Residual N effects from livestock manure inputs to soils

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Abstract
Organic inputs including livestock manures provide nitrogen (N) to crops beyond the year of their application. This so-called residual N effect should be taken into account when making decisions on N rates for individual fields, but also when interpreting N response trials in preparation of recommendations. This paper addresses general principles of residual N effects, gives literature-based estimates of them, and reviews to which extent residual N effects are included in recommendations and regulations in selected countries.

Introduction
The amount of nitrogen (N) available to a crop is determined, inter alia, by N inputs in preceding years, including manure-N. This ‘heritage’ of organically bound N (Norg) carried over from one season to a next, originates from earlier inputs that did not yet mineralize or that were temporarily immobilized. Consequently, the N fertilizer replacement value (NFRV, calculated as $ANR_{manure}/ANR_{mineral\ fertilizer}$, where ANR stands for Apparent Nitrogen Recovery) of manures increases due to previous manure applications until a steady state is reached when the cumulative amount of Norg that is mineralized equals the annual input of Norg. Note: post-harvest soil mineral N (Nmin) residues that carry over to the next season, wherever Nmin is not leached by excess rain, is excluded in the present definition of residual N effects. Farmers find it difficult to credit the residual N as it is not always apparent while mineral fertilizer N can still be applied based on post-emergence testing methods. Lack of sufficiently accurate analytical indicators of mineralizable N, combined with the unpredictability of weather both in terms of N mineralization and crop response to N, further undermine a proper account of residual N. Instead of analytical indicators (e.g. soil or crop sampling), administrative records (e.g. number of years x manure rates x composition x availability factor) may serve as a proxy of mineralizable N. This paper explains the general principles and implications of residual N effects and reviews to what extent these effects are included in recommendations and regulations.

Review of experimental results
There is ample evidence that the manuring history of a field has a significant impact on the mineral fertilizer N requirement of crops, via residual N effects. Unfortunately, residual N effects of manures are not reported in a uniform way. They can be expressed in terms of (A) the observed additional mineralization during one of the years after the year of application, (B) the observed additional mineralization in subsequent years but restricted to the period during which a crop is responsive to N (approximating the residual NFRV), or (C) the observed additional N recovery in the harvested crop parts, with A > or = B > C. Moreover, residual N effects can be related to the previously applied amounts of total N (Ntot) or organic N (Norg), with $effect_{Norg} > effect_{Ntot}$. Residual N effects in terms of A (and B if the temporal patterns of mineralization and crop N uptake coincide) and related to organic N inputs equate to what some researchers call ‘decay series’. The literature generally shows that the annual rate of decomposition decreases with time, reflecting the diminishing amounts and

degradability of the remaining material (Table 1). Ultimately, the decomposition rate of manure will approximate the decomposition rate of the relatively recalcitrant soil organic matter. Calculation ‘A’ is affected by temperature, soil moisture, characteristics of Norg (e.g. C/N ratio in function with animal diets, use of bedding material or composting), tillage and clay content of soils; calculation ‘B’ is also affected by the duration of the crop’s N uptake period and the proportion of mineralized N leached; and calculation ‘C’ is also affected by N-uptake ability of the crop, harvest index, and the analytical methods used for determining the N recovery. Note that the mineralization of Norg commences in the year of application and generally amounts to 20-30% of Norg then. In areas with significant excess of winter precipitation a significant part of the mineralized N can be lost by leaching and denitrification (resulting in ‘B’ being less than ‘A’) or winter-mineralized N may be lost after spring thaw. The effect of repeated manure applications on the release of residual N is illustrated in Figure 1.

