ha).
[3] Tubers fresh weight (t/ha).
[4] Sugar (t/ha).
[5] See Table 16.2 for an explanation.
[6] Figures in parenthesis are standard errors.

Spring Barley

(100 – N min: 0–60 cm) kg/ha	applied at sowing
30 kg N/ha	at GS 30

Ware Potatoes

(285 – N min: 0–60 cm) kg/ha	66% before planting; 33% at tuber initiation

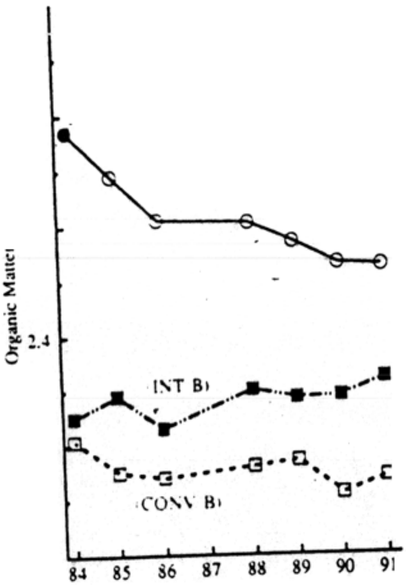
Phosphorus was considered sufficient if the phosphorus extractable in water (van der Paauw, 1971) achieved a value of 35 (mg phosphate l dry soil). Depletion of soil phosphorus was compensated by applications of 115 kg phosphate/ha each year, and depletion of soil potassium by applications of 280 kg potash/ha before sugarbeet and 330 kg/ha before potatoes. In the INT plots the mineral nitrogen supply was reduced to 50–60% of the supply in the CONV plots; the phosphorus and potassium contents of the manure were simply subtracted from the recommended maintenance applications. Several different kinds of organic manuring were applied to the integrated plots during the course of the experiment. These, and their composition and estimated nitrogen supply, are shown in Table 16.4. As discussed below, these factors have an important bearing on the interpretation of the results. Overall, the integrated plots yielded about 90% of the conventional system (Table 16.3). In the integrated plots, organic manures supplied 35% of the crops' demands for nitrogen, not all being immediately available. During the 6-year course of the experiment, the percentages of organic carbon in the soil were maintained on these plots but fell by 0.2% on the conventional plots (Figure 16.3). In terms of soil maintenance, and within the 6-year duration of the experiment, yields obtained on the integrated plots may be thought of as *sustainable*, provided sources of organic matter are introduced.

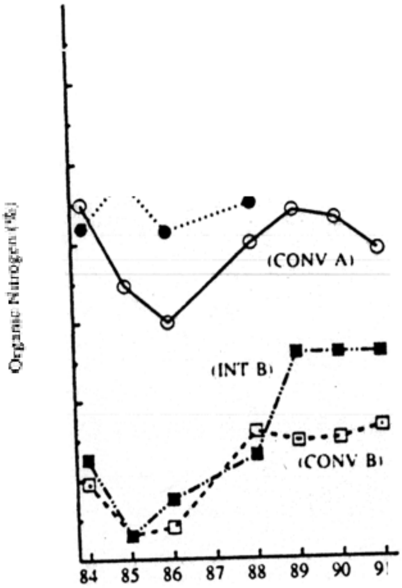
Yield is not the only criterion; deleterious effects on the environment must be considered also. Here it is convenient to quantify the efficiency with which nutrients, in particular nitrogen, were used in the experiment. Figure 16.4 shows the total recovery of nitrogen during the last 4 years of the experiment, throughout the four course rotation, side by side with the nitro-

