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ORIGINAL ARTICLE

Nitrogen fertiliser replacement values for organic amendments appear to increase with N application rates

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Abstract Nitrogen (N) supply from organic amendments [such as farmyard manure (FYM), slurries or crop residues] to crops is commonly expressed in the amendment's Nitrogen Fertiliser Replacement Value (*NFRV*). Values for *NFRV* can be determined by comparison of crop yield or N uptake in amended plots against mineral fertiliser-only plots. *NFRV* is then defined as the amount of mineral fertiliser N saved when using organic amendment-N (kg/kg), while attaining the same crop yield. Factors known to affect NFRV are crop type cultivated, soil type, manuring history and method or time of application. We investigated whether long-term *NFRV* depends on N application rates. Using data from eight long term experiments in Europe, values of *NFRV* at low total N supply were compared with values of *NFRV* at high total N supply. Our findings show that FYM has a significant higher *NFRV* value at high total N supply than at low total N supply (1.12 vs. 0.53, $p = 0.04$). For the other amendment types investigated, *NFRV* was also higher at high total N supply than at low total N supply, but sample sizes were too small or variations too large to detect significant differences. Farmers in Europe usually operate at high rates of total N applied. If fertiliser supplements are based on *NFRV* of the manure estimated at low total N supply, N fertiliser requirements might be overestimated. This might lead to overuse of N, lower N use efficiency and larger losses of N to the environment.

Keywords Nitrogen fertiliser replacement value · Mineral fertiliser equivalent · Organic amendments · Mineral fertiliser · Nitrogen · Soil fertility · Crop yield

Abbreviations

DM	Dry matter weight
FM	Fresh matter weight
FYM	Farmyard manure
K	Potassium
LS	Least squares
N	Nitrogen
NFRV	Nitrogen fertiliser replacement value
$NFRV_{high}$	Nitrogen fertiliser replacement value at high total N supply

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$NFRV_{low}$	Nitrogen fertiliser replacement value at low total N supply
$N_{saved\ high}$	Mineral fertiliser N saved from organic amendments at high total N supply
$N_{saved\ low}$	Mineral fertiliser N saved from organic amendments at low total N supply
N yield	N content crop yield
P	Phosphorus

Introduction

Efficient use of nitrogen (N) requires careful matching of N supply to crop demand. Often application of mineral fertilisers is combined with application of organic amendments such as farmyard manure (FYM), slurries, and crop residues (also called organic manures, organic fertilisers or organic inputs). N in organic amendments generally has a lower availability to crops than N in mineral fertilisers, mainly depending on the C:N ratio of the amendment (Flavel and Murphy 2006). Therefore, N in organic amendments must be carefully matched with mineral fertiliser N application to avoid leaching while making sure sufficient N is available for crop growth. This requires the characterization of the organic amendments by their Nitrogen Fertiliser Replacement Value (*NFRV*), also called the Mineral Fertiliser Equivalent (Jensen 2013).

NFRV can be based on the amount of mineral fertiliser N which is substituted by an amount of organic amendment-N (kg/kg) while attaining the same crop yield (Herron and Erhart 1965; Schröder 2005a; Schilling 1987). Crop yields can be expressed as fresh matter weights (FM), dry matter weights (DM) or N contents (N yields, Jensen 2013). These are all valid procedures, with the difference that values of *NFRV* based on N yields are often slightly lower than those based on DM or FM weights (Jensen 2013). N in organic amendments is always accompanied by other nutrients, such as phosphorus (P), potassium (K) or sulphur (S) which also affect crop yields. It is therefore important to exclude these effects when estimating values of *NFRV* based on yields (either DM, FM or N yields, Schröder 2005a).

Lory et al. (1995) have suggested to calculate *NFRV* using economic optimal N rates (mineral fertiliser N application rates at which marginal crop yields offset marginal fertiliser costs) with and without organic amendments. Yields at economic N rates with and without organic amendments might however differ, which hampers comparison at equal yield levels. In addition, economic N rates are dependent on prices of fertilisers and harvested products, which makes estimations less robust through time and space.

Another manner to determine *NFRV* of organic amendments is by using isotope dilution techniques. Using ^{15}N labelled materials, the fate of N from either organic amendments or mineral fertilisers is measured among plant and soil fractions and compared (Diekmann et al. 1993; Janzen et al. 1990). Additional methods to calculate *NFRV* (such as the analysis of near infrared reflectance spectra of organic amendments) have been proposed but need further development (Delin et al. 2012).

