NUTRIENT MINING OR CARBON SEQUESTRATION? BNF INPUTS CAN MAKE THE DIFFERENCE

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Intensive mechanised grain production systems in Brazil occupy over 40 million hectares (Mha). Most of this area is dedicated to soybean and maize production in summer in rotation with oats, wheat, or green manure crops in the winter. In the 1960s and 1970s, it was common to grow soybean continuously, followed by wheat using conventional tillage. Apart from the problems of pest and disease build up owing to low crop diversity, the twice-yearly intensive tillage led to loss of soil organic matter (SOM) and increasing soil erosion, especially on more sandy soils. Because of this, at the start of the 1970s, several wealthy innovative farmers started to experiment with direct drilling of crops (zero tillage, ZT). With the help of the state and federal research institutes, university agricultural faculties and the pesticide companies, this technology gradually developed and approx. 1 Mha was under ZT by the start of the 1990s. However, as better practices and herbicides were developed, it became evident that as ploughing was abandoned, there were large savings to be made in terms of tractor fuel. Hence, even in areas where soil erosion was not an evident problem, adoption of ZT increased rapidly not only in the southern region, but also in the Cerrado (central tropical savanna) region of Brazil such that today over 24 Mha are cropped under this system.

There is a general consensus in North America that, where reduced or zero tillage has been adopted, SOM levels will increase with time. Recently, this consensus has been challenged by Baker et al. (2007), who suggested that the conclusion that the adoption of ZT stimulates soil C sequestration was probably an artefact of the fact that soil sampling in such studies was limited to only 20–30 cm depth. However, recent studies in Brazil, where soils were sampled to 80 or 100 cm depth (e.g., Sisti et al., 2004;

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Diekow et al., 2005), show conclusively that, in medium to high productivity systems when the cropping system showed a positive N balance, soil C accumulation can reach or exceed 1 mg ha^{-1} $year^{-1}$ for at least 10 years. For the system to have a positive N balance, it is necessary that the external inputs of N to the system (fertiliser N and biological nitrogen fixation, BNF) exceed the N exported in grain or lost by leaching or in gaseous forms. In these studies, the N balances were positive because the crop rotations included N_2-fixing leguminous cover crops such as lupins, vetch or clover from which no grain was exported. Almost all of these rotations are based on soybean, which we have shown can contribute in excess of 200 kg N ha^{-1} $crop^{-1}$. However, the quantity of N exported in the grain (~80% of shoot N) usually exceeds the BNF contribution and the N balance of crop rotations comprised only of soybean and cereal crops rarely show a positive N balance and no detectable C sequestration occurs (Machado and Silva, 2001; Sisti et al., 2004).

The loss of SOM from tropical soils caused by frequent tillage is well documented and is particularly acute when agricultural products are removed from the field and there are no inputs of nutrients from fertilisers or other sources. In the countries of sub-Saharan Africa, the great majority of farming systems do export more from farm properties than is applied in external inputs (Stoorvogel and Smaling, 1998). This phenomenon, known as “nutrient mining”, results in the gradual decrease in soil fertility with time. The questions are: can the technology of zero tillage and the introduction of leguminous cover crops be adapted for resource-poor farmers in such regions? And, will it both increase food crop yields and promote a gradual increase in SOM levels?

With regard to first question, the prerequisites appear to be some correction of soil fertility with modest applications of P and K fertilisers, and sufficient length of the rainy season (or a bimodal rainy season) to allow at least 90 days of legume cover crop growth prior to the main grain crop. Several reports from various regions have shown that crop yields can be increased with such technology (VanLauwe et al., 2002). In Swaziland, the FAO technical mission undertaken by Prof. Telmo Amado showed convincingly that yields of maize and sorghum on small-holder properties could be increased from less than 1 mg ha^{-1} to up to 4 mg ha^{-1} with the adoption of this package of technology (results shown at this Congress). The question of whether SOM levels will increase has not been answered satisfactorily as yet. Long-term monitoring of soil SOM levels in fields where this package of technologies has been adapted is highly desirable but nutrient balance studies can more rapidly, albeit less convincingly, demonstrate how SOM stocks are changing.