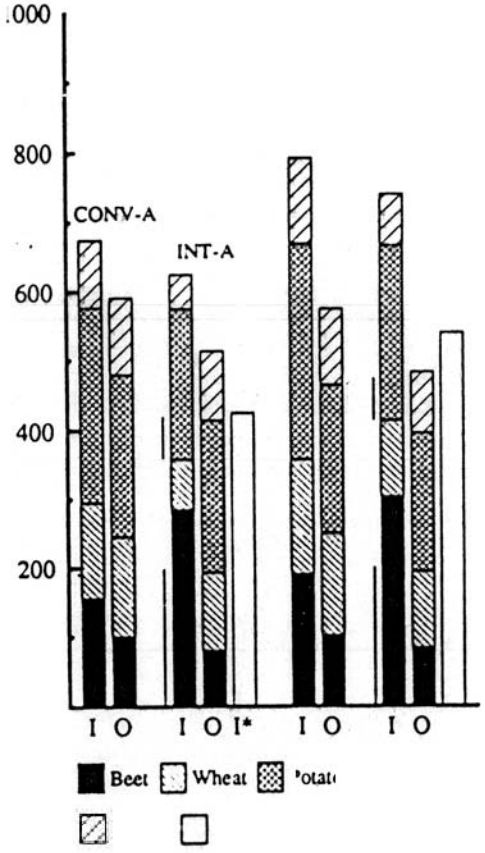
Table 16.4. Content and supply of nitrogen from organic manures (Reproduced by permission from van Faassen & Lebbink, 1990)

	Organic matter (kg/ha)	*Nitrogen[1] (kg/ha)*	*Mineralization (kg/ha)*
Pig slurry	3700	170	58 (@ 20°C during 24 weeks)
Champost	5300	210	negligible
Granular organic	1800	60	not determined

[1] Mineral and organic N.


Organic Matter
2.4
(INT B)
(CONV B)
84
85
86
87
88
89
90
91


Organic Nitrogen (%)
(CONV A)
(INT B)
(CONV B)
84
85
86
87
88
89
90
91



.000
800
600
400
200
CONV-A
INT-A
I O I O I* I O I O
Beet
Wheat
'otat

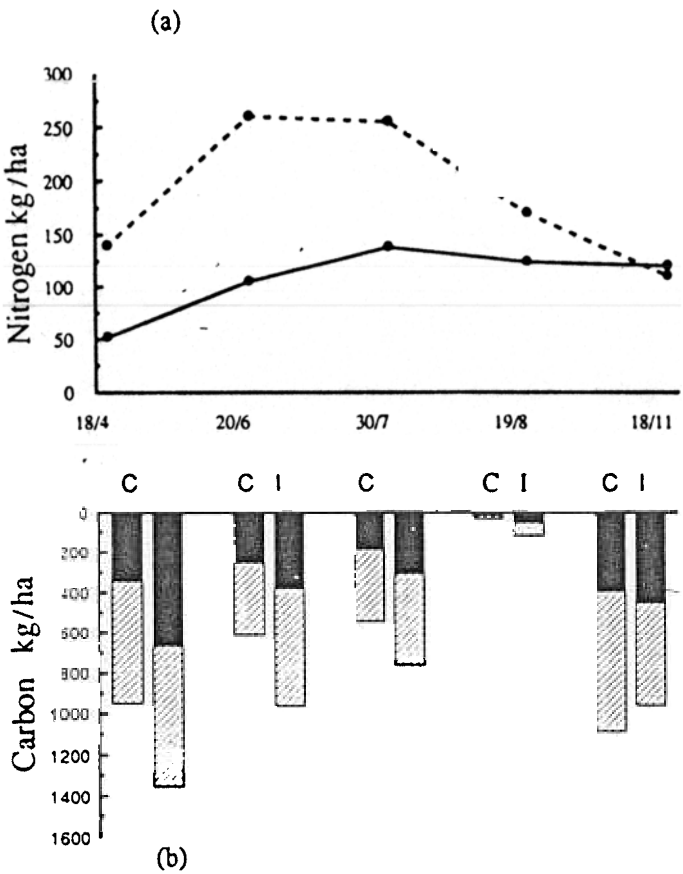


Figure 16.5. Showing on five specific dates during 1986 (a) the potential mineralization of nitrogen from soils from conventional (—•—) and integrated (- -•- -) farming plots and (b) the amount of carbon found in the microbial biomass in the same plots (Reproduced by permission from Brussaard *et al.*, 1990). ■, 0–10 cm; ▨, 10–25 cm

