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Management of organic inputs in East Africa: A review of current knowledge and future challenges

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ABSTRACT

Organic inputs in Africa are used mainly as sources of crop nutrients but most of the ones available on the farms such as crop residues, animal manures and composts are of low quality and insufficient quantity. Proper management of such organic inputs to ensure sustained crop productivity poses a major challenge. Current research efforts aim to increase the understanding of the interactions between organic inputs, the soil and the crop with a view to developing predictive management guidelines. The factors influencing nitrogen mineralization in various plant residues have been identified and a decision support system (DSS) which makes practical recommendations for their appropriate use as nitrogen sources has subsequently been developed. This DSS has, however, not proved useful when applied to animal manures. To increase nutrient use efficiency, synchronization of nutrient release from the organic materials with crop demand has been attempted but attainment of perfect synchrony appears unlikely. Given that neither organic nor inorganic fertilizers alone can achieve sustainable crop productivity, focus has now shifted to the integrated soil fertility management paradigm that advocates for combined use of organic and inorganic sources of nutrients. Whereas the biophysical aspects of organic input management have been studied in detail, social and economic analyses are rare. Our knowledge of organic input systems, therefore, remains imprecise. This has made development of economically and socially acceptable guidelines for organic input management difficult. Adoption of the organic input technologies is consequently disappointingly low and the biggest challenge is to have these technologies adopted by farmers.

Key words: Adoption, integrated soil fertility management, organic inputs, predictive guidelines.

INTRODUCTION

Management of organic inputs in Africa has evolved over the years alongside the paradigms related to soil fertility management. Use of organic inputs was the traditional way of replenishing soil fertility but emphasis shifted to the use of mineral fertilizers in the 1960's as they became more abundant and economically attractive [1]. Increasing costs of fertilizers and concerns for sustainability, however, renewed interest in the use of organic inputs such as animal manures, green manures, composts and crop residues to replenish soil fertility in the 1980's in the so-called low input sustainable agriculture (LISA) [2]. Later it was realized that the LISA techniques could not produce crop yield increases that were commensurate with the increasing populations as the productivity of organic farming systems was considerably lower than the conventional use of mineral fertilizers [3]. The need to balance productivity and sustainability was recognized and thus at the turn of the millennium the paradigm of integrated nutrient management gained currency [4].

Each shift in the paradigm of organic input management was accompanied by intense research in an attempt to better understand the role of organic inputs in improving soil quality and mechanisms by which they improved crop yields. The ultimate aim was to arrive at a deeper understanding of the interactions of organic inputs with the soil and crop, which would lead to predictive management of organic inputs similar to that of inorganic fertilizers. While the roles of organic inputs and soil organic matter in soil fertility are now well documented, guidelines for their proper management are yet to be fully developed. This paper reviews advances in our understanding of both the biophysical and socio-economic aspects of the management of organic inputs in East Africa with special focus on their role of supplying crop nutrients, particularly nitrogen and phosphorus.

Quality and Quantities of nutrients supplied via organic inputs on the farms

In East Africa, organic materials are often more important than fertilizers in maintaining soil fertility. The traditional organic resources on most farms are crop residues, compost and animal manures. A question often posed is; what quantity of nutrients can be produced on smallholder farms by organic resources? Determination of quantities of organic inputs and the nutrients they supply has, therefore, always been a pertinent issue. Knowledge of the biomass production and nutrient concentration of the nutrients in the plant tissues is essential in calculating the potential nutrient supply from plant residues. The biomass and nutrient content within the biomass will vary with the soil properties, climate and the production system under which the organic material is grown [5]. Variability of these factors from region to region has hampered efforts to derive a universal predictive model for the amounts of nutrients that could be provided by plant residues. Nevertheless, tremendous progress has been made in characterizing the nutrient content of the available organic resources in eastern Africa [6,7]. Most of these organic materials are low in nutrients, particularly P, as illustrated in Table 1. Substantial amounts of these materials would, therefore be required to provide sufficient nutrients for most crops. Some of the organic materials e.g. crop residues have competing uses, primarily as livestock feed and fuel that reduce the amounts that are available for managing soil fertility [8]. Production of sufficient organic resources from the commonly available plant residues on farms, to meet crop nutrient demand, thus remains a major challenge in East Africa. Recent research efforts have focused on increasing the generation of non-traditional organic resources using agroforestry interventions such as improved fallows and biomass transfers to increase the amount of nutrients supplied by organic inputs.

