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Original article

Organic resource management in sub-Saharan Africa: validation of a residue quality-driven decision support system

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Abstract – A conceptual Decision Support System (DSS) for organic N management was developed based on information on residue quality N-mineralization relationships. The current paper aims at validating the DSS using data obtained in sub-Saharan Africa on biomass transfer systems with maize. The percentage fertilizer equivalency (% FE) values of the organic resources increased linearly with their N content above a minimum of 2.3% N. For resources with high polyphenol contents, the slope of the regression decreased and the critical N content increased to 2.8%. For manures, no clear relationship between their % FE and quality was observed. Medium quality materials are to be applied together with mineral N. Several cases are discussed in which added benefits as a result of positive interactions between medium quality organic resources and mineral N were generated. Finally, thought is given to the information needed to turn the DSS from a concept into a useful soil management tool.

farmyard manure / fertilizer / organic-mineral interactions / Organic Resource Database / percentage fertilizer equivalency

Résumé – Gestion de ressources organiques en Afrique sub-Saharienne : validation d'un système d'aide à la décision pour la gestion de la qualité des résidus. Un système d'aide à la décision conceptuel (DSS) pour la gestion de l'azote organique a été développé à partir d'informations sur la qualité des résidus relations de minéralisation de N. Le présent article a pour but de valider le DSS en utilisant les données obtenues en Afrique sub-Saharienne sur les systèmes de transfert de biomasse avec le maïs. Les valeurs du pourcentage d'équivalent-fertilisant (% FE) des ressources organiques ont augmenté linéairement avec leur contenu en N à partir d'un minimum de 2,3 % N. Pour les ressources avec une forte teneur en polyphénols, la pente de la régression a diminué et le contenu critique de N a augmenté jusqu'à 2,8 %. Pour les fumiers, aucune relation claire entre leur % FE et leur qualité n'a été observée. Les matériaux de qualité moyenne ont dû être appliqués simultanément avec de l'azote minéral. Plusieurs cas sont discutés, parmi lesquels les bénéfices générés qui résultent des interactions positives entre les ressources organiques de qualité moyenne et l'azote minéral. L'information nécessaire apparaît finalement pour transformer le concept de DSS en un outil utile de gestion des sols.

fumier / fertilisant / interactions organique-minérale / base de données de ressources organiques / pourcentage d'équivalent-fertilisant

1. INTRODUCTION

For a long time, agricultural production depended on organic resources for soil fertility replenishment, either by including long-term fallow periods, as was, e.g., the case in sub-Saharan Africa (SSA), or by application of vast amounts of manures or other organic resources, e.g., sods of peat in northern Belgium [5]. The use of fertilizers started in western Europe only at the end of the 19th century in response to a higher demand for food. Other continents followed at a later stage, but even up to the mid-1960s, fertilizer use in SSA was restricted to export crops such as groundnut, cotton, coffee, tobacco, or oil palm [5].

During the 'Green Revolution' in the 1960s in Asia and Latin America organic resources were not considered essential in boosting agricultural production. In this context, Sanchez [17] stated that when mechanization is feasible and fertilizers are available at reasonable cost, there is no reason to consider the maintenance of soil organic matter (SOM) as a major management goal. However, application of the 'Green

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Table I. A brief summary of the science of tropical organic resource management.

Period	Scientific progress	Reference
< 1970s	Organic matter as a 'blob'	Palm, personal communication
1979	Organisms – Physical environment – Quality framework for organic matter decomposition	[24]
1984–1986	Development of the 'synchrony' research theme within the Tropical Soil Biology and Fertility programme	[21–23]
1990s	Various experiments addressing the 'synchrony' hypothesis	Various
1995	International Symposium on 'Plant Litter Quality and Decomposition'	[2]
2000	Development of the 'Organic Resource Database' and the Decision Support System for organic N management	[16]
> 2001	Quantification of the Decision Support System for organic N management	Future publications

Revolution' strategy in SSA resulted only in minor achievements because of a variety of reasons [6]. This, together with environmental degradation resulting from the massive applications of fertilizers and pesticides and the abolition of the fertilizer subsidies in SSA, imposed by structural adjustment programs, led to a renewed interest in organic resources in the early 1980s (Tab. I). This interest has only grown stronger in recent years, driven by the development of an Integrated Soil Fertility Management (ISFM) strategy for soil fertility replenishment, of which the combined application of organic resources and mineral inputs forms the technical backbone. In this context, Sanchez [18] revised his earlier statement by formulating the Second Paradigm for tropical soil fertility research: 'Rely more on biological processes by adapting germplasm to adverse soil conditions, enhancing soil biological activity and optimizing nutrient cycling to minimize external inputs and maximize the efficiency of their use'.