One question not yet addressed here is *why* integrated systems should be more efficient. Figure 16.5a shows the potential mineralization rate (nitrogen released during 2 weeks laboratory incubation at 20°C) of soil sampled at five specific times during the growing season in 1986. Figure 16.5b shows the numbers of bacteria in the soils, at the same times, obtained by microscopic counting. Numbers of most other soil organisms were counted at the same times but the trends very roughly followed the pattern of bacteria (Brussaard *et al.*, 1990) and will not be considered here. It is not surprising that the integrated plots mineralize more nitrogen or contain greater numbers of soil bacteria as they have after all received more organic inputs expressly with this purpose in mind. What is interesting is that the peak mineralization in this system occurs during spring and early summer, which is exactly when a growing crop requires most nitrogen. In contrast, the peak in mineralization from the conventional plots is broad and occurs after the peak in demand from the crop. Also, it is interesting to note that the number of bacteria in the conventional plots only exceeds that in the integrated plots in autumn, precisely the time of year when mineralization needs to be discouraged if nitrate leaching is to be avoided. The integrated system goes some way to solving one of the more intractable problems in intensive but environmentally sound agriculture: the gap in time between when nutrients are required and when they are supplied. Fertilizer applications solve the problem perfectly from the farmers' point of view but the risk of late autumn mineralization has tarnished the reputation of fertilizers in recent years. Synchronizing soil supply more closely with crop demand increases efficiency and reduces waste.

Another possible reason why the integrated system out-performs the con-

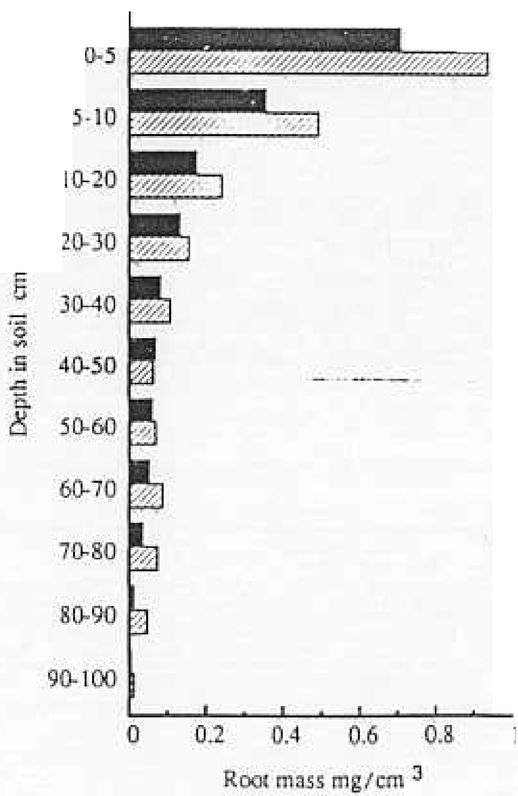


Figure 16.6. Fine root production in winter wheat as measured at anthesis on conventional (■) and integrated (▨) farming plots (van Noordwijk *et al.*, 1994)

ventional system lies in the distribution of crops' roots. Figure 16.6 shows the distribution of fine roots of winter wheat down the soil profile at anthesis in both conventional and integrated plots. The plants on the integrated plots clearly have more root weight, particularly in the nutrient-rich upper layers. Root lengths and weights for other crops at other times confirm this overall trend (van Noordwijk *et al.*, 1994). Although more root, like greater numbers of micro-organisms, does not prove their greater activity it does suggest that the crop and soil in the integrated system are more in tune with each other, meaning that the plant is better able to make use of nutrients as and when they become available from mineralization during the growing season. By and large, the soil supplies nutrients when they are needed. It is true that a somewhat greater root density may have relatively little effect on nitrogen extraction by crops, but the phosphate supply, which is controlled by a much slower diffusion in soil than nitrate, may become limiting, particularly as the soil dries in May and June. Here, then, is a partial solution to the problem that crops and nutrients are not always present in the same place: the gap in space. Roots can compensate at least partly for the spatial variability of nutrient supply within reach of a single plant, say within a radius of about 0.5 m: varying fertilizer applications from area to area might compensate for the remainder.

16.5 CONCLUSIONS

Although currently in vogue as ideals, wholly natural ecosystems are not without their own kind of 'pollution' or competition between organisms, otherwise there would be no pressure of evolution. However, farming disturbs natural ecosystems to a much greater extent than is 'natural' and the key to sustainable and environmentally acceptable farming systems is to try to imitate the natural system as far as is possible or sensible given the constraints of population, of hunger and of economics.