Table 1. Nutrient contents of commonly available organic resources among smallholder farmers in Kenya. [6, 9]

Resource	Nutrient content (% dry matter)				
	N	P	K	Ca	Mg
Napier grass	1.02	0.11	2.63	0.35	0.06
Maize stover	0.89	0.80	2.78	0.41	0.18
Bean trash	1.20	0.13	2.06	0.89	0.16
Cowpea trash	0.57	0.05	1.79	0.81	0.08
Pigeon pea prunings	1.33	0.10	1.02	0.37	0.09
Sweat potato vines	2.27	0.14	3.05	1.32	0.53
Cattle boma manure	1.40	0.20	2.38	0.39	0.27
Poultry manure	3.11	0.42	2.40	0.82	0.42
Goat/sheep manure	1.48	0.20	3.31	0.94	0.42
Domestic compost	1.34	0.20	1.82	0.39	0.22
Tithonia diversifolia (Leaf)	4.25	0.26	4.03	1.93	0.41
Calliandra calothyrsus (Leaf)	3.03	0.11	0.61	0.91	0.40
Sesbania sesban (Leaf)	4.58	0.24	1.13	5.43	0.49
Crotalaria grahamiana (Leaf)	3.42	0.16	0.64	1.84	0.53
Lantana camara (Leaf)	4.51	0.33	2.59	1.49	0.66

Animal manures are perhaps the most widely used organic inputs on smallholder farms in East Africa. Most work on animal manures has focused on cattle, which are the most important livestock in most farming systems in terms of abundance and amounts of nutrients transferred [10]. The task of accurately predicting the quantity and quality of animal manures on smallholder farms has proved to be difficult. This is mainly due to the diverse livestock management practices that are used in producing manure. However, estimates of the amount of manure produced on farms have been attempted based on reports that most ruminants produce 0.8% dry matter of their live-weight as faecal material [11]. While several studies previously concluded that the quantities of manure available on smallholder farms are inadequate to meet crop nutrient demand [e.g. 12; 13], a recent study in central Kenya [14] indicates that production of manure in some localities can be substantial under proper management. In this study, it was reported that some small-scale farms (less than 0.45 ha) produced an average of 8.2 t dry weight/ha/year of manure (Table 2) when improved collection and storage techniques were used. This amount of manure could sustain the nutrient extraction rates required by intensive cropping as long as farmers continued to supplement livestock feeds from off-farm. However, scarcity of manures in relation to cropped land rather than excesses still remains the norm in East Africa. Recent research effort is thus focused on ways of increasing the quantities and quality of manures that are produced on smallholder farms under the various livestock management systems. Specifically, emphasis is on designing storage technologies that reduce losses after manure excretion. For example, [15] found that improving the roofs and floors of cattle stalls can assist in minimizing N losses and contamination of manure, thus resulting in a more concentrated product containing greater amounts of the nutrients excreted.

Table 2. Ruminant holdings on farms of varying size and estimated annual production of faeces ha^{-1} in Central Kenya [14]

Farm size	Mean (and range of) ruminant livestock numbers			Mean (and range of) estimated production of faeces (t DM/ha/yr)
	Large cattle	Small cattle	Small ruminants	
Small	3.1 (1-9)	1.5 (0-9)	1.5 (0-9)	8.2 (3.1-18.9)
Medium	3.5 (1-11)	2.3 (0-8)	2.3 (0-8)	3.6 (0.5-10.2)
Large	5.4 (0-20)	1.2 (0-5)	4.6 (0-21)	2.2 (0.1-5.1)

Predicting nutrient release from organic inputs

In soil fertility management of many tropical farming systems, organic inputs play a dominant role because of their short term effects on nutrient supply to crops. The bulk of the nutrients in organic materials are in the organic form and thus not available to plants unless mineralization takes place. An understanding of the nutrient release patterns of organic resources is, therefore, important in assessing their potential to supply nutrients to a crop [16]. This section examines the release of nutrients from organic inputs through the mineralization process with specific focus on N and P.