Since the early 1980s, progress in developing organic resource management-related knowledge has been substantial, driven by the hypotheses formulated by Swift et al. [24] and Swift [21–23], culminating in an International Symposium in 1995 (Tab. I). As a result of the Symposium, efforts were made to consolidate information on residue quality N dynamics relationships, resulting in an Organic Resource Database (ORD). The ORD contains information on organic resource quality parameters and N mineralization dynamics from almost 300 species found in tropical agroecosystems (Palm et al., 2001). A careful analysis of the information in the ORD has led to the development of a Decision Support System (DSS) for organic matter (OM) management (Fig. 1) [16]. The DSS makes recommendations for the appropriate use of organic materials, based on their N, polyphenol, and lignin contents, resulting in four classes of organic resources [16]. For instance, high quality organic resources with a N content > 2.5%, a lignin content of < 15% and a polyphenol content of < 4% are recommended to be applied directly to the soil as these are expected to release a substantial part of their N in the short term (Fig. 1). Medium quality organic residues having < 2.5% N and < 15% lignin, or > 2.5% N and a polyphenol content > 4%, on the other hand, are recommended to be applied together with fertilizer N or high quality organic resources. Lastly, low quality organic resources with a low N and high lignin content are recommended to be surface-applied as such residues would result in the most

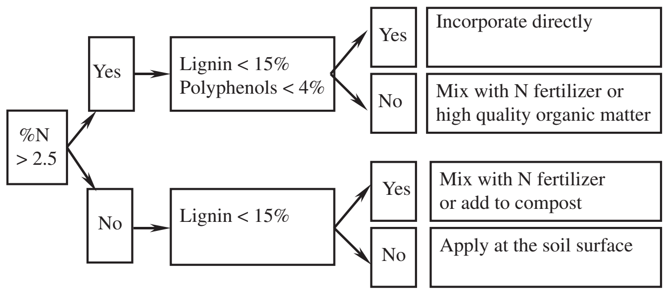

Figure 1. The Decision Support System for organic N management, leading to 4 classes of organic resources (adapted from Palm et al. [16]).

substantial mulch effects. The combined application of organic resources and mineral N is hypothesized to yield added benefits in terms of extra yield or improved soil fertility compared with the sum of the responses in the treatments with a sole application of organic resources and mineral N. A *Direct* and *Indirect Hypothesis* which could form the basis for the occurrence of such benefits has been formulated by Vanlauwe et al. [26]. The *Direct Hypothesis* was formulated as: *temporary immobilization of applied fertilizer N may improve the synchrony between the supply of and demand for N and reduce losses to the environment*. The *Indirect Hypothesis* was formulated for N supplied as fertilizer as: *any organic matter-related improvement in soil conditions affecting plant growth (except N) may lead to better plant growth and consequently enhanced efficiency of the applied N*. Both hypotheses, when proven, lead to an enhancement in N use efficiency, processes following the *Direct Hypothesis* through improvement of the N supply and processes following the *Indirect Hypothesis* through an increase in the demand for N. Obviously, mechanisms supporting both hypotheses may occur simultaneously.

The objectives of the current paper are: (i) to validate the concepts proposed in the DSS with field data, including plant materials and animal manure as organic resources; (ii) to explore the occurrence of added benefits when applying organic resources in combination with mineral N; and (iii) to reflect on the activities required to develop the DSS into a practical recommendation tool.