Nutrient efficiency must be improved as we enter the twenty-first century and nowhere is the scope greater to do so than in grazed systems. None the less, simple solutions based on resolving the balance between input and output of nutrients will probably not help. Decisions on nutrient input are based on relatively simple calculations of the requirements of the system. Where these requirements vary in space or time, the decisions must reflect the fact. Worse, the requirements themselves are often estimated on field plots where much effort has been put into excluding any form of variability. Estimates based on such plots will be unrepresentative of conditions on farms.

The ideas on variability of crop response expressed in this chapter are easily extended to other field quantities normally expressed as an average (mean or otherwise). For example, crop residues mineralize after harvest, but the speed, and perhaps efficiency in microbiological terms, with which they do so may well vary from point to point in the field. If so, the net concentration of nitrate found in percolating water is unlikely to be linearly related to the average amount of crop residue left in the field above. By extension, a similar argument can be advanced for the losses of phosphate or of pesticides and their decomposition products in leachates and run-off. Likewise the amounts of denitrification, which are driven by spatially variable anoxic patches in carbon rich soil, will also be non-linearly related to the average amount of crop residue or nitrate in the field. While these effects may be difficult to quantify on a field by field basis, it may be possible to establish norms for variability. In that case, the bias introduced by assuming linearity may be estimated and corrections applied where scaling up is necessary, as, for example, in estimating the nitrate loading in aquifers or nitrous oxide production from large areas of agricultural land.

Farmers and growers are not passively at the mercy of their growing conditions. There is much they can do themselves to integrate farming methods and to adapt soil conditions to the requirements of their crops. While the duration of the experiments presented in this chapter is too short to be sure how organic matter amounts in soil change with management, it seems likely that yields can be maintained at approximately 90% of current values using about half the amount of chemical nitrogen, provided it can be supplied at the time the crop most requires it and provided large amounts of organic matter can be maintained safely in soils. If so, profitability may be maintained despite loss of yield. Viewed as a whole, farming efficiencies may be improved still further where arable fields recycle animal manures.

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In increasing productivity, farming sometimes neglected to maintain or preserve the natural resources needed to sustain land in its multiple functions to the community. In some countries, environmental controls, that limit the freedom of farms in much the same way as other industries, are now in force. Thus, a gap is appearing between what is possible and what is wise or, where environmental legislation is in place, between what is possible and what is permitted. In closing this second gap, the consumption gap should not be ignored: reducing farm productivity may reduce environmental problems but aggravate the difference between the haves and the have-nots. However, such matters are largely determined by socio-economic factors and should be addressed by political rather than agricultural measures.

To rise to the challenge of bridging these gaps, an effective diagnosis of the problems to be faced is needed. In this chapter the efficiency of nutrient use and, especially, the gap between the demand expressed by a plant and the supply it experiences in terms of the amount, the timing and the location of nutrient supply will be focused upon.

16.2 NUTRIENT BALANCES: THE GAP BETWEEN DEMAND AND SUPPLY

Table 16.1 illustrates the problem found when inputs and outputs of nutrients in agriculture are considered. It shows the nutrient use on a dairy farm in the Netherlands (Joosten & Terwan, 1990). What is striking are the large amounts of added nutrients that are not accounted for in saleable produce. A more general estimate for the Netherlands, based on the total use of nitrogen in all kinds of farming throughout the whole country (approximately 1100×10^6 kg/year), and on the total amount of nitrogen removed in farm produce, indicates that 75% is wasted (Goossensen & Meeuwissen, 1990). Similar nitrogen balance sheets have been drawn up in other European countries (e.g. The Royal Society, 1983; Hansen, 1989). Although much of the discrepancy is denitrified or leached, not all will have been immediate losses. In relatively young swards, much nitrogen may be immobilized in organic matter and go towards increasing the indigenous soil nitrogen. However, it is also true that, when the sward is ploughed, this nitrogen is likely to be remineralized and, crucially, probably be mineralized at a far faster rate than any crop can use it. Even if unploughed, any system must attain a more or less steady state after a number of years and, under such conditions, all of the above annual discrepancy must, indeed, be lost. Such a system is only sustainable if the nitrogen that is lost can be recaptured and reused. A further problem in estimating balances is encountered in soils recently reclaimed from the sea. During the ripening process, immediately after the land is reclaimed, many nutrients are released from the clay minerals and, at the same time, shifts in organic matter levels can be enormous.