Table 1. Residual N effect of manure (kg N released per 100 kg organic N applied) in the years following the year of application, where needed converted to ‘decay series’, i.e. expressed as the N release over the entire year (‘type A’, consult text)

Reference	Type of manure	NH_4-N/ total N	Test crop	Year: 2nd	3rd	4th
[1]	Cattle FYM, slurry	0.17-0.51	Maize	9	3	3
[2]	Pig slurry	0.69	Ryegrass	16	6	-
[3]	Cattle slurry	0.60	Barley	13-18	13	-
[4]	Pig slurry	0.76	Barley	13	-	-
[5]	Cattle slurry	0.53	Maize	19-22	14-15	10-11
[6]	Cattle FYM, slurry	0.12-0.51	Grassland	9	8	7
[7]	Cattle slurry	0.57	Grassland	6	-	-
[8]	Cattle FYM	0.31	Maize	13-17	4-7	-
[9]	FYM, compost	-	-	8-15	5-8	3-5
Mean				*13*	*8*	*6*

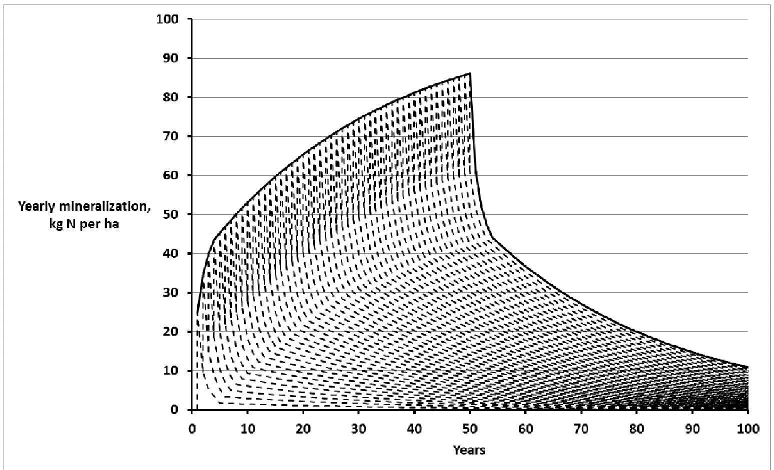

Figure 1. Cumulative contributions of the residual N effects from 50 annual applications of 100 kg organic N per ha and decomposition rates gradually decreasing from 25% in the 1st year (e.g. [5]), to 13% to 8% to 6% in the 2nd, 3rd and 4th year (Table 1), respectively, and to 3% thereafter, followed by 50 years withheld organic N inputs.

Implications

Bearing in mind that phosphorus (P) is becoming increasingly important for permitted manure rates in environmentally sensitive regions, we have also estimated the residual N effect in relation to applied P. Pig manure is generally rich in P and poor in Norg and, hence, residual N effects per kg P applied are relatively small compared to cattle manures. Even in the case of pig manures, however, notable residual N effects occur after repeated applications. Note that residual N effects per kg P applied can be quite similar for solid manures and slurries (Table 2).

Table 2. Residual N effect of manure (kg N per 40 kg P applied), adopting manure compositions as reported by [10] and average decomposition rates as shown in Table 1.

	Composition, kg per tonne fresh:				Residual N release, kg N per 40 kg P			
	Total N	Norg	P	Norg/P	2nd year	3rd year	4th year	Cumulative*
Cattle, solid	5.3	4.4	1.2	3.7	19	12	9	103-117
Cattle, slurry	4.1	2.1	0.7	3.0	16	10	7	84-96
Pig, solid	7.9	5.3	3.5	1.5	8	5	4	42-48
Pig, slurry	7.1	2.5	2.0	1.3	7	4	3	35-40

*N release over many decades assuming that only 20-30% of Norg mineralizes in the year of application and the remainder (70-80%) in the following decades as long term soil total N accumulation is generally small

Farmers rightly point at the reverse side of this coin: when mineral fertilizer N recommendations are based on response trials executed on fields that were amply manured in the recent past, the true N demand of crops (i.e. in an equilibrium situation without recent manure inputs) may be underestimated. And so are the yield penalties resulting from withheld N, as test crops can benefit from former Norg inputs for many years (Figure 1). This aspect of residual N effects also needs our attention.