2. EXPERIMENTAL APPROACHES

2.1. Experiments in West, East and southern Africa studying the N supply potential of organic resources

A greenhouse trial was carried out in Ibadan, southwestern Nigeria, aiming at quantifying immediate and residual relationships between organic resource quality and maize N uptake (Vanlauwe et al., unpublished data). A range of organic materials containing between 0.14 and 3.53% N was applied in pots with a Nitisol from the Southern Benin Republic at an equivalent rate of 90 kg $N \cdot ha^{-1}$ and maize was grown for 7 weeks. After harvesting the first crop, a second crop was grown for another 7 weeks without fresh residue application. Total N uptake by the maize in the shoots and roots was measured at each harvest.

In East and southern Africa, a set of field experiments was set up to determine the fertilizer equivalency values of organic resources [10]. Each trial contained a set of locally available sources of plant materials or cattle manure. The organic resources were applied on the field in a randomized complete block design, which included a number of plots aimed at determining the response to fertilizer N, using maize as a test crop. Based on the response curve and the yield increases in the organic resource treatments, fertilizer equivalency values were calculated and converted to percentage fertilizer equivalency values (% FE), taking into account the N application rates of the organic materials.

In West Africa, a multilocational set of field experiments also using maize as a test crop was established using various inputs of plant materials and cattle manure in a single case and the % FE was calculated using the same approach as indicated above [27]. In both sets of trials, P and K were applied in non-limiting quantities to ensure that N was the sole nutrient limiting maize production.

2.2. Evaluation and quantification of added benefits in experiments with simultaneous application of organic resources and mineral N in West, East and southern Africa

Several trials were established in the various sub-regions aiming at quantifying potential added benefits in treatments with combined applications of organic resources and mineral N (Tab. II). All cropping systems considered were organic resource transfer or biomass transfer systems using maize as a test crop.

Added benefits were mathematically evaluated using the equation:

$$AB = Y_{comb} - (Y_{fert} - Y_{con}) - (Y_{OM} - Y_{con}) - Y_{con} \qquad (1)$$

where AB signifies *Added Benefits* and Y_{con}, Y_{fert}, Y_{OM}, and Y_{comb} mean grain yields in the control treatment, in the treatments with sole application of fertilizer and organic matter, and in the treatment receiving both inputs, respectively [26]. In equation (1), the yields are adjusted for similar amounts of organic resources and mineral N applied in the combined as in the sole treatments, following information obtained through the N response curve, or if the latter is absent, assuming linear responses to applied organic and mineral N.

3. EVIDENCE FROM FIELD TRIALS IN WEST, EAST AND SOUTHERN AFRICA

3.1. Agronomic evaluation of organic resources of varying quality as source of N

The greenhouse trial data clearly showed a significant positive relationship between the organic resource N content and the total maize N uptake of the first crop (Fig. 2). Low quality

Table II. Treatment structures and year/season of implementation of the various experiments on organic-mineral interactions in West, East, and southern Africa. An appreciation of the rainfall received during the experiments is also given.

Site – country (reference)	Organic resources used (% N)	Mineral N used	Organic resources application rates	Mineral N application rates	Year – season[a]	Rainfall
Sekou – Benin [27]	*Leucaena leucocephala* (4.7%), *Azadirachta indica* (2.4%), *Senna siamea* (3.0%)	Urea	90 kg $N \cdot ha^{-1}$ in sole; 45 kg $N \cdot ha^{-1}$ in combined treatments	N response curve (0, 22.5, 45, 67.5, 90 kg $N \cdot ha^{-1}$); 45 kg $N \cdot ha^{-1}$ in combined treatments	1997–1	Drought stress during flowering
Meru – Kenya [9]	*Leucaena leucocephala* (3.8%), *Calliandra calothyrsus* (3.3%), *Tithonia diversifolia* (3.0%), Cattle manure (1.4%)	Compound fertilizer (23:23:0)	60 kg $N \cdot ha^{-1}$ in sole; 30 kg $N \cdot ha^{-1}$ in combined treatments	60 kg $N \cdot ha^{-1}$ in sole; 30 kg $N \cdot ha^{-1}$ in combined treatments	2000–1	Low rainfall during first 20 days
					2000–2	Normal
Eldoret – Kenya [14]	Wheat straw (0.7%), Soybean trash (1.1%)	Urea	2 ton dry matter$\cdot ha^{-1}$	80 kg $N \cdot ha^{-1}$ in sole; 20, 40, 80, and 100 kg $N \cdot ha^{-1}$ in combined treatments	1997	Low rainfall and poor distribution
					1998	Normal
Various – Zimbabwe [11]	Cattle manure (2.6%)	Ammonium nitrate	25, 50, 75, and 100 kg $N \cdot ha^{-1}$	Complement organic resource application rates to reach 100 kg $N \cdot ha^{-1}$	1997/98	Normal
					1998/99	Normal

[a] Only given when more than 1 season per year occurs.