Values for *NFRV* differ when estimated in the first year of application of organic amendments (short-term *NFRV*) or after repeated applications and several years (long-term *NFRV*, Gutser et al. 2005; Schröder 2005b), with higher values found for long-term *NFRV*. For FYM, *NFRV* ranges between 0.10 and 0.70 (Birkmose 2009; Jensen 2013; Pikula et al. 2016; Webb et al. 2013). For slurry, *NFRV* ranges between 0.20 and 0.90 (Birkmose 2009; Delin et al. 2012; Jensen 2013; Kundler et al. 1989; Langmeier et al. 2002; Webb et al. 2013). For straw, *NFRV* has been estimated to be around zero (Dhillon and Dev (1984) as cited by Katyal 1993). For green manures, *NFRV* has been estimated ca. 0.4 (Janzen et al. 1990), but this will probably depend on the species of green manure cultivated.

Factors known to affect *NFRV* (at a given dose of the amendment) include the form of N in the amendment, crop type cultivated, soil type, method of application, time of application and the manuring history which may govern N retention and losses (Birkmose 2009; Jensen 2013; Katyal 1993; Kundler et al. 1989; Webb et al. 2013). Here we evaluate the effect of an additional factor on *NFRV* which is currently not taken into account: the total N supply. We address the following research question: Does *NFRV* of organic amendments depend on total N supply?

Materials and methods

To answer the research question, values for long-term *NFRV* were calculated based on yield response curves (either DM or FM weights of marketable products) at low and high total N supply. This required data from field trials where different N rates were applied with and without organic amendments. In such a set-up, mineral fertiliser N saved with an addition of organic amendment at low mineral fertiliser rates ($N_{saved\ low}$) can be compared with mineral fertiliser N saved by adding the same amount of organic amendment at high mineral fertiliser rates ($N_{saved\ high}$). In these cases, sufficient P and K has to be applied to ensure these macro-nutrients are not a yield limiting factor and affect the calculation of *NFRV* of organic amendments. Organic amendments however do not only supply N, P and K but also other nutrients, such as sulphur (S). Over the past decades, S was often not yield limiting due to the ample supply from the atmosphere (Eriksen 2009). More recently this has changed but not always adjusted for in field experiments.

In a recent meta-analysis of long term experiments in Europe (Hijbeek et al. 2017), a database was compiled with data from 20 long term experiments. All these 20 experiments fulfilled the following six criteria: (1) at least four increasing levels of mineral fertiliser N rates without organic amendments; (2) at least four increasing mineral fertiliser N rates with organic amendments; (3) P and K applied in ample amounts on all fields; (4) at least five years of yield data; (5) if crops are cultivated in rotation, yield data available for at least two rotation cycles; (6) yield data reported for individual crop types (no aggregated data of whole-rotation yield output were used). Assessing *NFRV* called for an additional requirement particular to this study: (7) N contents of organic amendments must be known.

Using these seven criteria, we assembled a total of 38 data sets (with multiple crops and organic amendment types) from eight experiments in five countries across Europe (Table 1). The experiments ranged in duration between 15 and 44 years. These data, therefore, can be used to consider long-term *NFRV*, including the greater part of the residual effect of manure application (Hernández et al. 2013; Jensen 2013; Schröder 2005b). The setup of these

Table 1 Details of eight experiments included in the meta-analysis

Experiment	Starting time	Crops	Years of crop yield used	Types of organic amendments	References
Bologna 1, Italy	1966	Maize, Winter wheat	1990–2001	FYM (1/1), Cattle slurry (1/1)), Straw (1/1)	(Giordani et al. 2010; Triberti et al. 2008)
Iasi, Romania	1984	Maize Sugar beet	1984–1992, 1996–2006	FYM (1/3), straw and beet leaves (2/3)	(Hideborn Alm and Dahlin 2007; Mogârzan et al. 2007; Vasilica et al. 1997)
Keszthely, Hungary	1984	Winter barley	1999–2010	FYM (1/3)	(Hoffmann et al. 1997; Kismányoky and Tóth 2012)
Lukavec, Czech Republic	1984	Potatoes, Winter barley	2002–2007	FYM (1/3)	(Káš et al. 2010; Vrkoc et al. 1996; Vrkoč et al. 2002)
Methau, Germany	1966	Potatoes Sugar beet Spring barley Winter wheat	1999–2010	Straw (1/2)	(Albert and Grunert 2013; Körschens et al. 2014)
Muencheberg, Germany	1963	Sugar beets Spring barley Potatoes Maize Winter rye Winter wheat	1978–2004	FYM (1/1), Straw (1/2)	(Barkusky 2009)
Speyer, Germany	1984	Sugar beet Winter barley Winter wheat	1994–1999	FYM (1/3), straw and green manure & beet leaves (3/3)	(Bischoff 1995)
Sproda, Gemany	1966	Spring barley Sugar beet Winter wheat	1999–2010	FYM (1/2), Straw (1/2)	(Albert and Grunert 2013; Körschens et al. 2014)

For Muencheberg additional data was provided by Dietmar Barkusky (ZALF). For Bologna additional data was provided by Guido Baldoni (University of Bologna). *FYM* farmyard manure. Numbers in brackets indicate timing of application (number of applications/years) experiments implies that mineral fertiliser N rates are always confounded with total N supply. We therefore use the term ‘total N supply’.

