Potential greenhouse gas savings from balanced fertilisation

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Abstract
World fertiliser consumption has moved largely to high analysis, non-sulfur containing products which, in many situations, has led to sulfur (S) deficiency and consequently reduced nitrogen use efficiency (NUE). Calculations on data from field experiments conducted in China with rice and soybeans have been used to estimate the reduction in N_2O emissions resulting from addition of S to mono-ammonium phosphate (MAP). Balanced nutrition using MAP+S in two experiments in China resulted in an increase in NUE of 9.4% in flooded rice and 12.6% in soybeans. Assuming a loss of 20% of fertiliser N as N_2O in flooded rice and 10% in soybeans the increased N usage by the crop results in a potential N_2O saving of 3.9 and 1.2 kg N_2O/ha, respectively, in the two crops.

Balanced fertilisation and crop residue management can also be used to abate agricultural CO_2 emissions. Using data from an extensive field research program, it is estimated that addition of S to MAP in a temperate climate can result in an incremental CO_2 sequestration in excess of 8 t CO_2/t applied S and this can be increased a further 4% if crop residues are retained. The increased crop residue produced, and retained, as a result of balanced fertilisation resulted in an estimated incremental CO_2 sequestration of 3.7 t CO_2/t S applied in a tropical crop production system to 5.5 t CO_2/t S applied in a temperate system.

Key words: greenhouse gas, carbon dioxide, methane, fertiliser efficiency

Introduction
The plant response to balanced nutrition can result in an increase in the yield of product (grain, oil, cash crop etc.), in the yield of residues (straw, stover etc.) and root mass. The question arises as to the value of these additional residues and root mass. Can they be used effectively in the system and what effect is there on the global CO_2 balance? In general, the residues either remain in the field or are removed and used in other ways. If they remain in the field, they can be left on the soil surface, incorporated by ploughing, or burnt. If they are removed they can be used in the manufacture of carbon stable products, fed to animals, used for animal bedding, or used as fuels. These alternative uses have vastly different consequences for C sequestration and global CO_2 fluxes.

Most of the current discussion on global warming is concentrated on the greenhouse gas (GHG) carbon dioxide (CO_2). However, gasses such as nitrous oxide and methane are also significant contributors to global warming. The relative global warming potential of these gasses relative to CO_2 is methane (CH_4) 21 times and nitrous oxide (N_2O) 310 times (Myhre 2013)., Of the GHGs released to the atmosphere internationally, agriculture accounted for approximately 25% of CO_2, 50% of CH_4 and 70% of N_2O in 2007. (Smith et al., 2007)

When S is applied to a soil that is deficient in S a yield response can be anticipated. Improvement in the nutrient balance of the system may result in an improvement in the utilization efficiency of other plant nutrients. In the case of S, there is most often an increase in both N and P use efficiency.

The effect of adding S to MAP has been evaluated in a wide range of climatic/soil/crop situations (Blair 2015). Of the 136 field experiments conducted, where nitrogen and all other nutrients were balanced between treatments so that S was the only variable, 84 were responsive to S with a weighted mean yield increase to S of 14%, compared with the zero S control. These data form the basis of this study.

In addition to increased crop yield, increased crop residue production results and the management of this can have a marked effect on C and N balances. Lal (1997) has estimated from a survey of world literature that approximately 15% of the biomass of crop residues retained in the field is retained in the soil and can be sequestered in the soil C pool. Contributions to this figure come predominantly from temperate agriculture. It would be expected that the C sequestration rate would be lower in tropical agriculture because of higher degradation rates resulting from higher temperatures and generally higher rainfall. A retention value of 10% has been assumed for tropical systems in this exercise.

When investigating the results from a study by Blair et al (2006a) on the Rothamsted, Broadbalk long term experiment it was shown that 11 years of straw retention had resulted in the retention of approximately 12%

of the C from the returned straw within the soil plough layer, while 155 years of farm yard manure (FYM) application at 35 t/ha/yr (fresh weight) had resulted in the retention of approximately 4% of the C from the added FYM being retained in this soil layer. In another study by Blair et al (2006b) on the Bad Lauchstadt extreme manure experiment it was determined that the addition of 200 t/ha/yr (fresh weight) of FYM for 14 years had resulted in the retention in the soil plough layer of approximately 9% of the additional C added in the FYM. The lower C retention from the FYM compared with straw mainly results from the additional nitrogen from livestock urine, increasing the microbial decomposition of the straw and manure in the FYM. Decomposition of FYM in soils can vary widely and is dependent on several factors including storage time before field application, climatic conditions and feedstuffs fed to the livestock which will influence the chemical composition of the FYM.