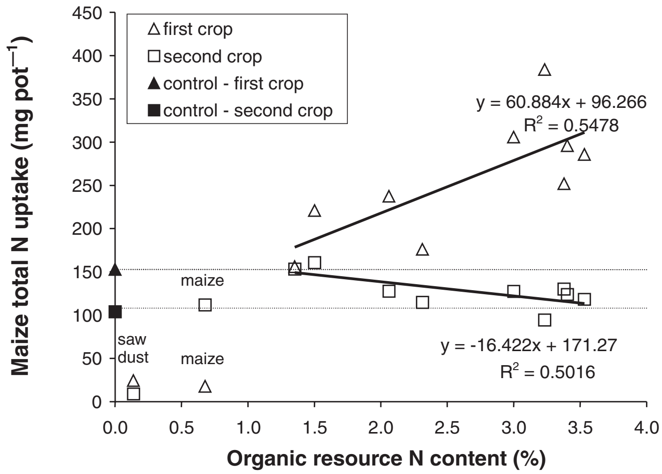

Figure 2. Relationship between the N content of a wide range of organic resources and the total (shoot + root) N uptake by maize in a greenhouse pot trial. The regression equations were calculated for all residues excluding maize and sawdust. The dashed lines give the maize total N uptake in the control soils.

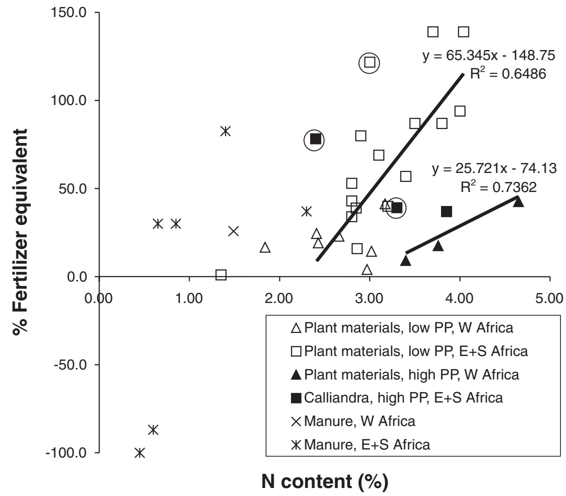

Figure 3. Relationship between the N fertilizer equivalent and the N content of plant residues and manure for a series of sites in West (W), East and Southern (E+S) Africa. The linear regression equations were calculated separately for the plant materials with low and high polyphenol (PP) content. Encircled values were excluded from the regression analysis. Source: [7, 9, 10, 27].

materials such as maize stover or sawdust immobilized N, resulting in less N uptake compared with the unamended control. For the second crop, however, the relationship was negative, indicating that the medium to low quality materials provide more N to a second growing maize crop compared with the high quality materials (Fig. 2). Even in the treatment with maize stover, no further immobilization of N was observed. Only the sawdust treatment kept the N immobilized beyond the second crop. These data show that while organic resources with a high amount of available N can immediately stimulate crop growth, for medium to low quality materials, residual N supplies are greater. More cropping cycles would be needed to judge whether the cumulative yields are similar for the high and low N organic resources. Cadisch et al. [3], on the other hand, observed no compensation in initial N release from low quality, high polyphenol-containing prunings at later harvests compared with high quality materials, and attributed this to the stability of polyphenol-N complexes. The data also indicate that for materials with a N content below 1%, additional N should be applied either as fertilizer or as high quality organic matter to overcome the negative impacts caused by N immobilization.

