Feed the Crop or Feed the Soil? A Case Study in Leek (*Allium porrum* L.)

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Abstract

The purpose of our study was to assess the role of soil quality parameters in leek production and to assess their importance relative to nitrogen (N) applied as fertilizer. We selected seven (2004) and seven (2005) fields on leek farms in the southern sand district of the Netherlands and measured physical and chemical soil properties. Three N rates (0, 90 and 360 kg N ha^{-1} as calcium ammonium nitrate; denoted as N_0, N_{90}, N_{360}) were given at each site. Leek (*Allium porrum* L. 'Kenton') was planted in June-July and harvested next spring. Measured response variables were shoot biomass yield (gross and net, fresh and dry) and shoot N-yield (gross, net) at harvest. Pooled data from both years were analyzed by linear regression. N uptake from unfertilized soil (U_0), and topsoil properties soluble organic N (N_{so}), soil organic matter content (SOM), total nitrogen (N_{tot}) and water content at field capacity (W_{fc}) all had large and significant impacts on biomass yield and N yield. These five properties (X_i) were correlated and were therefore used alternately in regression models. Effects of soil properties found by regression refer to a shift in the regressor from its 25% to its 75% percentile value, and are expressed here relative to mean yields (both years, all treatments). This normalization facilitates direct comparison with fertilizer effects. Normalized effects of X_i variables on biomass yield and N yield were between +0.10 and +0.20. Effects of fertilizer application at N_{90} were about +0.10 (biomass yield) and +0.20 (N yield). At N_{360} effects were +0.10 to +0.20 (biomass yield) and +0.30 to +0.40 (N-yield). So while N fertilizer strongly promoted N-uptake relative to growth, soil properties X_i affected growth and N yield more evenly. With shifts in X_i variables, dry matter produced per kg additional N uptake was 1.49 to 1.77 times larger than with extra N uptake resulting from fertilizer application at N_{90}. This indicates that soil properties X_i promoted yield not only via enhanced N supply. Besides effects of X_i properties and N fertilizer, we found significant effects of year, soil texture, *pH* and inorganic soil N at planting, on biomass yield. Texture parameters F_{sfine} (50-210 µm) and M_{50} (median of particle size in 50-2000 µm fraction) had large and additive positive effects on net fresh yield. Apparent recovery of fertilizer N (ANR) averaged 0.35 at N_{90}, and 0.17 at N_{360}. ANR decreased with higher N_{so} and increased with higher W_{fc}.

INTRODUCTION

The widespread adoption of chemical fertilizers in the early decades of the 20th century spurred many long term experiments on soil management, that often aimed to expose if fertilizers could replace organic manures, and whether organic inputs are necessary besides fertilizers to assure good yields. Results from such experiments were still prominent at the ISHS Symposium on Nutrition and Fertilization of Vegetables, held in Warsaw just over 35 years ago (Nowosielski and Szmidt, 1973). At the meeting, Fritz and Wonneberger (1973) concluded their extensive review stating that '…organic fertilization increases and guarantees yield, facilitates mechanization, and raises quality of

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vegetables. It cannot be missed.' Cited benefits from organic manuring included improved physical properties (aggregation, porosity, water retention, aeration, early warming, workability and avoidance of slaking), enhanced cation exchange capacity and pH buffering; and biological activity affecting soil borne diseases, nutrient cycling and the behaviour of pesticides in soils. At the same occasion, Chroboczek (1973) - on the basis of the Skierniewice long term vegetable trial - specified vegetables that respond positively to organic amendments. Among them were leek, onion, celeriac, beans, carrot, parsley, and chicory. Other crops (tomato, potato, sweet pepper) did equally well on mineral N, P, and K fertilizers. Beresniewicz and Nowosielski (1973) reported that yields at elevated N, P and K levels were enhanced by organic amendments (peat and brown coal), but at low nutrient supply they were not. More recently, Evanylo et al. (2008) documented improvements of physical properties due to organic inputs, but found no yield effects in bell pepper, pumpkin and sweet corn, other than through enhanced N supply. Nutrient runoff losses decreased fourfold, but leaching losses increased. Mallory and Porter (2007) reported yield responses up to +55% in potato due to organic soil amendments, and stressed the enhancement of yield stability by reducing the impact of adverse growth conditions. Chan et al. (2007) found strong interactions of organic inputs (biochar) with N fertilizer, with radish yield responses to N fertilizer tripling in presence of biochar (pot experiments). Moccia et al. (2006) found no yield effects (lettuce, cherry tomato) of organic amendments over mineral fertilizers in a 7-year field experiment, but Bulluck et al. (2002) reported positive effects for tomato. Even more complex and seemingly inconsistent are studies on disease incidence in vegetables, as affected by combined effects of soil amendments, soil quality parameters and nutrients (e.g., Rotenberg et al., 2005).