Nitrogen mineralization

There is considerable literature reporting decomposition and nitrogen release patterns for a variety of organic materials from tropical agroecosytems. The factors determining decomposition and nutrient release patterns have now been established. These include quality of the organic resource, temperature, moisture, and soil factors such as texture, pH, biological activity and presence of other nutrients [17]. Of these factors, most research attention has focused on organic resource quality because it is easier to manipulate [18]. Several chemical indices which represent the quality parameters have now been identified and used to predict mineralization of N from organic materials. These include the C:N ratio, N, lignin and polyphenol contents [19, 20]. In general, high quality organic residues are low in lignin (< 15%) and polyphenol (< 4%) content and high in %N (> 2.5 %) and release nutrients rapidly during decomposition while low quality materials release nutrients slowly or immobilize nutrients during early stages of decomposition [21]. An organic resource database (ORD) which contains information on organic resource quality parameters, including macronutrients, lignin and polyphenol contents of fresh leaves, litter, stems and/or roots from almost 300 species found in tropical agroecosystems has been developed [22]. A decision support system (DSS) (Figure 1) which makes practical recommendations for the appropriate use of organic materials as sources of N based on whether they mineralize or immobilize N was subsequently developed from the analysis of the ORD [22, 23].

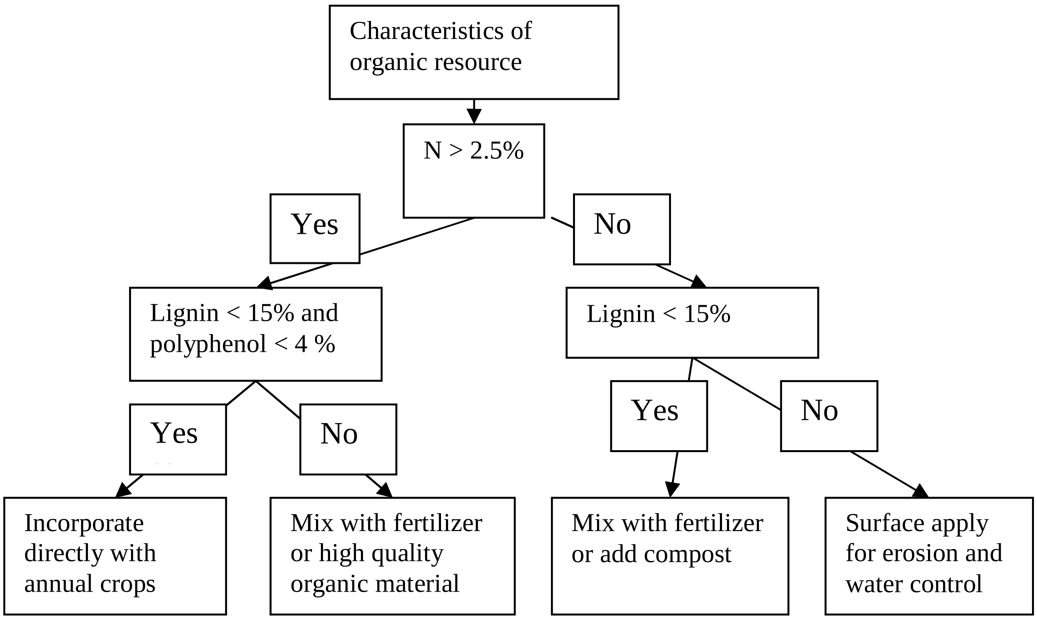

Figure 1. A decision tree for the guiding the use of organic resources in agriculture [Source: 22]

This DSS is, however, not universally applicable to all organic inputs. For example, cattle manure does not seem to conform to outcomes predicted by the decision tree since manure is normally a low quality organic resource (usually < 2% N) if not well managed and yet it promotes crop performance to an extent similar to high quality resources of plant origin [15]. The need to develop different criteria for predicting manure quality based on chemical characteristics unique to manures that can be linked to nutrient mineralization and crop performance has therefore been recognized [14].