Table 16.1. Nutrient balance on a Dutch dairy farm (Reproduced by permission from Joosten & Terwan, 1990)

	kg/N ha			*kg/P ha*			*kg/K ha*		
	1986	*1987*	*1988*	*1986*	*1987*	*1988*	*1986*	*1987*	*1988*
Inputs									
Supplements	112	121	109	22	22	21	65	61	62
Fertilizer	309	259	176	-	2	12		8	5
Deposition	36	36	36	1	1	1	4	4	4
Net mineralization	66	60	60	7	6	6	-	-	
Miscellaneous	6	7	9	2	2	1	1	1	5
Total inputs	529	483	390	32	33	41	70	74	76
Outputs									
Sale of meat	18	8	14	5	2	4	1	1	1
Sale of milk	56	55	56	9	9	9	16	16	16
Total outputs	74	63	70	14	11	13	17	17	17
Losses									
Loss/ha	455	420	320	18	22	28	53	57	59

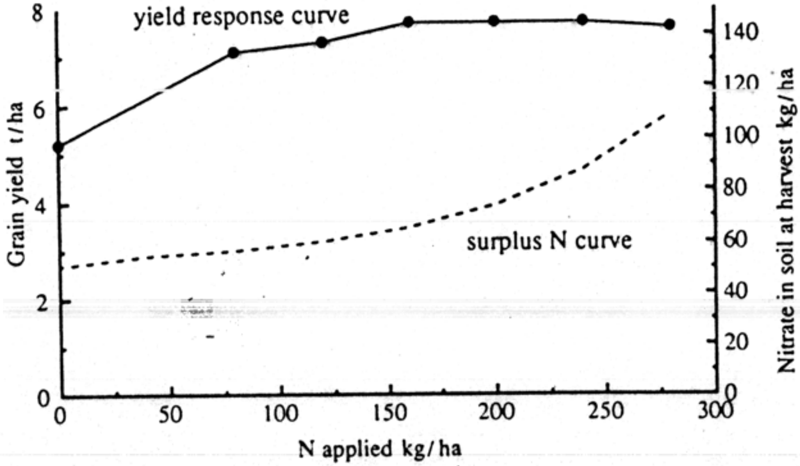

Figure 16.1. The yield response of winter wheat and residual nitrate left in soil at harvest, in relation to the nitrogen applied as fertilizer. Data from Chaney (1990)

Figure 16.1 shows an example that is sometimes helpful in interpreting the environmental efficiencies of arable farming systems (data from Chaney, 1990). The upper line, the yield response curve, possesses the usual broad, ill-defined maximum which is, none the less, often reckoned to a distinct optimum value of applied fertilizer by differentiating a fitted curve. The economic optimum falls somewhat to the left of the physiological optimum and depends upon the price of the inputs. The lower curve, sometimes called the surplus nitrogen curve (e.g. Addiscott *et al.*, 1991), shows how residual nitrate remaining in soil at harvest varies with the applied nitrogen. Three aspects of Figure 16.1 deserve mention: (1) the intercept with the yield axis (nitrate residue in the absence of fertilizer use) is normally considerable; (2) there is a phase with little or no change in residual nitrate found in soil until (3) a phase is reached where the residue increases sharply, even to the extent that the line has a slope of unity. The first aspect may be explained either by incomplete uptake by root systems or by mineralization during the ripening phase. Somewhere between (2) and (3) there is a sort of environmental optimum where water quality standards can just be met, even if all the nitrate remaining dissolves in the excess winter rainfall. In winter wheat, according to these data, the economic and environmental optima coincide. Evidence for other crops is lacking but it seems possible that for oilseed rape (R. Sylvester-Bradley, personal communication) and potatoes (Neeteson & Wadman, 1991) the environmental optima are not so well defined and fall at a value of applied nitrogen somewhat less than the economic optimum. Unfortunately, evidence is accumulating to suggest that, even for winter wheat, the optima may be out of step with one another.