Recent decades saw an increased concern for nutrient losses to the wider environment, which inspired a more technological research agenda emphasizing nutrient use efficiency, notably N use efficieny. Technological developments brought better water control, gradual-release of nutrients, fertigation, monitoring of crop nutrient status, and methods for precise application of fertilizers (in time and space). Booij and Meurs (2002); and Van Geel et al. (2006) demonstrated that indeed N demand in vegetables on sandy soils can be drastically reduced, along this line. Does this imply a lesser role for soil fertility management?

Now that inputs of manures, composts and fertilizers are being reduced in response to tightening legislation, renewed attention for soil quality seems timely. Organic inputs today are well below those common during past decades in open field horticulture. Vegetable growers on sandy soils are concerned that this will reduce soil fertility, and so will jeopardize quality production and profits. While no general decline in soil fertility has been documented, it is recognized that past management by vegetable growers has resulted in often high levels of fertility indicators (soil organic matter content, N mineralization and phosphorus availability). It is questionable indeed whether such levels can be maintained under current restrictions, especially in vegetable production where inputs of crop residues are often small (Haynes and Tregurtha, 1999).

What kind of soil management can help reduce emissions while sustaining yields: spoon-feeding the crop on a lean soil, or maintaining fertility indicators above some threshold level? What soil attributes are essential, and what are best strategies to enhance them? To address these issues, we first need to investigate the relevance of various soil properties to yield formation and to the utilization of fertilizer N. This is what we aimed to do in the present study. For lack of long term experiments relating to Dutch vegetable farming, we resorted to a comparative multi-location approach, involving contrasting soil conditions as well as small N response trials at each site.

MATERIALS AND METHODS

We selected seven (2004) and seven (2005) fields all situated on Plaggic Anthrosols on commercial leek farms in the southern sand district of the Netherlands, aiming to cover a range in soil fertility within these sandy soils. To enhance contrasts in soil fertility, fields in some locations were split in two subfields. While the root zone remained unchanged in one subfield (A), topsoil was removed in the other subfield (B), with the aim to decrease soil fertility in the root zone. Subfields were treated as two separate locations. Locations in 2004 were at villages of Prinsenbeek, Oud Gastel (subfields A, B), Grubbenvorst (A, B), Sevenum, and Boekel. Locations in 2005 were at villages of Grubbenvorst, Mariahoop, Bladel (two locations undisturbed), America (two locations undisturbed), and Boekel.

Fields were sampled at 0.00-0.20 m, 0.20-0.40 m and 0.40-0.80 m depth intervals. Soil was analyzed for inorganic N at planting (N_{min}, nitrate plus ammonium), total N (N_{tot}), soluble organic N (N_{so}; by $CaCl_2$ extraction), total C (C_{tot}), soil organic matter (*SOM*), pH_{KCl}, P_{w}, K-content, penetrometer resistance, bulk density, texture, and gravimetric water content at field capacity (W_{fc}). Soil texture was determined and is expressed here by the fine sand fraction (50-210 um; F_{sfine},), and the median (M_{50}) of particle size distribution in the sand fraction (50-2000 µm). Crop N uptake from soil in non-fertilized plots (U_0) was measured and used as indicator for soil N supply.

In each field, N was applied as calcium ammonium nitrate, at three rates: 0, 90 and 360 kg N ha^{-1}, denoted as N_0, N_{90} and N_{360}, respectively. Treatments were replicated twice. Of the total N dose, 33% was given at planting, 33% six weeks after planting, and 33% twelve weeks after planting. N rates were not chosen to construct response curves, but rather to create sub- and supra-optimal N availability, enabling to study uptake efficiency and the fate of surplus N.