Recommendations and regulations

We have investigated how recommendations and regulations take into account the residual effect in six countries (Denmark, France, the Netherlands, Portugal, Ireland and Sweden) and two regions (Lombardia in Italy, and Ontario in Canada). We have recorded both recommended (commonly advised by consultants) and legally prescribed NFRVs.

Recommended NFRVs. In three cases (Ireland for cattle slurry; UK for all manures; and Portugal for FYM and cattle slurry) the NFRVs reflect the amount of N that is available for crop uptake if the manure is used for the very first time (first year effect only; no direct consideration of residual effects, these are accounted for in background soil nitrogen supply assessments). In two cases (Ireland for pig slurry, FYM, poultry manure and mushroom compost; Ontario) the residual effect is taken into account by estimating the amount of N that is available for crop uptake if the manure was used for many years in a row (combination of first year and residual effect). In five cases (Lombardia for FYM only; Sweden; the Netherlands; Denmark; France) the residual effects are estimated separately from the first year effect.

For grasslands in the Netherlands, *in situ* measurements of organic N content in the upper soil layer are used to estimate the residual effect. In the other countries/regions, the residual effect is estimated either using table values (Lombardia; Ireland; arable crops in the Netherlands) or using classes of soil organic matter level based on previous manure application and presence of grass crops (Denmark), on the total amount of N added during the past 30 years or animal-density related numbers (Sweden), on the amount of organic N applied during the previous years (Ontario), or using a multiplication factor that modifies the rate of mineralisation of the humified soil organic matter, considering two types of manure (pig, cattle manures and composts *vs* the other animal manures), and the frequency of manure application (France).

Prescribed NFRVs. In the case of UK, no direct consideration of residual effect is made in legally prescribed NFRVs, which provide only first year effects based on the type of livestock manure. In Ireland, Denmark and the Netherlands, prescribed NFRVs (Table 3) combine first year and residual effects, based on manure type and period of application, crop, and soil type (only in the Netherlands). In the Netherlands residual N effects of manure were also implicitly accounted for in the permitted N rates according to EU Nitrates Directive Action Programs. In Sweden and Lombardia, the prescribed NFRVs are equal to recommended NFRVs (i.e. 30% of N applied with FYM during the previous year in Lombardia; animal-density related or 0.7 % per year of the total amount of N added during the past 30 years in Sweden). No *in situ* soil analyses are legally prescribed to determine the NFRV in the countries and regions surveyed.

Conclusions

Despite the complexity there are environmental and economic pressures on farmers to apply as little N as possible to their crops. As reliable soil and crop tests for predicting the effects of historical manure applications are lacking, we need to resort to records of the manuring history of fields.

The disadvantages of this method are that field spatial variability cannot be taken into account (as would be possible with soil or crop indicators), that the organic N content of manure must be assessed regularly, and that separate calculations are needed for each source of Norg. For now, recommended and prescribed NFRVs are difficult to compare among countries, due to the heterogeneous categorisation of manure types and of other factors affecting NFRVs (e.g. soil type, application date and method).

Table 3. Prescribed NFRVs (%) of livestock manures combining first year effects and residual effects, in three European countries.

Manure source	Manure type	Denmark	Ireland	The Netherlands
Pig	Slurry	75	50	60-70
Cattle	Slurry	70	40	45-60
Mink		70 (slurry)		55 (solid)
Poultry		70 (slurry)	50	55 (solid)
-	Urine	65		80
Cattle, pig, poultry, sheep	Solid manure	65 (solid)	30 (FYM)	30-60, depending on application date
Cattle, pig, poultry, sheep	Deep litter	45		
Pig	Solid manure			55
Other manure types		65	0-40, depending on C/N ratio	60 (slurry)
Other manure types			0-40, depending on C/N ratio	30-40 (solid)
Liquid fraction from slurry separation		85		80
Sewage sludge				40
Compost			20 (mushroom) 0-25, depending on C/N ratio (other types)	10

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