16.3 SPATIAL VARIABILITY THE GAP IN SPACE

Fertilizer estimates are often calculated on the basis of a simple scaling up of the response of crops found within a small area on experimental plots. For example, the response per hectare is simply estimated by multiplying the response per square metre by 10^4. However, soil is far from being a homogeneous medium in which to grow crops. Yet the variability of water and nutrient supply in space, the resistance to erosion, and even the relief and consequent interception of radiation by the growing canopy are all extremely difficult to take into account when reckoning fertilizer applications. However, recently van Noordwijk & Wadman (1992) showed how such variability may play an important role, not just in estimating fertilizer applications but, also, in determining the extent of the risk of loss of unused or unharvested nutrients in the field. Experimental design often explicitly masks the variability, but farmers must deal with its effects as best they can. A similar study in the United States produced the same general conclusions (Cassman & Plant, 1992).

In essence, the idea is as follows: crops are normally fertilized as though they have an average response to the uniform applications of nutrients they are given. However, other factors in the field will limit (or in some cases enhance) this response so that a uniform fertilizer application can be calculated in (nominally) three different ways: (1) to obtain maximum yield from the least responsive parts of the field; (2) to obtain an average response; or (3) to obtain maximum yield in only the most fertile parts of the field. The norm is probably somewhere between (1) and (2) while the environmentally most favoured option and least wasteful of inputs would be (3). The ideal might be to vary fertilizer applications to match precisely the varying demands of the crop throughout the field.

van Noordwijk & Wadman's (1992) model took account of the variation found in imaginary small plots, each nominally the environment of a single cereal plant, and summed the yields over a whole field taking into account the effects of variation in these micro-environments. Four components of variation were brought into the reckoning: (1) the quantity of mineral nitrogen present at the beginning of the growing season, N_{min}; (2) the net mineralization during the growing season, R_{Netmin}; (3) the nitrogen applied as fertilizer, N_f; and (4) the amount of nitrogen, N_{nut}, that cannot be taken up by a crop because of restrictions in transport to the rhizosphere, which also vary in space. The total variation in nitrogen use per plant was reckoned assuming either normal or log-normal distributions of each of the four properties. The variation in nitrogen supply from the soil, ${\sigma_{Ns}}^2$, was calculated from the standard deviation of N_{min}, σ_{Nmin}, the standard deviation of R_{Netmin}, $\sigma_{RNetmin}$, and from the spatial correlation between the two, ρ:

$$\sigma^2_{Ns} = \sigma^2_{Nmin} + \sigma^2_{RNetmin} + 2\rho\sigma_{Nmin}\,\sigma_{RNetmin} \qquad (1)$$

Estimates of the variation in each component were obtained from the literature; the values used in the example here are given in the legend to Figure 16.2. The coefficient of variation in applied fertilizer, N_f, was estimated to be about 10%, so the total variation seen by the plants, N_a, is a linear combination of $\sigma_{N_s}{}^2$ and the variation in N_f, σN_f^2; this assumes, at least within a plot, that there is no correlation between nitrogen application and supply:

$$\sigma^2_{N_a} = \sigma^2_{N_s} + N_f^2(\sigma/\mu)^2_{N_f} \quad (2)$$

where μ is the amount of fertilizer given ($\sigma/\mu = 0.1$). One way in which the variability of the plants' response to nitrogen might be reduced is to introduce negative correlation between N_f and N_s; that is either reduce applications of fertilizer where, for example, the supply from soil is larger than average, or increase them where supply is suboptimal.
The fraction taken up by the crop, f_u, or the uptake efficiency at maximum uptake may be expressed as:

$$f_u = \frac{N_{uR}}{N_{uR} + N_{nat}}$$

where N_{uR} is the nitrogen taken up at maximum efficiency. Crops may take more nitrogen than is strictly required for growth or optimum growth. This so-called luxury consumption (λ) is allowed to be up to 25% greater than N_{uR}. Note that such luxury consumption reduces the amount of nitrogen found in the soil at harvest. Thus, where N_a is less than demand, the uptake, N_u, is:

$$N_u = f_u N_a = \frac{N_a N_{uR}}{(N_{uR} + N_{nat})}, \; for \; N_a < (N_{uR} + N_{nat})(1 + \lambda) \quad (4a)$$

and where N_a is greater than demand:

$$N_u = N_{uR}(1 + \lambda), \; for \; (N_{uR} + N_{nat})(1 + \lambda) \quad (4b)$$