For each data set, two yield response curves to mineral fertiliser-N were fitted, one without (Y^0) and one with organic amendments (Y^A), following George (1984), see Fig. 1.

$$Y = a + b * 0.99^N + c * N + \varepsilon \quad (1)$$

In Eq. 1, *Y* is crop yield (t/ha) expressed in either fresh or dry matter weight of the marketable product, *N* is the mineral fertiliser N rate (kg N/ha), *a*, *b* and *c* are parameters to be fitted and **ε** is the error term.

For each pair of curves, the amount of mineral fertiliser saved by using an organic amendment was calculated at low and high total N supply ($N_{\text{saved low}}$ and $N_{\text{saved high}}$). $N_{\text{saved low}}$ was defined as the amount of mineral fertiliser N required without organic amendments to match the yield obtained with the amendment alone (N = 0, Eq. 2):

$$Y^0(N_{saved\,low}) = Y^A(N = 0) \quad (2)$$

To calculate $N_{\text{saved high}}$, the highest yield level which was reached by both response curves within the experimental set-up was determined for each pair of response curves and called $Y^{0,A}_{\text{max}}$. This could be the maximum of one of the two response curves (as in Fig. 1a) or the highest yield reached within the experimental set-up (as in Fig. 1b). Accordingly, N^0_{max} was defined as the mineral fertiliser N rate needed to reach $Y^{0,A}_{\text{max}}$ without organic amendments. Following, $N_{\text{saved high}}$ is the reduction in mineral N fertiliser when reaching $Y^{0,A}_{\text{max}}$ with organic amendments:

$$Y^A\left(N^0_{max} - N_{saved\ high}\right) = Y^{0,A}_{max} \quad (3)$$

Thus, $N_{\text{saved low}}$ represents the reduction of mineral fertiliser when using organic amendments at low total N supply. $N_{\text{saved high}}$ represents the reduction of mineral fertiliser when using organic amendments at high total N supply. In some cases, additional mineral fertiliser N was added to the organic amendments to allow for decomposition of straw or successful cultivation of green manures. If so, this was included in the calculation of $N_{\text{saved low}}$ and $N_{\text{saved high}}$.

To find $NFRV_{\text{low}}$ and $NFRV_{\text{high}}$, both $N_{\text{saved low}}$ and $N_{\text{saved high}}$ were divided by the total N content of the organic amendments (Eqs. 4, 5).

Fig. 2 Yield response *curves* to mineral fertiliser, with and without FYM. *Blue arrows pointing to the left* indicate a saving of mineral fertiliser N when applying FYM. *Blue arrows pointing to the right* indicate additional mineral fertiliser N is needed when applying FYM. **a** winter wheat in Bologna 1990–2000; **b** sugar beet (DM) in Iasi 1986–2006; **c** maize (DM) in Iasi 1984–1992; **d** winter barley in Keszthely 1999–2010; **e** potatoes in Lukavec 2002–2007; **f** winter barley in Lukavec 2002–2007; **g** sugar beet (DM) in Muencheberg 1985–1993; **h** potatoes (DM) in Muencheberg 1983–1999; **i** winter rye (DM) in Muencheberg 1996–2004; **j** winter wheat (DM) in Muencheberg 1984–2002: **k** maize (DM) in Muencheberg 1995–2003; **l** spring barley (DM) in Muencheberg 1978–1982; **m** winter barley (DM) in Speyer 1994–1999; **n** winter wheat (DM) in Speyer 1994–1999; **o** sugar beet in Sproda 1999–2010; **p** spring barley (86% DM) in Sproda 1999–2010; **q** winter wheat (86% DM) in Sproda 1999-2010. (Color figure online)