Leek (*Allium porrum* L. 'Kenton') was planted in all fields between June 19 and July 28 (2004) and between July 10 and July 29 (2005). Crops were grown overwinter and were harvested between January 12 and April 6 (2005) and between March 7 and April 5 (2006). At harvest we measured gross and net (i.e., marketable) aboveground fresh biomass; gross and net aboveground dry matter; and N concentration in gross aboveground dry matter.

We pooled data from both years and analyzed them by linear regression, to identify the effects of soil properties and N rate on biomass yield and N yield. GenStat's RSEARCH procedure with 'all possible subset selection' was used to identify the best parameter combinations by evaluating the percentage of variance accounted for (R^2_{adj}), and the value of *Mallows'* C_{p}. We selected models with the highest R^2_{adj}, low *Mallows'* C_{p} and significant parameters. To avoid unstable models, only models with sufficiently uncorrelated regressors were accepted. Parameter estimates (effects) by the regression were then normalized so as to enable ranking of soil properties by their impact on yield variables; and to compare their effects versus those of fertilizer N. Normalization consisted of multiplying regression coefficients with the corresponding regressor ranges to obtain absolute effects; these were then divided by the mean (all treatments, both years pooled) of the corresponding response variable, to arrive at the 'normalized effect'. Regressor ranges were defined as the difference between 25% and 75% percentiles of each regressor (soil property), from the distribution in the pooled (two years) dataset.

Apparent N recovery (*ANR*) was calculated as the difference in N yield between fertilized and zero N treatments, divided by applied N rate. Separate regression analysis was conducted to assess effects of soil properties on *ANR*.

RESULTS

Mean values of soil properties are listed in Table 1, means of crop variables in Table 2. There was a marked difference between the two years in the level of most response variables. *Year* was therefore included as regressor in all models. N rate was significant for all response variables, and was included in all models. Because N rates were far apart and represent only three levels, we used N rate variables (N_{90}, N_{360}) as discrete regressors (relative to N_0 where no N was applied). The basic model evaluated for all response variables (Y) was:

$$Y = a + b\ Year + c\ N_{90} + d\ N_{360} \qquad \text{Eq. 1}$$

with *a, b, c, d* as regression coefficients. We found that soil variables U_0, N_{so}, *SOM*, N_{tot}, and W_{fc} were all important when added to Eq. 1, but they were highly correlated, with correlation coefficients between 0.71 and 0.91. Therefore, we adopted these variables alternately, which resulted in models of the form:

$$Y = a + b\ Year + c\ N_{90} + d\ N_{360} + e_i X_i \qquad \text{Eq. 2}$$

with X_i representing U_0, N_{so}, *SOM*, N_{tot}, or W_{fc}, respectively, and e_i the corresponding regression coefficient. Depending on the response variable *Y,* further regressor variables X_j were added to Eq. 2 if their impact was both significant and substantial. These (uncorrelated) additional variables were adopted in different combinations:

$$Y = a + b\ Year + c\ N_{90} + d\ N_{360} + e_i X_i + \sum p_j X_j \qquad \text{Eq. 3}$$

with regression coefficients p_j and with X_j referring to *pH*, N_{min}, F_{sfine}, $R_{C/N}$, or M_{50}. All soil properties in Eqs. 2 and 3 refer to depth 0.00-0.40 m.

The 25%-to-75% ranges of significant properties (as used to construct Table 3, see Methods section) were 55.5 (U_0), 1.5 (N_{so}), 1.60 (*SOM*), 520 (N_{tot}), 0.04 (W_{fc}), 1.1 (*pH*), 9.7 (F_{sfine}), 43.5 (N_{min}), 3.15 10^{-4} ($R_{C/N}$), 36.5 (M_{50}), all with units as in Table 1.

Results obtained with the best models are given in Table 3. Only significant effects are shown (see table header), and they are presented as normalized effects (see Methods). (The table includes means of the response variables, to enable reconversion back to absolute effects.). *Year* and N rate alone (Eq. 1) explained between 20% and 46% of the variance in the respective response variables. Normalized effects of N rate N_{90} on biomass variables (gross, net; fresh, dry) were close to +0.10, and on N yield variables (gross, net) about +0.20. N effects at N_{360} were in the range of +0.10 to +0.20 for the biomass variables, and above +0.30 for the N yield variables. N_{360} had significantly larger effect than N_{90} on gross fresh yield, shoot N content, and N yields (gross, net). For the other response variables, effects were not different between the two levels. The above holds for the pooled data. Separate analysis by year showed that effects of N rate were more pronounced in the first season; and were not significant for the biomass variables (gross, net; fresh, dry) in the second season.