For nutrient balance studies, nitrogen is an excellent indicator because it is usually the element in the highest quantity in the crop, and is highly susceptible to losses (gaseous or via leaching). To compute an N balance, it is necessary to estimate the inputs of N from BNF and fertiliser (inorganic or organic) and the N exported in crop products or lost in gaseous forms or by leaching. With ZT, erosion losses should be minimal, and models may indicate the approximate magnitude of N losses.

In a study planted in an N-deficient soil at Embrapa Agrobiologia by Dr Aimée Okito, a simple N balance (BNF–N exported in grain; no N fertiliser was applied) was computed for the sequences groundnut, Mucuna or fallow (Okito et al., 2004). BNF was quantified using the ^{15}N natural abundance technique. The results of the N balance showed that, when both groundnut (1.0 mg ha^{-1}) and maize grain (2.57 mg ha^{-1}) were removed from the system, there was an overall removal from the system of at least (N losses were not quantified) 36.5 kg N ha^{-1} (Table 1), which showed that soil N was being mined from the system. In the sequence Mucuna-maize (Mucuna seeds were not harvested, maize yield 2.97 kg ha^{-1}), there was small positive balance of +8 kg N ha^{-1}.

Table 1. Simple N balance for the sequence of groundnut, velvet bean (*Mucuna pruriens*) or natural fallow, followed by maize variety Sol de Manhã (after Okito et al., 2004).

Legume crop before maize	N derived from BNF	N exported in legume grain	N exported in maize grain	Overall N balance[a]
		(kg N ha^{-1}) Maize variety: Sol de Manhã		
Groundnut	55.6	49.4	42.7	–36.5
Velvet bean	59.6	0.0	51.8	+7.8
Fallow[b]	30.9	0.0	33.6	–2.7

[a]N Balance calculated from export of N in grains minus input of N from BNF in aerial tissue
[b]The natural fallow was rich (70% of dry matter) in the legume *Indigofera hirsuta*

The benefit of the introduction of either legume on maize or total (maize + groundnut) grain yield was clearly demonstrated. The system that gave most income to the farmer was the groundnut followed by maize (US$520 ha^{-1} compared to Mucuna followed by maize, only US$276) would not be sustainable because SOM reserves were being depleted. This simple study sounds a note of warning. The introduction of legumes into farmers systems should be accompanied by nutrient balance (or equivalent) studies to investigate if SOM is being depleted or accumulated. If the balance is negative, as in the case of the sequence groundnut-maize in this study, it will be necessary to modify the package (e.g., addition of N fertiliser to the maize) until at least an approximate neutral nutrient balance is achieved.

Increased SOM levels bring very considerable direct benefits to the farmer and the removal of CO_2 from the atmosphere during this process pleases environmentalists everywhere. SOM build-up increases the capacity of the soil to store and exchange nutrients, and strengthens soil structure to resist erosive losses. It follows that to increase the productivity of resource-poor smallholders, it is essential to eliminate nutrient mining and promote SOM acquisition. This can only be viable using N_2-fixing legumes in a technological package which includes the elimination of soil tillage and, where necessary, liming and mitigation of P and K deficiency with fertiliser addition. The search for suitable genotypes of grain and cover crop legumes, which are drought tolerant, should be an urgent research priority. The vast biological diversity of such legumes has hardly been investigated, let alone exploited. For example, there are approximately 800 species of *Crotlaria*, but only very few genotypes of one or two species have been tested for use as cover crops and this resource could be of enormous benefit to building soil fertility on small-holdings all over the developing world. We as specialists in biological N_2 fixation should be encouraging funding agencies to finance projects which acquire and test such legumes in real on-farm situations and examine nutrient balances and SOM dynamics *in situ*.

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References

Baker JM et al. (2007) Agric. Ecosyst. Environ. 118, 1–5.
Diekow J et al. (2005) Soil Till. Res. 81, 87–95.
Machado PLO de A and Silva CA (2001) Nutr. Cycl. Agroecosyst. 61, 119–130.
Okito A et al. (2004) Pesq. Agropec. Bras. 39, 1183–1190.
Sisti CPJ et al. (2004) Soil Till. Res. 76, 39–58.
Stoorvogel JJ and Smaling EMA (1998) Nutr. Cycl. Agroecosyst. 50, 151–158.
VanLauwe B et al. (2002) Integrated Plant Nutrient Management in Sub-Saharan Africa: From Concept to Practice. CABI, Wallingford/Oxon, UK.