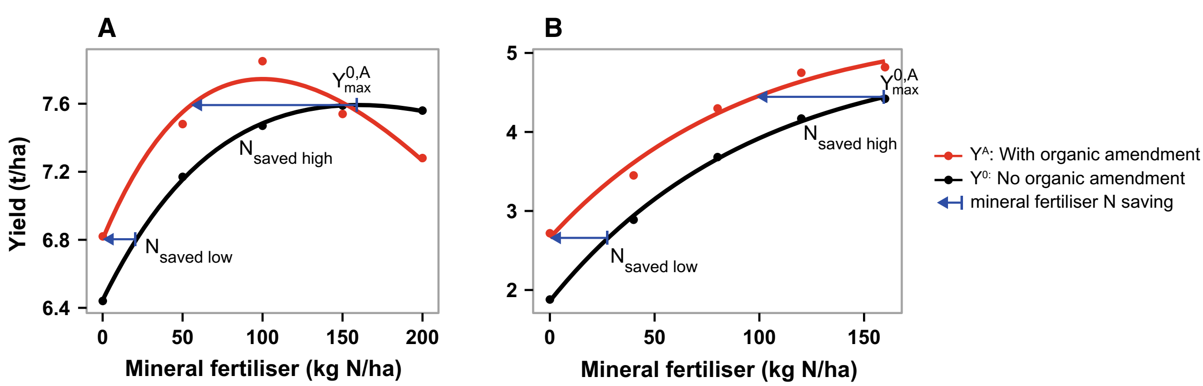
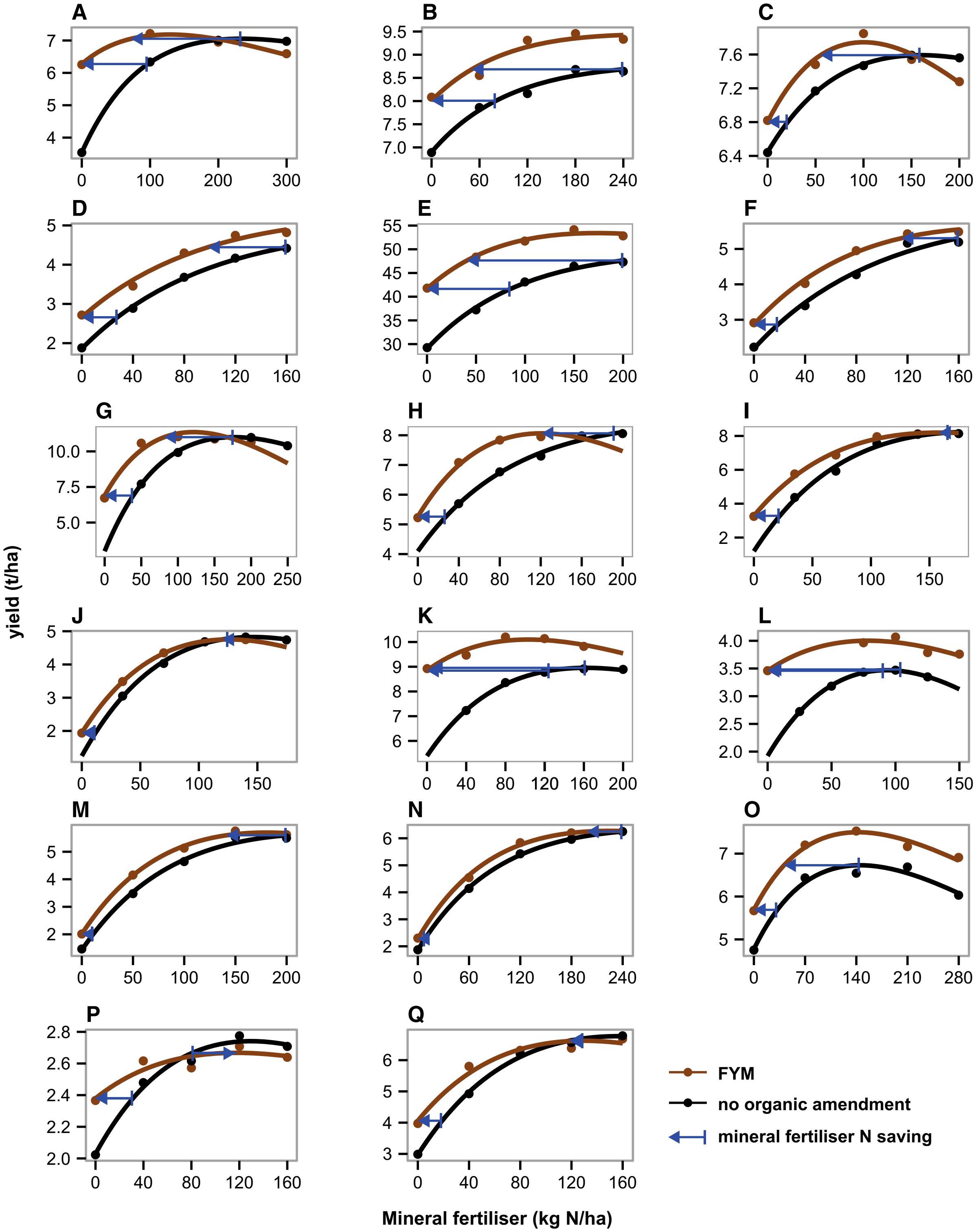


Fig. 1 Illustration of calculating mineral fertiliser N savings from organic amendments at low total N supply ($N_{\text{saved low}}$) and at high total N supply ($N_{\text{saved high}}$). Y^0 is the yield response curve without organic amendments. Y^A is the yield response curve with organic amendments. At the *left yields* are shown from maize cultivated in Iasi (Romania) between 1984 and 1992, with and without farmyard manure. At the *right yields* are shown from winter barley cultivated in Keszthely (Hungary) between 1999 and 2010, with and without farmyard manure


A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
yield (t/ha)
Mineral fertiliser (kg N/ha)
FYM
no organic amendment
mineral fertiliser N saving

$$NFRV_{low} = \frac{N_{saved\ low}}{Total\ N\ organic\ amendment} \quad (4)$$

$$NFRV_{high} = \frac{N_{saved\ high}}{Total\ N\ organic\ amendment} \quad (5)$$

Following, for each pair of response curves, the difference between $NFRV_{\mathrm{low}}$ and $NFRV_{\mathrm{high}}$ was calculated. Statistical models based on the function lme (linear mixed-effects model) of package nlme (Pinheiro et al. 2015) were used to find the least squares (LS) means for $NFRV_{\mathrm{low}}$ and $NFRV_{\mathrm{high}}$ per type of organic amendment. These models can account for random effects (Konstantopoulos 2011). In this analysis, the eight experiments were included as random effects. All data were processed in R (version 3.2.5; R Core Team 2015).