Phosphorus mineralization

Although an understanding has now emerged on the effect of quality of organic input on N release, little is known about quality with respect to P. The few studies reported on P indicate that net P mineralization patterns are determined primarily by P concentration in the organic material. Organic materials with a P content of less than 0.25% have been found to immobilize P [24, 25]. The C:P ratio has also been used to predict release of P from organic residues. C:P ratios of > 300 have been reported to induce immobilization while organic materials with C:P ratios of < 100 readily mineralize P [26]. Unlike for N, the effects of other quality parameters such as lignin and polyphenol content on P mineralization have rarely been reported in eastern Africa.

Simultaneous nitrogen and phosphorus mineralization

The relationship between N and P mineralization patterns from the same organic material is not clear. Only few studies have attempted to simultaneously investigate N and P mineralization. For example, [27] reported that some materials showing net N mineralization can result in net P immobilization and vice versa. For a simultaneous net mineralization of N and P to occur, the organic material should have a tissue N of > 2.5% [28] and a P concentration of > 0.25% [25]. Most of the organic materials listed in the ORD do not meet these criteria. This has practical implications in that some organic materials can release N while immobilizing P at the same time or vice versa, thus leading to lack of crop response in sites that are both N and P limited. No field studies have been reported on this phenomenon. Studies that simultaneously investigate the mineralization of N and P for a cross-section of organic resources and their effect on crop performance are needed.

Synchronizing nutrient release with crop demand

The aim of synchronizing nutrient release with crop demand is to increase the nutrient use efficiency. Studies on synchrony have mainly focused on N. A perfect N supply for plant growth should provide the required amounts of N in exact synchrony with plant demand [29]. Such a perfect supply for plant growth would have the dual benefits of ensuring efficient use of what are often scarce resources whilst avoiding unwarranted losses and associated environmental problems that such losses cause [30]. It is recognized though that such a perfect N supply is unlikely to be achieved in reality, but it serves to highlight the importance of quality and timing of N availability in the soil in relation to both the quantity and timing of N demand from the crop [31].

A two-pronged approach has usually been used in efforts to achieve N synchrony: (1) manipulating the decomposition of the organic materials to release nutrients when they are needed by the crop and (2) regulating demand by providing a favorable environment for plant growth [23]. [`32] reviewed the approaches that have been employed to manipulate decomposition of plant litter and hence enhance N synchrony. These mainly involve production of prunings of varied quality which are then mixed to regulate decomposition and nutrient release. Thus in the presence of low-quality (low N and P, high lignin or polyphenol content) organic inputs, immobilization of nutrients results, leading to short-term deficiencies, but these nutrients will later be released at a time of plant need. With high quality litter, nutrients are released rapidly, initially in excess of plant demand and there is a risk of nutrients such as N being lost through leaching or denitrification. A mixture of low quality and high quality material would result in better synchrony in supply and demand. Field management of the organic materials e.g. varying the way in which they are incorporated into the soil or surface applied and timing of the organic material application have also been tested to determine their effect on synchronization of nutrient release and crop demand [33].

Organic inputs in the integrated soil fertility management strategy

The realization that neither organic inputs nor inorganic fertilizers alone can achieve sustainable productivity of the soil and crop under highly intensive cropping systems has rekindled interest in the combined use of organic and inorganic sources of nutrients for crop production. This has culminated in the development of the integrated soil fertility management (ISFM) paradigm whose technical backbone is the optimal management of organic resources, mineral fertilizer inputs and soil organic matter pools [34]. Combination of mineral fertilizers and organic nutrient sources often results in synergistic effects on crop yields. For example, [35] demonstrated that application of three inorganic P sources i.e. triple superphospate (TSP), Minjingu phosphate rock (MPR) or Busumbu phosphate rock (BPR) at a P rate of 40 kg ha^{-1} in combination with tithonia green leaf biomass applied to provide 20 kg P ha^{-1}, gave maize yields that were more than 90% those obtained from their respective combinations with urea (total P rate for the urea and inorganic P sources was also 60 kg ha^{-1}) in the three seasons of experimentation in an acid soil.