Data from the field experiments in West, East and southern Africa show that the percentage fertilizer equivalencies (% FE) values for organic materials with a low polyphenol content (< 4%) and a N content > 2.3% were positively related to their N content (Fig. 3). The critical level of N for increasing crop yield was 2.3%, confirming the initial value hypothesized by Palm et al. [16]. Organic matter with a high polyphenol content (> 4%) still led to positive % FE values, but the increase with increased N content was less and the N content needed to improve maize yield was 2.8% rather than 2.3% (Fig. 3). Polyphenol-N interactions seem to delay the immediate availability of N, as concluded by others from data obtained under controlled laboratory or greenhouse conditions [13, 15]. Data obtained with *Calliandra calothyrsus* residues did not show a consistent trend. While in all cases their polyphenol content was high, data from certain sites did not show any reduction in % FE. This may be related to the specific rainfall patterns, as high rainfall immediately after applying the *Calliandra* residues may remove a substantial part of the polyphenols through leaching. While from the current data, polyphenols appeared to be under certain conditions important modifiers guiding initial N release from organic materials, the lignin content was not observed to improve on the derived equations. This does, however, not exclude their importance in medium– to long-term N dynamics, as shown in the greenhouse experiment (Fig. 1).

Some organic resources led to N fertilizer equivalency values exceeding 100%, especially in the case of *Tithonia diversifolia* (Fig. 3). This is likely caused by a better synchrony between the supply of and demand for N derived from *Tithonia* residues than immediately available fertilizer-derived N. Mineral N inputs are readily available and, as such, prone to leaching and/or gaseous losses, even if split-applied.

Manure does not show a consistent trend across sites (Fig. 3). Very low N-containing cattle manure was observed to decrease crop yield but fertilizer equivalency values of manure containing between 0.7 and 2.4% N were almost the same and equal to about 35%. N content alone could not satisfactorily explain the observed responses to manure application, indicating that other indicators are necessary for quantitative evaluation of manure. This may be related to changes in quality and partial stabilization of the organic resources while passing through the rumen or while storing pending application on the field. Nzuma and Murwira [12] showed considerable differences in manure quality when stored in a pit or heap. Manure may require other indicators for assessing its quality, likely based on the nutrient and biochemical components of the soluble fraction rather than on the overall material.

3.2. Occurrence and quantification of added benefits

Organic resources with a N content below 2.5% would need to be applied in combination with additional mineral N to substantially increase crop yields (Fig. 3). Significant added benefits in treatments with combined application of organic resources and mineral N do occur in various experiments, although the mechanisms governing these benefits are not always clearly understood. In the experiment in Zimbabwe with various mixtures of cattle manure and ammonium nitrate, added benefits ranging between 663 and 1188 kg maize grains·ha^{-1} were observed by Nhamo [11], as calculated using equation (1) (Fig. 4). The author related this to the supply of cations, contained in the manure, which may have alleviated constraints to crop growth caused by the low cation content (CEC varied between 1.2 and 2.5 cmol$_c$·kg^{-1} with an average of 1.7 cmol$_c$·kg^{-1}) of the very sandy sites (clay content varied between 2 and 10% with an average of 4%). Although temporary immobilization of fertilizer N by decomposing manure cannot be excluded, this may be less likely as the C/N content of the used manure was below 10, assuming that this is a suitable indicator for assessing the N dynamics of manure. In a trial in central Kenya, Okalebo et al. (2002) similary observed added benefits of 684 kg grains·ha^{-1} in 1998 when mixing low quality wheat straw and soybean trash with urea for an acidic Ferralsol (pH-water of 4.9) (Fig. 5). After application of the organic residues, the pH-water increased to 5.4, on average, while pH in the control soils remained unchanged. Rainfall in 1997 was low and not well distributed, leading to an absence of major responses to applied N.