Results

$N_{\mathrm{saved\ low}}$ and $N_{\mathrm{saved\ high}}$ for FYM were calculated for seventeen pairs of response curves (Fig. 2). Mean $NFRV_{\mathrm{low}}$ of FYM was 0.53 (±0.26–95% Confidence Interval (CI)) and mean $NFRV_{high}$ of FYM was 1.12 (±0.71–95% CI) (n = 17, Table 2). $NFRV_{\mathrm{high}}$ was 2.13 times larger than $NFRV_{\mathrm{low}}$ ($p = 0.04$, Table 2).

For slurry, only one dataset was available (Fig. 3). For this dataset, $NFRV_{\mathrm{low}}$ was 0.35 and $NFRV_{\mathrm{high}}$ was 0.58. The ratio between $NFRV_{\mathrm{high}}$ and $NFRV_{\mathrm{low}}$ was 1.65 (n = 1, Table 2).

For straw, one-third of the *NFRV* values was negative at low total N supply, while almost half (47%) of the *NFRV* values for straw was negative at high total N supply (n = 15, Fig. 4). Mean $NFRV_{\mathrm{low}}$ for straw was 0.12 (±0.36–95% CI) and mean $NFRV_{\mathrm{high}}$ was 0.35 (±1.67–95% CI). $NFRV_{\mathrm{high}}$ for straw was 3.07 times larger than mean $NFRV_{\mathrm{low}}$, but not significantly so due to the large variation in the effects of straw on mineral fertiliser requirements ($p = 0.79$).

In five data sets, a combination of straw and green residues (green manures and/or beet leaves) was used as an organic amendment (Fig. 5). In all five cases, additional mineral fertiliser N was added to support decomposition of straw and/or cultivation of green manures, which was accounted for. At low total N supply, combining straw and green residues had a negative *NFRV* in two cases. At high total N supply,

Table 2 Long-term $NFRV_{\mathrm{low}}$ and $NFRV_{\mathrm{high}}$ for different types of organic amendment

	# data sets	Total N in organic amendments (kg N/ha/yr)	$N_{\mathrm{saved\ low}}$ (kg N/ha/yr)	$N_{\mathrm{saved\ high}}$ (kg N/ha/yr)	Ratio $N_{\mathrm{saved\ high}}$/$N_{\mathrm{saved\ low}}$	*P* (paired sample test $N_{\mathrm{saved\ high}}$ and $N_{\mathrm{saved\ low}}$)	$NFRV_{\mathrm{low}}$ (kg N/kg N)	$NFRV_{\mathrm{high}}$ (kg N/kg N)	Ratio $NFRV_{\mathrm{high}}$/$NFRV_{\mathrm{low}}$	*P* (paired sample test $NFRV_{\mathrm{high}}$ and $NFRV_{\mathrm{low}}$)
Animal manures										
FYM	17	120.2	−44.0	−76.9	1.75	0.02	0.53	1.12	2.13	0.04
Slurry	1	189.7	−66.1	−109.3	1.65	NA	0.35	0.58	1.65	NA
Crop residues										
Straw	15	22.2	−4.6	−7.4	1.61	0.85	0.12	0.35	3.07	0.79
Straw and green residues	5	61.4	−7.7	−54.5	7.10	0.07	0.14	0.91	6.62	0.10

Negative values for $N_{\mathrm{saved\ low}}$ and $N_{\mathrm{saved\ high}}$ indicate a saving of mineral fertiliser N. Mean values for $N_{\mathrm{saved\ low}}$, $N_{\mathrm{saved\ high}}$, $NFRV_{\mathrm{low}}$ and $NFRV_{\mathrm{high}}$ are calculated using a mixed effect model taking experiment as a random effect. Green residues refer to green manures and/or beet leaves

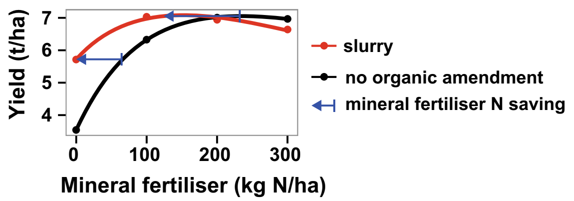


Fig. 3 Yield response curves of winter wheat to mineral fertiliser, with and without slurry applied in Bologna (1999–2010). *Blue arrows pointing to the left* indicate saving of mineral fertiliser N when applying slurry at low and high total N supply. (Color figure online)

negative *NFRV* did not occur for a combination of straw and green residues in our dataset. Mean $NFRV_{low}$ was 0.14 (±0.39–95% CI) and mean $NFRV_{high}$ was 0.91 (±1.21–95% CI). For the combination of straw and green residues, $NFRV_{high}$ was 6.6 times larger than $NFRV_{low}$, but not significantly different, due to the small sample size (Table 2).