The actual yield, Y, may be assumed to be related to the harvest index, f_h (taken as 0.5), and the concentration of nitrogen in the plant, C_m, when nitrogen is not limiting:

$$Y = f_h \frac{2N_u}{C_m}\left\{1 - \frac{N_u}{2N_{uR}}\right\} \; for \; N_u < N_{uR} \quad (5)$$

De Willigen & van Noordwijk (1987) showed that:

$$C_m = 0.05, \; for \; Y_D < 2000 \quad (6a)$$

$$C_m = 0.01 + 80/Y_D, \text{ for } Y_D < 2000 \tag{6b}$$

where Y_D is the total above-ground dry matter ($= f_h Y$). The amount of nitrogen remaining unused in the soil at harvest, N_r, is calculated as follows:

$$N_r = N_a - N_u + R_{netmin} \tag{7}$$

where R_{netmin} is the mineralization between maturity (when the crop ceases to take up nitrogen) and harvest. Thus, equations (1) and (2) formulate the variability of nutrient supply, and equations (4) and (5) the crop response to nitrogen. Equation (7) estimates the nitrate residue at harvest. Note that there is no variability ascribed to plant growth apart from the restrictions in nitrogen supply; the crop is assumed to be genetically homogeneous and capable of a uniform response. Figure 16.2 quantifies the amounts of nitrogen remaining in the soil and removed by the crop with and without variation in the four quantities on which the model is assumed to depend. Other examples of how normal and log-normal variation and the various parameters in the model affect the outcome can be found in van Noordwijk & Wadman (1992) and de Willigen *et al.* (1992).

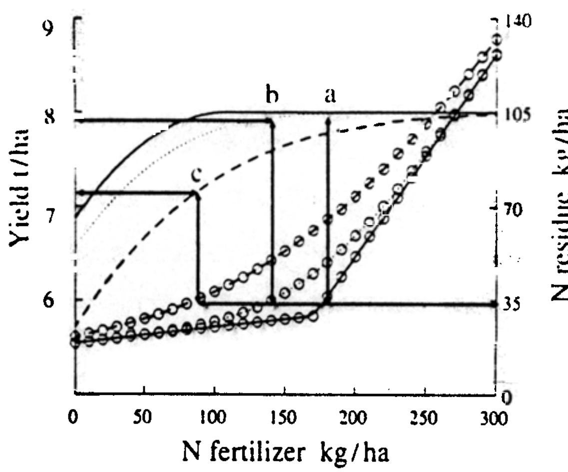

Figure 16.2. The way in which spatial variation in both the supply and availability of nitrogen to a winter wheat crop affects yield and residual nitrate as a function of applied nitrogen; variability in the parameters as described in the text assuming a normal distribution, (standard, double): ρ, 0.5, 1.0; $(\sigma/\mu)N_{nat}$, 20%, 40%; σN_{min}, 30 kg N/ha, 60; σR_{netmin}, 17 kg N/ha, 34 (van Noordwijk & Wadman, 1992). The horizontal line at 35 kg N/ha represents the 'safe' value of residual nitrate in soil. Points a, b and c show the amounts of nitrogen fertilizer that result in 35 kg residual N/ha remaining in soil, and the corresponding yields of winter wheat, with no variation (a), standard (b) or double variation (c) in spatial supply and availability of nitrogen. Variability: —— Y none; ..... Y stand; - - - Y double; —⊖— Nres, none; ····⊙··· Nres, stand; –⊖– Nres, double