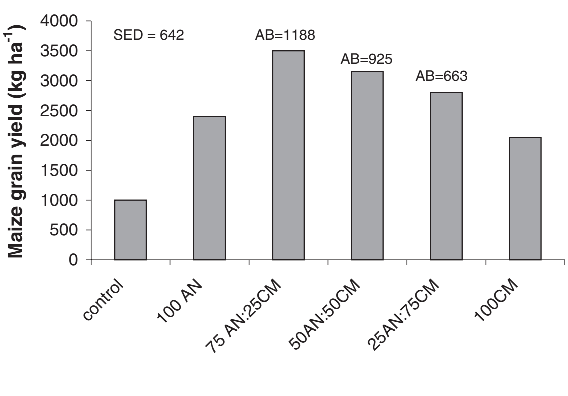

Figure 4. Maize grain yield as affected by inputs of various combinations of cattle manure (CM) and ammonium nitrate (AN) for a series of on-farm trials (14 trials) in Zimbabwe. Data are averaged over all sites and two seasons. The added benefits (AB) (in kg maize grain·ha^{-1}) have been calculated following equation (1). 'SED' means 'Standard Error of the Difference'. Adapted from Nhamo [11].

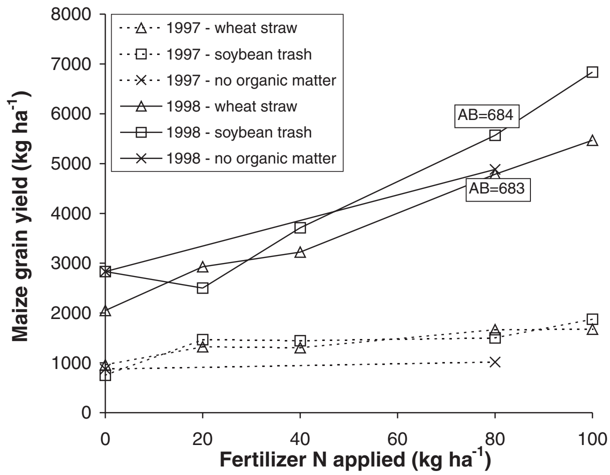

Figure 5. Maize grain yield in 1997 and 1998 as affected by the application of low quality organic resources supplemented with various rates of urea for a site in central Kenya. The added benefits (AB) (in kg maize grain·ha^{-1}) have been calculated following equation (1). Adapted from Okalebo et al. [14].

Mucheru et al. [9] observed added benefits ranging from –250 to + 550 kg maize grains·ha^{-1} during the short rainy season of 2000 (Fig. 6). Values for the long rainy season, which experienced a lack of rainfall after germination, were not different from 0. These benefits varied substantially for the different organic resources used. The high amount of K in the *Tithonia* residues may have caused the substantial added benefits in the combined *Tithonia*-N fertilizer treatment, as earlier observed by Sanchez and Jama [19]. Besides supplying K, *Tithonia* residues have been shown to ameliorate soil aggregation, reduce P sorption sites, reduce P-metal complexes and Al-toxicity [4]. Causes for the added benefits created in the cattle manure treatment are not clear.

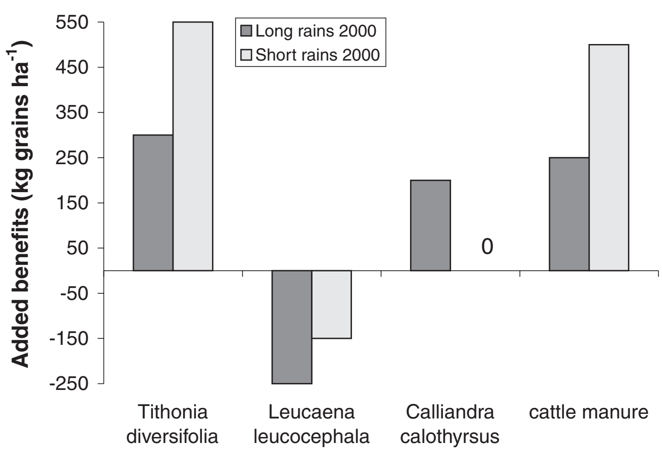

Figure 6. Added benefits (in kg maize grain·ha^{-1}) as affected by organic resources for 2 seasons on a site in central Kenya. The added benefits have been calculated following equation (1). Adapted from Mucheru et al. [9].