Discussion

For all types of organic amendments, mean *NFRV* was higher at high total N supply than at low total N supply. Only for FYM the difference was significant ($p = 0.04$). For the other types of organic amendment either the sample sizes were too small or the variation too large for detecting significant differences.

Currently, values for *NFRV* are often estimated by applying organic amendments without extra mineral fertilisers. In Europe, farmers often apply a mixture of organic amendments and mineral fertilisers, thus having a higher total N supply (Potter et al. 2010). We compared values for *NFRV* at high total N supply (either the highest yield within the experimental set-up or the maximum of a response curve) with values of *NFRV* for organic amendments at low total N supply (at the start of the response curves). In practice, farmers will (1) operate within environmental restrictions on N applications and (2) try to achieve an economic optimum. Therefore, most often farmers will target yields somewhat below the yield maximum of the N response curves, which will generally be closer to the values we calculated for $NFRV_{high}$ than for $NFRV_{low}$.

Crop residues are often not used by farmers to replace mineral fertilisers as they have a high C:N ratio and might require N for decomposition (Knapp et al. 1983). In these cases, crop residues have a negative *NFRV*. Straw had a negative NFRV in one-third ($NFRV_{low}$) to half ($NFRV_{high}$) of the cases in our study. A combination of green manures and straw had a negative NFRV in two-fifth ($NFRVl_{ow}$) to none ($NFRV_{high}$) of the cases.

Our findings are based on 38 datasets from eight long term experiments. Besides straw and FYM, however, there were only a limited number of observations per organic amendment type (Table 2). Further work is needed to assess to what extent *NFRV* differs between low and high total N supply for the other amendment types, for different soil and climate conditions and in combination with different crop types. Such an exercise would require a much larger dataset, preferably with N contents of organic amendments available.

A number of mechanisms might change the shape of the yield response curve and therefore cause a difference between the values of $NFRV_{low}$ and $NFRV_{high}$, on which we will now elaborate. A first mechanism could be that organic amendments provide other benefits than N to the crops (other nutrients or soil improvements), which has not been adjusted for in the mineral fertiliser only plots. In this case, the calculated values of *NFRV* cannot be solely attributed to N but include additional yield effects (Janssen 2002; Wadman et al. 1987). Elimination of the limitation(s) that cause such additional yield effect (e.g. by supplying a mineral S fertilizer) would result in a steeper mineral fertilizer response (i.e. a better conversion of applied mineral fertiliser N into DM or FM yield). Consequently, $NFRV_{high}$ would decrease and approach $NFRV_{low}$. A second alternative explanation is that addition of mineral fertiliser might increase available N from the amendment (or vice versa). Third, addition of mineral fertiliser could increase uptake efficiency of N from organic amendment (or vice versa). Finally, a combination of above mechanisms might take place at the same time.

In our study, savings of mineral fertiliser when using organic amendments were compared at low and high total N supply. At low N supply, using only organic amendments was compared with using only mineral fertiliser. At high total N supply, using a combination of organic amendments and mineral fertiliser was compared with using only mineral fertiliser. The larger value of NFRV at high total N supply could suggest that the NFRV of organic