Adding one of the soil properties from group X_i to Eq. 1 gave a drastic improvement in terms of R^2_{adj} (Eq. 2, Table 3). Overall, the normalized effects of properties X_i generally ranged between +0.10 and +0.25. Of regressors in group X_j (Eq. 3), the texture variables F_{sfine} and M_{50} had the most pronounced effects, often +0.10 to +0.20 and sometimes exceeding +0.20 (Table 3).

Apparent N recovery (*ANR*) was 0.35 at N rate of 90 kg ha^{-1}, and 0.17 at 360 kg ha^{-1} (averages across locations and both years). *ANR* was affected by *Year*, N rate, N_{so} and W_{fc}. Since the latter two soil properties were correlated, we inspected their effects carefully and concluded that these were complementary: the linear $ANR(N_{so})$ relation is ‘lifted up’ with increasing W_{fc}. The model for *ANR* is then written as:

$$ANR = a + b\ Year + c\ N_{360} + d\ N_{so} + e\ W_{fc} \qquad \text{Eq. 4}$$

Eq. 4 explained only 35% of the variance in *ANR*, but all effects were significant (p<0.01) with coefficients a = 0.655, b = -0.230 (second relative to first year), c = -0.177 (effect of N_{360} relative to N_{90}), d = -0.095, and e = +2.17. This implies that *ANR* decreased by 0.075 units when N_{so} increased by 1.5 mg kg^{-1} (its 25%-to-75% percentile range). Likewise, *ANR* increased by 0.087 when water holding capacity W_{fc} increased by 0.04 units.

DISCUSSION

Apparent Nitrogen Recovery

The dependence of *ANR* on N rate is common to all crops, and the substantial drop between N rates of 90 and 360 kg ha^{-1} was obviously the result of excessive N supply. Yet, *ANR* was low also at 90 kg ha^{-1} as is typical of many vegetable crops. Values in the second year were considerably lower, which corresponded to the lower yields. We found no clear effects of soil properties on *ANR*, besides N_{so} and W_{fc}. This was contrary to our expectation that soil conditions favoring growth would enhance N uptake efficiency at modest N availability (e.g., Wopereis et al., 2006; Zingore et al., 2007). Perhaps N availability was not all that modest, at the U_0 levels present (Table 1). As shown above, higher N_{so} reduced *ANR*. Across its 25-to-75 percentile range, N_{so} reduced fertilizer recovery by 0.15 units. At N rate of 90 kg ha^{-1}, this implies a decrease of 13.5 kg N ha^{-1} in fertilizer-N uptake. The same shift in N_{so} enhanced N uptake from soil by 40 kg ha^{-1}, based on the normalized effect of N_{so} on gross N yield (0.24, Table 3).

Effects of Soil Properties X_i versus N rate on Yield Variables

U_0 was highly significant ($p<0.001$) in models based on Eq. 2 as well as models based on Eq. 3, and for all response variables. Models with U_0 performed better (R^2_{adj}, Table 3) than models with N_{so}, *SOM*, N_{tot}, or W_{fc}, if no additional soil variables were included (Eq. 2). It is likely that U_0 not only indicates a soil characteristic (soil N supply) but also expresses other growth conditions, while N_{so}, *SOM*, N_{tot} and W_{fc} are properties of the soil strictly. This may explain the better performance of U_0 as regressor. This contrast largely disappeared when additional properties (group X_j in Eq. 3) were included (Table 3). Such additional properties did not generally reduce significance nor impact of the correlated soil properties in the X_i group (U_0 inclusive). Effects of X_i and X_j variables were additive (All effects listed in Table 3 were significant).