Combining these inorganic P sources with farmyard manure (FYM) also gave higher yields than those of inorganic P sources applied with urea but the increase in yields (about 50% in the three seasons) as a result of using FYM in the combination was much less than that obtained when tithonia was used. This implies that the quality of the organic material in the combination is important in determining the response of crops to the combined organic/inorganic input application. In the cited study, tithonia was a high quality organic material (3.4% N, 0.3% P and 4% K) whose ability to reduce the level of exchangeable Al and thus aluminum phytotoxicity in the acid soil used in the study, was superior to that of the low quality (1.2% N, 0.2% P and 2% K) FYM. The inability of the inorganic P sources when applied in combination with urea to reduce exchangeable Al contributed to the low yields recorded with those treatments. Several other studies in eastern Africa [e.g. 9; 36; 37] have similarly demonstrated synergism when organic materials were applied in combination with inorganic fertilizers. However, the cause of synergism in most of these studies was often attributed to the ability of the organic inputs to enhance P availability in the P-fixing soils. The organic materials were also credited with providing other macro/micro nutrients, especially those not present in the commonly used fertilizers and conserving moisture.

Combining organic and inorganic nutrient sources, however, does not always guarantee increased crop productivity. [38] observed a decline in dry matter yields of maize when Busumbu phosphate rock was combined with tithonia compared to application of tithonia alone. Similarly, the agronomic effectiveness was not improved when low quality composts were combined with Minjingu phosphate rock in Tanzania [39]. It is now emerging that combination of some organic materials with phosphate rock (PR) may retard the dissolution of the PR [40] thus reducing its agronomic effectiveness. Immobilization of nutrients (e.g. N) when low quality organic inputs such as maize stover or sawdust are used may also reduce crop yields. [41] reported that due to lack of proper management guidelines, most farmers who used a combination of organic and inorganic inputs often obtained low crop yields because of inadequate nutrient inputs, inappropriate quality of organic materials used and inefficient combinations. These authors thus proposed a systematic framework for investigating the combined use of organic and inorganic nutrient sources in relation to farmer circumstances, organic resource quality, and their fertilizer equivalency values. Not much progress has been made in using the suggested framework and considerable research challenges, therefore, still exist in identifying, quantifying and developing predictive ability of effects of organic materials on the effectiveness of inorganic fertilizers [42].

Table 3. Maize grain yield (t ha^{-1}) under different organic and inorganic input combinations at Kakamega in western Kenya [Source: 35].

Organic material (OM)	Inorganic P source											
	2006 Long rains season				2006 Short rains season				2007 Long rains season			
	MPR	BPR	TSP	Mean	MPR	BPR	TSP	Mean	MPR	BPR	TSP	Mean
Tithonia	4.9	4.4	5.1	4.8	2.3	1.3	2.4	2.0	4.4	3.9	5.3	4.5
FYM	3.2	2.9	2.7	3.0	1.4	1.0	1.4	1.3	2.7	2.4	3.0	2.7
Urea	2.6	2.0	2.2	2.3	1.1	0.7	1.0	0.9	2.4	1.4	1.5	4.5
Mean	3.6	3.0	3.4	3.3	1.6	1.0	1.6	1.4	3.2	2.6	3.3	3.0
SED OM	0.26				0.18				0.19			
SED inorg. P	0.26				0.18				0.19			
SED OM X inorg. P	0.44				0.31				0.33			

Note: The P rate was balanced at 60 kg P ha^{-1} in each of the treatment combinations. Tithonia and FYM provided 20 kg P ha^{-1} while TSP, MPR or BPR provided 40 kg P ha^{-1} in the combination. Where urea was used, the inorganic P sources were applied at 60 kg ha^{-1}. FYM = Farmyard manure; TSP = triple superphosphate; MPR = Minjingu phosphate rock; BPR = Busumbu phosphate rock; inorg. P = Inorganic P source 2006 LR and 2007 LR are the 2006 and 2007 long rains seasons respectively, 2006 SR is the 2006 short rains season. SED = standard error of difference between means.