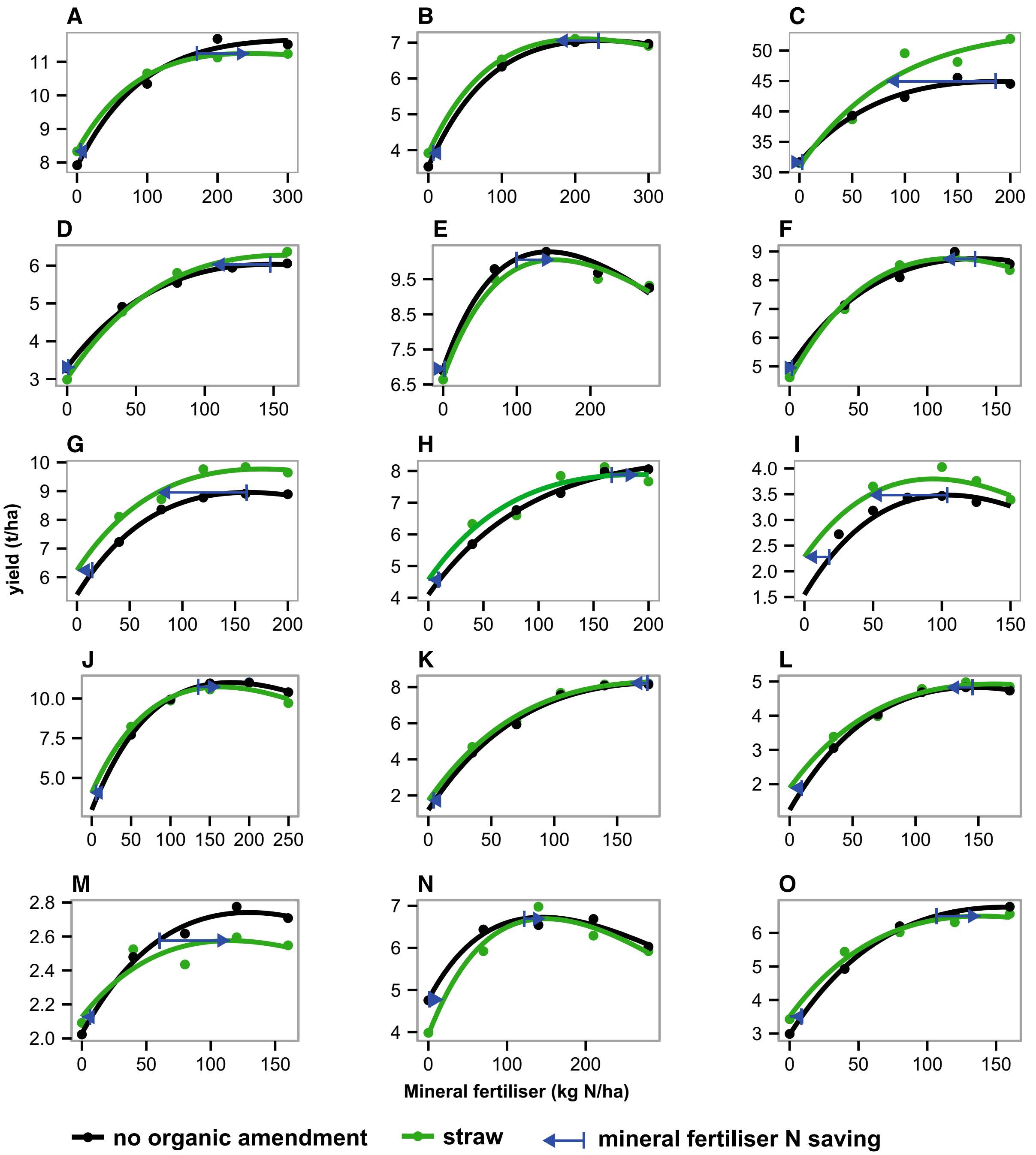


Fig. 4 Yield response curves to mineral fertiliser, with and without straw application. *Blue arrows pointing to the left* indicate a saving of mineral fertiliser N when applying straw. *Blue arrows pointing to the right* indicate additional mineral fertiliser N is needed when applying straw. **a** maize in Bologna 1991–2001; **b** winter wheat in Bologna 1990–2000; **c** potatoes (FM) in Methau 1999–2010; **d** spring barley (86% DM) in Methau 1999–2010; **e** sugar beet in Methau 1999-2010; **f** winter wheat (86% DM) in Methau 1999–2010; **g** maize (DM) in Muencheberg 1995–2003; **h** potatoes (DM) in Muencheberg 1983–1999; **i** spring barley (DM) in Muencheberg 1978–1982; **j** sugar beet (DM) in Muencheberg 1985–1993; **k** winter rye (DM) in Muencheberg 1996–2004; **l** winter wheat (DM) in Muencheberg 1984–2002; **m** spring barley (86% DM) in Sproda 1999–2010; **n** sugar beet in Sproda 1999–2010; **o** winter what (86% DM) in Sproda 1999–2010. (Color figure online)