Regression, obviously, does not expose straightaway the biophysical relations causing observed crop responses. As the X_i variables are all correlated, it may well be that a single associated factor caused the effects observed. Might this be N availability, so might X_i effects essentially be nitrogen effects? We will investigate these questions now. According to the presented models (Table 3), an increment in *SOM*, for example, from its 25%-to-75% percentile is associated with increases in biomass yield and N yield. The quotient of these two increments is the extra biomass yield per kg of extra N uptake, denoted for brevity as $NUE_{\text{int}}^{\text{incr}}$ (internal incremental N use efficiency). This parameter can, obviously, be expressed in fresh or dry, and gross or net biomass (We avoid the term 'physiological N use efficiency' as it usually reserved for dry biomass production, and for total instead of incremental amounts of biomass and N yield). In this example of *SOM*, $NUE_{\text{int}}^{\text{incr}}$ is obtained from Table 3 as 0.24*5500 (dry matter yield increment associated with *SOM* increment) divided by 0.33*160.5 (N yield increment associated with *SOM* increment). This equals 25 kg gross dry matter yield per kg extra N uptake. Likewise, one can calculate $NUE_{\text{int}}^{\text{incr}}$ for fertilizer N uptake, by using the effects of N_{90} (Table 3, eighth column) instead of *SOM*. This gives the markedly smaller value of 16 kg gross dry matter yield per kg extra N uptake, at rate of 90 kg N ha^{-1}. So, $NUE_{\text{int}}^{\text{incr}}$ for N uptake associated with increased *SOM* is larger than for N uptake from fertilizer, by a factor 25/16 = 1.56 ('efficiency ratio' on dry matter basis). For the various properties X_i it can be inferred from Table 3 that this factor is between 1.00 and 1.32 (gross fresh biomass), or between 1.50 and 1.74 (gross dry biomass). Now there is a pitfall in comparing efficiency values, namely that they do depend on the absolute level of N availability, too. This is reflected in the non-linear response - common to all crops - of biomass yield to N uptake, with yield increments levelling off at higher N uptake. The effects of N_{90} listed in Table 3 obviously refer to responses found at N rate of 90 kg ha^{-1} (relative to the unfertilized treatment N_0). Effects of X_i, on the other hand, were based on the whole dataset including N_0, N_{90} and N_{360} plots. To assure that we compare $NUE_{\text{int}}^{\text{incr}}$ values at similar N availability, we must restrict the analysis of X_i effects and associated $NUE_{\text{int}}^{\text{incr}}$ to only data from N_{90} plots. This resulted in similar efficiency ratios (different for different X_i): 1.17 to 1.57 (gross fresh biomass) and 1.49 to 1.77 (gross dry biomass). For net yields, we found ratios of 1.17 to 1.66 (fresh) and 1.40 to 2.00 (dry biomass). To conclude, these ratios larger than unity show that additional N uptake associated with increased X_i values promotes leek yields more than additional uptake due to fertilizer application. Effects of X_i properties are not just N effects. They may be caused by other nutrients, water availability, mechanical properties affecting root growth, or other factors.

Soil Texture

Effects of soil texture parameters F_{sfine} and M_{50} were significant, large and both positive (Table 3), but their interpretation presents some difficulties. These parameters were not correlated with other soil properties, but between them a pronounced negative correlation existed (R = -0.79). Negative correlation is obvious: more fine sand will decrease the median of particle size distribution in the sand fraction, clay and silt being virtually absent. Then why are effects not opposed? We inspected carefully the distribution of both parameters in the two years and in the pooled data, and confirmed that their effects were not essentially masked year-effects. We also confirmed that effects of F_{sfine} and M_{50} were additive, and that both parameters may be combined in regression despite their correlation. Across their 25%-to-75% ranges, these parameters increased net fresh biomass yield of leeks by about +25% (F_{sfine}) and +30% (M_{50}), variation depending on X_i. F_{sfine} affected fresh biomass (gross, net) and net dry biomass but not N yields, thus lowering shoot N content (cf. Table 3). So, it promoted growth but not N uptake. M_{50}, on the other hand, promoted growth as well as N uptake, thereby leaving shoot N content unaffected. We can only speculate that the fine sand fraction had a positive effect via water holding capacity or hydraulic properties of topsoil or subsoil; whereas the presence of coarser sand, as expressed in M_{50}, may have enhanced soil exploration by roots.