Socio-economic issues in management of organic inputs

Whereas the biophysical aspects of organic input management have been studied in detail, social and economic analyses in studies with organic inputs have been rare in East Africa. The ability of farmers to make informed choices on the organic input technologies to adopt, based on economic data, has thus been greatly limited. It is now widely recognized that profitability is a good indicator towards the adoption process of technologies, particularly in the smallholder farming community [43]. Consequently, several recent studies [e.g. 44, 45; 46] have now combined agronomic evaluation with economic analyses of the tested organic input technologies. Results of these economic analyses invariably demonstrated positive economic benefits of using most of the commonly available organic materials on smallholder farms. However, they did not always confirm the popular belief that organic inputs are cheaper and hence give more profit when used for crop production than inorganic fertilizers.

Typical results from such analyses from a study in Meru South District in Kenya [47] are presented in Table 4. The results indicated that on average, across the seven seasons of the study, tithonia with half the recommended rate of mineral fertilizer recorded the highest net benefit of USD 787 ha^{-1} while the control had the lowest (USD 272 ha^{-1}). On average across the seven seasons, treatments with sole application of organics recorded a higher benefit cost ratio (BCR) compared to treatments with combined organic and mineral fertilizers. Conversely treatments with sole organics recorded lower return to labour compared to the treatments with combined organic and inorganic inputs, apart from leucaena. Indeed, the high costs of labour associated with the use of some organic inputs led to negative financial returns in some other studies [48]. This is likely one of the reasons for the slow pace or lack of adoption of some agronomically very effective technologies such as the tithonia biomass transfer. Other reported constraints to the adoption of organic matter technologies by smallholder farmers include; limited income, substantial risk aversion and the need to produce food crops on almost all the arable land thus leaving room for organic matter technologies such as improved fallows [5].

Table 4. Net benefit, benefit-cost-ratio (BCR) and return to labour from 2000 to 2003 in Chuka, Meru South District, Kenya [47]

Treatment	USD ha^{-1}		
	Net benefit	BCR	Return to labour
Cattle manure	645 b	5.0 bc	5.0 cb
Cattle manure + 30 kg N ha^{-1}	616 b	3.5 c	6.8 bc
Tithonia	784 a	4.0 bc	4.0 d
Calliandra	653 b	5.8 ab	5.9 cd
Leucaena	780 a	7.0 a	7.0 bc
Tithonia + 30 kg N ha^{-1}	787 a	3.5 c	6.3 cd
Calliandra+ 30 kg N ha^{-1}	747 a	4.4 bc	9.0 b
Leucaena + 30 kg N ha^{-1}	572 b	4.3 bc	6.9 bc
60 kg N ha^{-1}	666 b	3.6 c	12.5 a
Control	272 c	5.2 abc	5.2 cd

Means with the same letter in each column are not statistically different at $p < 0.05$. The 30 and 60 kg N ha^{-1} are provided by mineral fertilizer.

In an effort to improve adoption rates of organic input technologies among smallholder farmers, several solutions have been proposed. Participatory technology development (PTD), where farmers are involved in the research process, is the most popular of the suggested solutions [49,50]. It is believed that, the more client-driven a technology is, the higher the chances that users will themselves have an interest in having the innovations scaled up [51]. However, while involving farmers is important, it may not be a sufficient condition for ensuring that the developed technologies are adopted. There are many examples of projects where farmers have been involved but nevertheless failed to adopt the technologies [52]. There is evidence, however, that technologies that are economically profitable in the short-run, have low initial investment capital, reduce discomfort or save time and effort, or provide social prestige would sustain interest in those technologies [52]. Unfortunately not many organic input technologies meet these criteria.

CONCLUSION

Tremendous progress has been made over the years towards understanding the biophysical aspects of organic input management in East Africa. Many organic input technologies have been generated in the process. However, our knowledge of organic input systems still remains imprecise particularly from the socio-economic perspective. This has made development of economically, socially and environmentally acceptable guidelines for organic input management difficult. Adoption of organic input technologies by farmers is thus disappointingly low. The biggest challenge facing organic input management research in East Africa is, therefore, to bridge the gap between generation of technologies and their actual uptake by the farmers. Consequently while efforts are required to expand our knowledge of the biophysical aspects of organic input management, similar efforts should be directed towards socio-economic aspects of organic input management.

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