CO_2 sequestration from increased product yield and crop residue retention

A scoping exercise based on field studies has been undertaken to examine the likely consequences for CO_2 balances when S is added as MAP or DAP in S responsive situations. The values presented in Table 1 have been used for key variables.

Table 1. Values used in the worked example of CO_2 sequestration when SEF replaces MAP

Variable	Value	Rationale
Crop economic yield	6 t/ha	FAO statistics
Crop residue yield	Equal to economic yield	Experience
Crop root yield	Half of residue yield	Estimate
C concentration in crop	50%	Average of world literature
Crop response to S	14%	Average of field trials
S application rate	30 kg/ha	A rate generally used
Residue retention rate in soil in temperate region	15%	Survey of Lal (1997) and data of Blair et al. (2006a)
Residue retention rate in soil in tropical region	10%	Estimate based on temperate data
Return of farm yard manure (FYM)	Equal to residue yield	Estimate
FYM C retention rate in soil	5%	Blair et al. (2006a)

There is no net effect from increased product yield (grain) on the global CO_2 balance because the CO_2 fixed by photosynthesis into the product is respired as CO_2 by the consumer or lost in decomposition of wastes.

Table 2. Estimated CO_2 sequestration when a crop response of 10% is obtained when S is added to MAP in a range of cropping situations.

Region	Residue management	Incremental CO_2 sequestration ($t\ CO_2/ha$)	Incremental CO_2 sequestration per ton of S applied ($t\ CO_2/t\ S$)
Temperate	All returned [1]	0.25	8.26
Temperate	All removed	0.08	2.75
Tropical	All returned [1]	0.17	5.51
Tropical	All removed	0.06	1.84

[1] In the all residue returned areas additional residue returned = 10% of tops = 0.6 t/ha. In all cases 50% of additional roots produced (0.3t/ha) are assumed to remain in the soil. It is assumed that 15% and 10% of the returned crop residues contribute long term to the soil C pool in temperate and tropical areas, respectively.

Additional tops and root yields can contribute to stored soil carbon and hence CO_2 sequestration by increasing soil organic matter as shown in Table 2. Maximum estimated gains are in temperate areas where all the additional crop residues are returned and amount to in excess of 8 t CO_2/t S applied. This figure is reduced to 5.5 t CO_2/t S applied in tropical areas because of more rapid turnover of organic matter.

Increased nitrogen use efficiency (NUE) resulting from increased product yield

Data for rice grown at Putian, Fujian, China have been used to estimate the potential N_2O reduction resulting from the increased yields and consequent better nitrogen use efficiency (NUE) resulting from the addition of S to MAP. Increased NUE results from higher crop N uptake and hence in less N being available for denitrification where NO_3^- is converted to N_2O. The data in Table 3 show an estimated 12.6% increase in NUE when S and MAP were applied.

Table 3. Calculation of fertiliser N "saving" and potential N_2O emission saving using actual yield and N content data for rice grown at Putian, Fujian, China in 2004

Treatment	Yield (kg/ha)	N content of tops (kg/ha)	NUE (kg grain/kg N applied)
-S control	6090	84.1	45.1
SEF	6860	89.3	50.8
Difference	770	5.2	5.7 (12.6%)

Average data from S responsive trials in China have shown that increases in NUE in both rice and soybeans resulted in higher yield with the same N application rate and considerable fertiliser N "savings" (Table 4). The better utilization of N by the crops results in less N being available in the soil for leaching and losses as N_2O, a major greenhouse gas.

Table 4. Potential N_2O emission saving (kg/ha) resulting from balanced ferilisation in rice and soybeans in China.

Fertiliser	Grain Yield (t/ha)	Nitrogen Use Efficiency (NUE) (kg grain/kg N applied)	% increase in NUE over nil S control	Fertiliser N "saving" (kg/ha)	% N "saved"	Potential N_2O emission saving[1] (kg/ha)
				Rice		
MAP	6.53	43.9				
MAP+S	7.07	48.0	9.4	12.3	6.2	3.9
				Soybeans		
MAP	1.89	30.6				
MAP+S	2.13	34.5	12.6	7.8	11.7	1.2

[1] Assuming a loss of N as N_2O at 20% for rice and 20% for soybeans and 1 kg N denitrifies to 1.57 kg N_2O

Conclusions

Field experiments in China have demonstrated that the application of S to overcome soil sulfur deficiency improves the efficiency of utilization of other nutrients, particularly N, and this improvement in N use efficiency results in less N being available to be denitrified and potentially reduced N_2O emissions. These trials indicate that the resultant increase in crop yields not only contributes to increased CO_2 sequestration, particularly when crop residues are retained but also decreases the potential N losses from denitrification through greater crop N utilization .

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