Economic Value of Soil Organic Matter

It is admittedly speculative to express soil properties in economic terms, as we lack full understanding of the multiple pathways by which they affect yield. Nevertheless, it is tempting because opportunities to do so are rare, and such expression is relevant to farmers. Based on an average product price of € 0.55 per kg fresh leeks (De Wolf and Van der Klooster, 2006), we can calculate the economic value of *SOM*, given its effect on net fresh yield (Table 3). Across its 1.6% range (25%-to-75% percentiles of distribution) *SOM* enhanced net output value by € 1663 per ha. This implies a value of € 1000 per ha per year, per %-point of soil organic matter content (ignoring effects on possible short duration crops preceding leek in the same year). This is much more than the (simulated) ‘yield benefit’ value of organic matter cited by Sparling et al. (2006) for New Zealand dairy systems, but far below the corresponding carbon credit values cited in the same study. On the other hand, the carbon value used by Hartridge and Pearce (2001) and Glendening et al. (2009) (GBP 30 per Mg) would correspond roughly to € 1000 per %-point of soil organic matter content, per ha. Its value per year, then, would obviously be much smaller, and well below our estimated agronomic value.

CONCLUSIONS

Our results must be viewed with some reserve because the data are subject to several constraints. First, they cover a limited number of locations, only two years, and one cultivar. Second, average yield differed between the two years, which forced us to adopt *Year* as a factor in the regression models. Third, regression analysis on multi-location data is unsuited to prove causal relationships between soil properties and crop yield. Finally, only three N rates were included, two of them far apart, and there were only two replicates per treatment. On the other hand, we believe that the unconventional setup may have exposed important effects that go unnoticed in more extensive single-location experiments. Subject to these reservations we conclude the following.

N uptake from unfertilized soil (U_0), and topsoil (0.00-0.40 m) properties soluble organic N (N_{so}), soil organic matter content (SOM), total nitrogen (N_{tot}) and water content at field capacity (W_{fc}) all had large and significant impact on biomass yield (gross, net; fresh, dry) and N yield (gross, net) in leek on sandy soils. These properties (collectively denoted as X_i) were highly correlated in our study. This complicates the search for causal relations. Across their 25-to-75 percentile ranges, these properties enhanced fresh biomass yield by amounts equal to or larger than the effect of 90 kg fertilizer N ha^{-1}. Effects of soil properties on dry matter yields were even larger than those obtained by 360 kg fertilizer N ha^{-1}. N yield, too, was substantially affected by properties X_i, but more so by 360 kg fertilizer N ha^{-1}. While properties X_i are generally believed to be related to soil N supply, we could not explain their full yield effects via enhancement of N uptake alone.

Apparent recovery of fertilizer N (ANR) was affected by year, N rate, and two soil properties. Of these, higher soluble organic N (N_{so}) reduced ANR, while higher water holding capacity (W_{fc}) elevated the $ANR(N_{so})$ relation to a higher level. The model explained only 35% of the variance in ANR.

Economy and environment are central to today's farming. How must soils be managed to strike the best compromise? More in particular, how should farmers split their allowed nutrient quota into manures, composts and mineral fertilizers; what qualities of organic inputs are needed; and how do answers depend on crop and soil properties? To return now to this paper's title, our study looked at only one aspect of the puzzle. We quantified effects of soil properties on yield, both in absolute terms and relative to fertilizer N. All properties investigated, except soil texture, can be deliberately forced by input management into a desired direction - at least to some extent and in the long term. When and where is this wise, and how to do it? Answering these questions requires a broader analysis. Firstly, what are the mechanisms behind positive effects of soil properties - such as organic matter content - on yield, could these be mimicked by other means, and at what cost? Buffering of water and nutrients, for example, can be regulated in absence of organic matter with the help of technology (e.g., fertigation). But how do costs and emissions of technological alternatives relate to costs and emissions associated with soil fertility based systems? Secondly, if the optimization of particular soil properties is essential for maximum profits within constraints defined by emission targets, what are the optimum values, and how can they best be achieved (rate and quality of inputs)? Thirdly, as for organic versus inorganic N inputs, environmental impact will critically depend on: (i) the fraction of annual N mineralization captured by crops, and its value relative to fertilizer-N recovery; (ii) effects of 'manure-amendable' soil properties on in-season fertilizer-N recovery, and on conservation (beyond season) of non-recovered N; (iii) effects of fertilizer application on mineralization of N and its capture by crops (priming); (iv) effects of soil properties on yield potential, apart from nitrogen; (v) 'leachability' of N from fertilizers versus N mineralized from organic sources (in view of possible contrasts in denitrification). A systems approach addressing all these issues is required before we can resolve the dilemma expressed in our title.