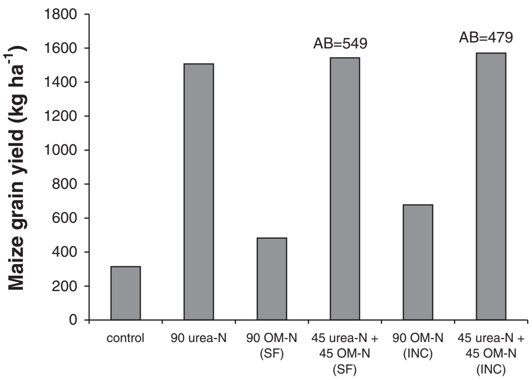

Figure 7. Maize grain yields in Sekou as affected by the application of urea, organic materials, or the combination of both. 'SF', 'INC', and 'OM' mean 'surface-applied', 'incorporated', and 'organic matter', respectively. Numerical values for treatments are expressed as kg N·ha^{-1}. The added benefits (AB) (in kg maize grain·ha^{-1}) have been calculated following equation (1). Adapted from Vanlauwe et al. [27].

While in the above experiments, added benefits were observed only for certain organic resources, in the Sekou experiment, in which organic resources with a N content varying between 2.4 and 4.7% were used, similar added benefits were observed for all organic resources (Fig. 7). As the site experienced drought stress during maize grain filling, Vanlauwe et al. [27] attributed the added benefits to improved soil water conditions in the mixed treatments, caused by the surface or sub-surface placement of the organic resources, compared with the treatment with sole application of fertilizer. Alleviation of moisture stress may have improved the N use efficiency of the applied fertilizer. In formerly discussed trials with organic resources, no alleviation of moisture stress was observed (Figs. 5 and 6) but in these trials, organic resources were incorporated. During seasons with a shortage of rain, this residue management practice has been shown not to substantially alter soil moisture conditions vis-à-vis surface or subsurface placement [8, 20]. No soil water data were taken, so the above would need to be evidenced.

4. LOOKING AHEAD

The final product of all the above work should be a tool to assist farmers on how to optimally manage their scarcely available organic resources and costly mineral fertilizers, preferably adapted to their biophysical environment and targeted yields for specific crops. Although this seems like an impossible task, generation of the following information would signify substantial progress: (i) generation of a more detailed understanding of the mechanisms creating added benefits, (ii) assessment of the influence of intrinsic soil properties (e.g., texture and clay mineralogy, water holding capacity), and climate conditions (e.g., risk of rain shortage) on the latter, (iii) quantification of the residual effects of organic resources of varying quality, applied sole or in combination with fertilizer, on crop yield, and (iv) evaluation of the immediate and residual responses of other crops besides maize to applied organic resources and fertilizer.

The mechanistic basis for added benefits created through positive interactions between OM and mineral N is broad and has not been clearly understood yet. Although in the above case studies, likely reasons behind the added benefits could be put forward, little or no evidence was gathered to substantiate these. Trials that explicitly quantify some of the changes in soil properties as affected by OM application are needed. Such trials would also include treatments in which the hypothesized constraint to crop growth is alleviated using external inputs containing only the agent addressing this constraint. Although it may be an illusion to aim at understanding all interactions between organic resources and fertilizer under all conditions, under certain specific conditions, clear organic resource-related improvements in soil fertility status could be identified. For instance, the use of high P-containing manure or compost on low P soil could lead to an improved use efficiency of N fertilizer and consequently added benefits. When looking at legume-cereal rotations, the mechanisms potentially creating added benefits may even be more diverse relative to the ones discussed in biomass transfer systems in this paper. Many rotational effects are often explained in terms of changes in pest and disease spectra during legume growth [1] or in terms of legume rhizosphere processes [25].

Organic resources are known to show some residual effects. Optimal nutrient management strategies need to take into account these effects. In the long term, an improved soil organic matter status may equally lead to enhanced N fertilizer use efficiencies, although quantifying the latter may prove very difficult. Vanlauwe et al. (unpublished data), e.g., showed a negative relationship between the proportion of maize N derived from urea and the soil total N content, presumably caused by a higher supply of native soil N in soils with a higher total N content.