Figure 16.2 shows how the variability in the model inputs affects both yield and residual soil nitrate at harvest given plausible values for the model parameters. With no variation the economic and environmental optima coincide at about 180 kg N/ha (point a, Figure 16.2). Introducing 'standard' variability produces little change in the optimum yield or its response to nitrogen but the 'safe' value of the residual nitrate in soil of 35 kg N/ha, the amount that it is thought may be present in soil in autumn yet present no danger to leaching (Goossensen and Meeuwissen, 1990), is reached with an application of 150 kg N/ha (point b, Figure 16.2). If double variation is allowed (twice the standard deviations in the study quoted), the environmental optimum is reached at just 100 kg applied N/ha (point c, Figure 16.2). In such a scenario, the yield optimum is clearly shifted to the right. This implies that farmers with heterogeneous fields, and who are chasing optimum yields, may be acting quite rationally in applying fertilizer well above recommended amounts. If borne out experimentally (on heterogeneous sites), these simulations have clear implications for the twenty-first century. Nutrient supply must be manipulated to match crop demand as closely in space as possible. One way to do this is to introduce a correlation term in equation (2) as already described. Where the problem is not only spatial there may be other ways to achieve the same aim.

16.4 NUTRIENT EFFICIENCIES: A SYSTEMS APPROACH TO CLOSING THE GAPS

In 1985, the Dutch Programme on Soil Ecology of Arable Farming Systems was initiated to study how matching nutrient supply more closely to crop demand, both in time and amount, might improve the efficiency of farming systems, and to what extent yield might be maintained at 80% or 90% of control levels with a 50% or 60% reduction in mineral nitrogen inputs. As a necessary part of such an investigation, the interactions of soil organisms and their contribution to nutrient supply, and maintenance of soil structure were studied. The working hypothesis of the programme was that by replacing mineral nitrogen with organic nitrogen, by reducing other inputs to agriculture, and by integrating operations more fully, the efficiency with which nutrients were used could be improved while still controlling pests and diseases effectively and with little drop in yield (Table 16.2). Here, some of the many results published more fully elsewhere (Kooistra *et al.*, 1989; Brussaard *et al.*, 1990; van Faassen & Lebbink, 1990, 1994) are summarized.

The experimental programme began in 1986 on a part of the Dr H.J. Lovinkhoeve Experimental Farm at Marknesse, the Netherlands. The experiments were laid out at right angles across the site of an older existing experiment comparing organic matter inputs. The four treatments were tested in a 2 × 2 combination of more (Block A) versus less (Block B) soil

Table 16.2. Management treatments in the Dutch programme on Soil Ecology of Arable Land

	Conventional (CONV)	*Integrated (INT)*
Soil organic matter	Both treatments were laid out across two blocks from an earlier experiment that had led to (A) more or (B) less indigenous organic matter in soil	
Inorganic N	$Ca(NO_3)_2$	Less than CONV
Organic N additions	Crop residues only	Crop residues + manure or compost
Crop protection	Pesticides + soil fumigation	Less than CONV; no fumigation
Tillage	20 or 25 cm	12–15 cm + subsoiling to 20 or 25 cm

organic matter, and conventional (CONV) versus integrated (INT) farming. Since the integrated treatments continued the application of organic manures and crop residue incorporation practized on the older experiment, it was suggested that the plots with more indigenous organic matter may represent the eventual state of the soils in the integrated plots on Block B. The soil was a calcareous silt loam, containing 20% clay, 68% silt and 12% sand, reclaimed for agricultural use in 1943. Annual rainfall between 1943 and 1987 averaged 730 mm. The rotation practized throughout the experiment was: potatoes–spring barley–sugarbeet–winter wheat. Catch crops were grown after the two cereals. Yields obtained from crops during the years 1988–91 are shown in Table 16.3. Block B contained less organic matter, so was given 30 kg/ha extra mineral nitrogen in order to raise the total nitrogen supply to about the same as on Block A. The amounts of nitrogen, phosphorus and potassium applied to the CONV plots were as recommended by the Agricultural Extension Service of the Netherlands Ministry of Agriculture (LNV, 1986). Mineral nitrogen was determined in soil samples taken in February or March, and the rate of application calculated as follows (growth stages according to Zadoks *et al.*, 1974):

Winter Wheat

(140 – N min: 0–100 cm) kg/ha	first application in March
60 kg N/ha	second application at GS 31–32
40 kg N/ha	for e.g. quality at GS 39–40

Sugarbeet

(220 – 1 7*N min: 0–60 cm) kg/ha	66% applied before sowing; 33% when canopy closes