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Tables

Table 1. Mean values of selected soil characteristics, averages across all fields per year. Acronyms see text. Farmers' fields on plaggic Anthrosols, Southern sand district, Netherlands.

Soil property	Unit	2004-2005	2005-2006
U_0	kg N ha^{-1}	139.6	119.9
N_{so} (0.00-0.40 m)	mg kg^{-1}	6.6	4.6
N_{min} (0.00-0.40 m)	kg N ha^{-1}	155.6	118.5
N_{tot} (0.00-0.40 m)	mg kg^{-1}	1225.0	936.0
N_{tot} (0.40-0.80 m)	mg kg^{-1}	616.6	479.0
C_{tot} (0.00-0.40 m)	%	1.9	1.6
C_{tot} (0.40-0.80 m)	%	1.1	0.9
SOM (0.00-0.40 m)	%	3.7	3.1
SOM (0.40-0.80 m)	%	2.3	1.9
pH (0.00-0.40 m)		5.8	5.8
pH (0.40-0.80 m)		5.8	5.5
clay (0.00-0.40 m)	%	7.1	3.5
F_{sfine} (0.00-0.40 m)	%	77.0	74.4
M_{50} (0.00-0.40 m)	µm	139.2	164.7

Table 2. Yield characteristics of Leek (*Allium porrum* 'Kenton'), averages across all fields per year and per N rate. Data for Leek on sandy soils in the Netherlands, 2004-2005 and 2005-2006. Net yield refers to marketable product; d.m. to dry matter.

Year (planting-harvest)	2004-2005			2005-2006		
	N rate (kg N/ha)			N rate (kg N/ha)		
	0.0	90.0	360.0	0.0	90.0	360.0
gross fresh yield (Mg ha^{-1})	51.7	59.5	68.2	38.8	42.3	41.0
net fresh yield (Mg ha^{-1})	27.8	32.6	33.3	22.7	24.8	24.0
gross d.m. yield (Mg ha^{-1})	5.9	6.7	7.3	4.2	4.4	4.4
net d.m. yield (Mg ha^{-1})	3.2	3.6	3.5	2.5	2.5	2.6
shoot N-content (g kg^{-1})	22.6	25.4	29.9	27.8	33.2	36.8
gross N yield (kg N ha^{-1})	139.6	174.9	218.9	119.9	146.9	162.5
net N yield (kg N ha^{-1})	73.3	93.8	104.4	70.1	85.5	95.0

Table 3. Values of R^2_{adj} and normalized effects of Year, N rate and soil properties on crop response variables as obtained by linear regression. Absolute effects of soil properties were first calculated by multiplication of parameter estimates with the regressor's 25%-to-75% percentile range, and then scaled relative to the response variable's mean across all treatments (given in first column). See text for regressor ranges. Effects are listed if significant ($p<0.05$). (Values in brackets for $0.05<p<0.10$). Data for Leek on sandy soils in the Netherlands, winters 2004-2005 and 2005-2006.