Most of the data presented in this paper, and similarly in other work dealing with soil fertility management, were obtained in maize-based cropping systems. It is likely, however, that farmers would prefer to use their often scarcely available organic resources on crops which yield more income. In this context, it has been observed that farmers in western Kenya would rather apply high quality *Tithonia* residues to kale (*Brassica oleracea*) rather than maize (Jama, personal communication). This would not necessitate the initiation of a vast amount of trials using crops other than maize, but to consider the nutrient uptake patterns of those other crops and use the information obtained for maize to test specific hypotheses related to the potential effects of organic resources and fertilizer on other crops.

After having obtained relevant information as described above, two extra steps may be required to complete the development of a user-friendly decision aid: (i) all the above information needs to be synthesized into a quantitative framework; and (ii) that framework needs to be translated into a format accessible to the end-users. The quantitative

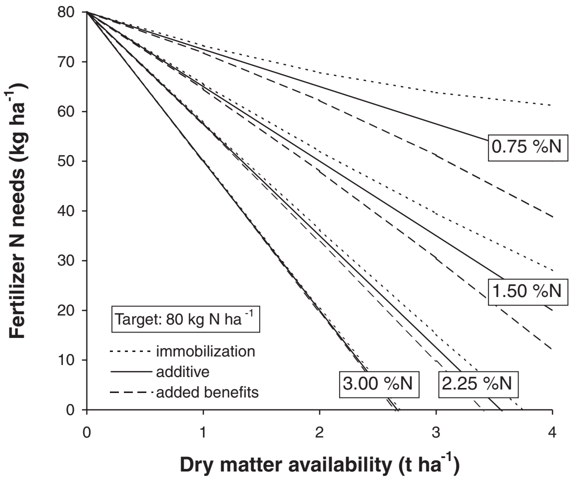

Figure 8. Conceptual model for recommending the amount of N fertilizer needed for a specific targeted crop yield when a certain amount of organic matter with a certain quality is available. The model assumes that direct interactions between organic matter and fertilizer will be more substantial as the quality of the organic matter decreases. Depending on the duration of the immobilization, less (in case of temporary immobilization with reduced losses of fertilizer N) or more (in case of prolonged immobilization, e.g., with sawdust Fig. 2) N fertilizer may be required to reach the same target (here hypothetically set at 80 kg $N \cdot ha^{-1}$).

framework could look as presented in Figure 8 for a situation where all interactions between organic matter and fertilizer happen through N immobilization reactions, thus supporting the *Direct Hypothesis.* Temporary immobilization of fertilizer N by medium to low quality resources may reduce the potential for losses of fertilizer N materials, and consequently less fertilizer N may be required to reach the same amount of available N (the 'added benefits' situation in Fig. 8). If the immobilization lasts beyond a growing season, on the other hand, additional fertilizer N may be required to reach the same amount of available N (the 'immobilization' situation in Fig. 8). The current concept may be adapted to initial soil fertility status by including a background soil N supply and to different crops. If the mechanisms creating added benefits following the *Indirect Hypothesis* are known, the concept could also be adapted to these conditions. The final format of the decision aid should take into account the realities in the field. Some of these realities, among others, are: (i) large-scale soil analyses are not feasible, so local soil quality indicators need to be included in decision aids as farmers use those to appreciate existing soil fertility gradients within a farm; (ii) conditions within farms vary as does the availability of organic resources and fertilizer, therefore rules of thumb rather than detailed quantitative recommendations would be more useful to convey the message to farmers; (iii) farmers' decision-making processes involve more than just soil and crop management; and (iv) access to computers, software and even electricity is limited, necessitating hard copy-based products.

5. CONCLUSIONS

Although the data obtained largely support the concepts outlined in the DSS for organic N management, the reality in the field is such that the availability of high quality, fertilizer-like organic materials is very limited. Therefore, the arms dealing with medium to low quality organic resources are likely to be most relevant for real cropping systems. Such organic resources are recommended to be applied in combination with mineral fertilizer, and when doing so, added benefits do occur, although their mechanistic basis is most of the time not clearly understood. The relevance of such potential added benefits needs to be assessed for various biophysical environments and crops. In conditions where it is difficult to assess these potential benefits, assuming additive effects is usually good enough as a first approach, as negative interactions are not commonly observed. Finally, generation of the needed knowledge will by itself not change the way farmers are managing their organic and mineral resources. This knowledge needs to be condensed into tools adapted to the clients targeted.

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