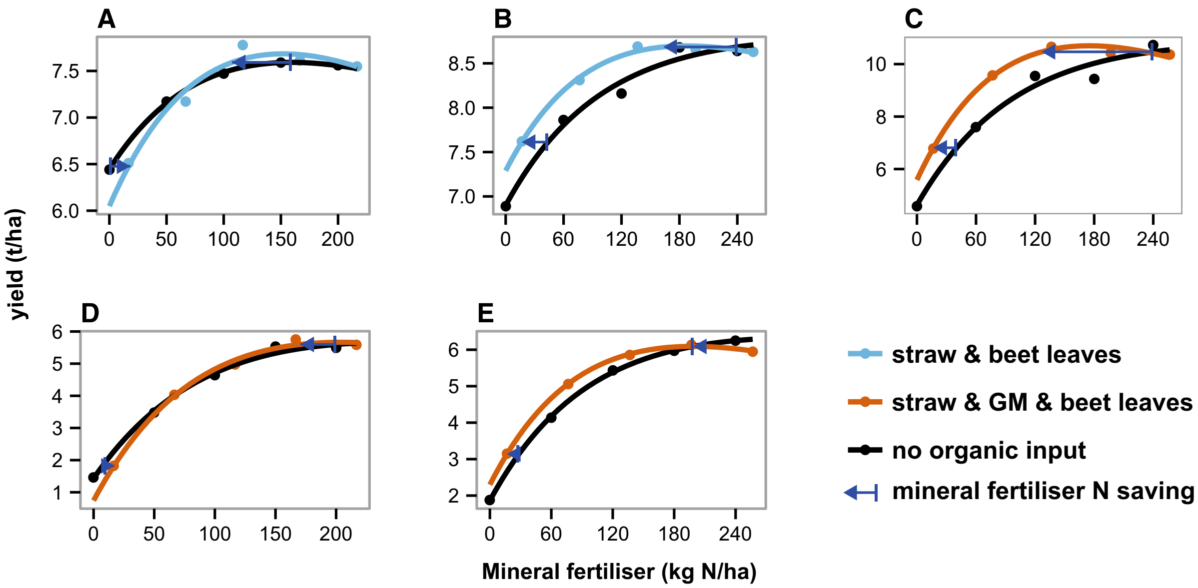


Fig. 5 Yield response curves to mineral fertiliser, with and without a combination of straw and green residues. *X-axes* indicate mineral fertiliser N, including additional mineral fertiliser N added for the cultivation of green manures or decomposition of straw (at each site on average 16.7 kg N/ha/year). *Blue arrows pointing to the left* indicate a saving of mineral fertiliser N for a combination of straw and green residues. *Blue arrows pointing to the right* indicate additional mineral fertiliser N is needed for a combination of straw and green residues. **a** maize (DM) in Iasi 1984–1992; **b** sugar beet (DM) in Iasi 1986–2006; **c** sugar beet in Speyer 1994–1999; **d** winter barley (DM) in Speyer 1994–1999; **e** winter wheat (DM) in Speyer 1994–1999. (Color figure online)

amendments is higher when organic inputs are combined with mineral fertiliser. This suggestion could be further investigated by calculating NFRV of organic amendments when applied in different amounts. If validated, this would open a new perspective on the advantage of distributing available organic amendments among many farmers in a given region: the region would require less fertiliser to produce the same yield output, than when the available organic amendments were concentrated in few farms.

In this study, we have used yield response curves expressed in either dry or fresh matter to calculate values for $NFRV_{low}$ and $NFRV_{high}$. Other methods exist to calculate *NFRV*, such as based on N content (Jensen 2013) or using isotope dilution techniques (Diekmann et al. 1993; Janzen et al. 1990). An exploration of different methods into NFRV_{low} and NFRV_{high} might give further insights into possible mechanisms.

If our findings can be further generalized, the observed contrast in *NFRV* between the respective N ranges may have practical implications for fertiliser recommendations, depending on the mechanisms underlying the contrast. Similarly, the contrast might justify adjustment of statutory values for fertiliser equivalency coefficients as used to regulate N use in the Action Programmes—under the Nitrates Directive—of various EU member states.

Conclusions

Currently, values for *NFRV* are often based on experiments where crop yields in plots with only organic amendments (no mineral fertilisers) are compared with crop yields in plots with only mineral fertiliser, at relatively low total N supply. In many European countries, however, farmers operate at high total N supply. *NFRV* coefficients play a key role in fertiliser recommendation systems and tools (e.g. MANNER-NPK, Nicholson et al. 2013) and various national Action Programmes in response to the EU Nitrates Directive (EEC 1991). For example, current Action Programmes in the UK, Denmark and the Netherlands use *NFRV* values of 0.10, 0.45 and 0.30–0.60 kg/kg, respectively for total N in FYM, and values of 0.45, 0.75 and 0.60–0.80 kg/kg for pig slurry (Dalgaard et al. 2014; RVO 2014; UK 2015).[1] These values are often a political compromise, but based on short or long-term estimations of *NFRV*. These statutory values define, in combination with N application standards, the maximum amounts of N fertiliser that farmers in those countries may apply, depending on crop and soil type.

This meta-analysis of eight long term experiments on different types of organic amendments shows that *NFRV* of FYM was roughly up to two times larger at high than at low total N supply rate. Currently, *NFRV* is usually assessed at the 'lower end' of the N response curve. Considering that farmers in Europe normally operate at relatively high mineral fertilisation rates, the use of *NFRV* determined at the 'lower' end of the N response curve may underestimate *NFRV* of organic amendments. When using these lower values to estimate the N fertilizer replacement value of organic amendments, complementary mineral N fertiliser requirements are estimated to be larger than actually needed for achieving certain yields. This might lead to overuse, lower N use efficiency and more losses to the environment.

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[1] Values for the Netherlands refer to arable crops on sandy soils.

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