Response variable	R^2_{adj} (%) Eq. 1	X_i (Eqs.2,3)	R^2_{adj} (%) Eq. 2	R^2_{adj} (%) Eq. 3	Effect (based on Eq.3)								
									X_j				
					X_i	$Year$	N_{90}	N_{360}	pH	F_{sfine}	N_{min}	$R_{\mathrm{C/N}}$	M_{50}
Gross fresh yield (kg ha^{-1}) (Mean 50300)	46.2	U_0	73.3	75.7	0.18	-0.33	0.11	0.19		0.10			
		N_{so}	61.9	66.4	0.16	-0.18	0.11	0.19		0.13			
		SOM	63.5	73.4	0.20	-0.36	0.11	0.19		0.14	0.05		0.19
		N_{tot}	57.1	74.7	0.23	-0.32	0.11	0.19		0.27	0.06		0.27
		W_{fc}	63.5	75.2	0.16	-0.29	0.11	0.19		0.16	0.06		0.15
Net fresh yield (kg ha^{-1}) (Mean 27500)	30.3	U_0	45.1	71.0	0.11	-0.33	0.12	0.12	-0.10	0.23	0.04		0.26
		N_{so}	43.3	70.4	0.12	-0.21	0.12	0.12	-0.07	0.26	0.04		0.28
		SOM	33.3	68.0	0.11	-0.35	0.12	0.12	(-0.06)	0.24	0.06		0.33
		N_{tot}	29.5	64.1	0.10	-0.32	0.12	0.12	-0.07	0.27	0.07		0.33
		W_{fc}	31.8	66.3	0.08	-0.31	0.12	0.12	-0.09	0.24	0.07		0.29
Gross dry matter yield (kg ha^{-1}) (Mean 5500)	42.6	U_0	77.3	76.9	0.22	-0.32	0.09	0.15					
		N_{so}	61.7	63.0	0.17	-0.16	(0.09)	0.15	(0.07)				
		SOM	68	75.2	0.24	-0.35	0.09	0.15	0.11		0.05		0.10
		N_{tot}	68.1	76.8	0.23	-0.24	0.09	0.15	0.10		0.08		
		W_{fc}	74.2	79.8	0.19	-0.25	0.09	0.15	(0.05)		0.07		

Table 3. continued.

Response variable	R^2_{adj} (%) Eq. 1	X_i (Eqs.2,3)	R^2_{adj} (%) Eq. 2	R^2_{adj} (%) Eq. 3	effect (based on Eq.3)								
									X_j				
					X_i	*Year*	N_{90}	N_{360}	*pH*	F_{sfine}	N_{min}	$R_{C/N}$	M_{50}
Net dry matter yield (kg ha^{-1}) (Mean 3000)	35.6	U_0	62.6	71.8	0.13	-0.31	0.10	0.08		0.10	0.04		0.16
		N_{so}	57	68.3	0.13	-0.19	0.10	0.08		0.13	0.04		0.18
		SOM	45.1	69.1	0.14	-0.33	0.10	0.08		0.12	0.06		0.24
		N_{tot}	40.5	67.2	0.14	-0.30	0.10	0.08		0.20	0.07		0.28
		W_{fc}	46.4	68.6	0.10	-0.29	0.10	0.08		0.13	0.07		0.21
Shoot N content (g kg^{-1}) (Mean 28.8)	49.3	U_0	70.3	73.7	0.08	0.19	0.14	0.28		-0.08		0.06	
		N_{so}	62.1	70.0	0.05	0.21	0.14	0.28		-0.10		0.09	
		SOM	62.8	71.4	0.07	0.17	0.14	0.28		-0.12		0.08	
		N_{tot}	59.1	70.2	0.05	0.16	0.14	0.28		-0.12		0.09	
		W_{fc}	61.4	70.9	0.05	0.17	0.14	0.28		-0.11		0.09	
Gross N yield (kg N ha^{-1}) (Mean 160.5)	25.5	U_0	80.5	81.4	0.31	-0.11	0.19	0.38			-0.04		
		N_{so}	56.8	60.4	0.24	0.04	0.19	0.38	0.09			(0.05)	
		SOM	65.9	76.9	0.33	-0.19	0.19	0.38	0.17				0.17
		N_{tot}	61.8	77.3	0.30	-0.16	0.19	0.38	0.11		0.06	0.10	0.15
		W_{fc}	69.8	76.7	0.23	-0.13	0.19	0.38			0.05	0.07	0.09
Net N yield (kg N ha^{-1}) (Mean 87.0)	20.4	U_0	73	77.9	0.19	-0.13	0.21	0.32				0.05	0.13
		N_{so}	58.6	69.3	0.16	-0.02	0.21	0.32				0.09	0.15
		SOM	46.8	72.5	0.18	-0.20	0.21	0.32			0.04	0.08	0.24
		N_{tot}	36.6	68.6	0.16	-0.18	0.21	0.32			0.06	0.12	0.23
		W_{fc}	46.3	70.3	0.13	-0.16	0.21	0.32			0.06	0.10	0.20