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Do You Think it is Time to Consider Legume-Based Cropping Systems Again?

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Agriculture is one of the major global sources of greenhouse gas (GHG) emissions; on-farm sources alone emit roughly 60% of all nitrous oxide and 50% of all methane emissions (WRI, 2012). Modern agriculture is more intensified, mechanised and modernised than ever before, and there are increasing demands for more fuel, electricity, farm machinery and agrochemicals. In addition, many associated off-farm operations require significant energy inputs, resulting in even more GHG emissions [1-12]. As a result, from 1990 to 2005, GHG emissions from agriculture increased by 14%, with average annual increase in emissions of 49 Mt CO2e/yr (US-EPA 2006). Significant reductions in farm inputs are needed to reduce farming costs and to curb increasing GHG emissions. Cropping systems that minimise farm input related costs and GHG emissions and also improve the sustainability of the soil system are the demand of this century.

In the past, legume-dependent cropping systems were very popular across the world and a key factor in maintaining nitrogen levels in the soil. With the invention of the Haber-Bosch process of synthesizing ammonia, the primary ingredient for producing synthetic N fertilizers, farmers around the world replaced legume rotations and other traditional sources of N fertility with synthetic N fertilizers during the 20th century [13]. The rapid adoption of synthetic N fertiliser is reflected in increasing global fertiliser consumption. In conjunction with the replacement of legume based N-fertiliser by synthetic N-fertiliser, the worldwide use of agricultural pesticides also increased rapidly [2].

Part of the applied N-fertiliser and biologically-fixed N emits into the atmosphere in the form of N_2O, which has 298 times more global warming potential than CO_2 [14]. As a result, N_2O is responsible for an estimated 6% of observed global warming [15]. There is some debate within the scientific community about whether the biologically-fixed N emits as much GHG as N fertiliser. For example, Maraseni et al. [15] suggested that the N_2O emissions from legume crops exceed those from N due to frequent wetting and drying cycles over a longer period, while [16] argued that the biologically-fixed N is ultimately derived from solar energy while N fertiliser requires significant amounts of fossil fuels, thus, legumes should be have a lower impact. Despite this, the IPCC has set the same emission factor of 1.25% NO_2-N emissions per kg for both N-fertiliser and biologically fixed N.

Concern has also been expressed that the human population now exceeds the carrying capacity of agricultural systems that depend on legumes for N inputs [16,17] thus the complete avoidance of synthetic N fertiliser may be impossible, especially in densely populated countries with limited cultivatable land.

Despite these debates, in recent years, legume-based rotational cropping systems have become more popular for various reasons:

- N fertilizers have been linked to numerous environmental problems including marine eutrophication, global warming, groundwater contamination and stratospheric ozone destruction [15]
- Legumes can fix N and make N available to companion and/or subsequent crops thus reducing reliance on N-fertilisation and related costs and GHG emissions [6]
- Globally the price of N-fertiliser is escalating, and is expected to rise further with the global commitment to reduce energy consumption and GHG emissions; legumes offer a cheaper alternative;
- Legume-based rotations help to maintain pest populations and retard pest evolution [15] and therefore reduce pesticides application rates, related costs and GHG emissions;
- Legume-based rotations help to reduce weed seed banks [16] and therefore reduce herbicides application rates, related cost and GHG emissions;
- Under a global emissions reduction commitment, meat would be considerably more expensive and protein-rich legumes could provide a good substitute for animal protein;
- There is increasing recognition of the role of legumes in reducing cholesterol levels in the blood, reducing heart-disease risk and helping people with diabetes;
- N-fixing legumes can increase soil carbon levels [17] further improving the productivity, profitability and sustainability of soil systems, and help generate soil carbon credits if agriculture is included in the emission reduction targets;
- Some legumes have the capacity to prevent N leaching by producing nitrification inhibitors [18].
- Some legumes increase crops yield. For example, in Australia, the legume vetch increased cotton yield by ~18% when grown in rotation with cotton [19]. Cotton grown after vetch was better at taking up N, P, K, Zn and Cu [19]. Similarly, grain legumes in rotation with tropical crops improve the yield of cereals in tropical regions, and also reduce the incidence of wheat root rot which reduces wheat leaf disease and pests and
- Obtaining N from legumes is potentially more sustainable than from industrial sources [15].

Hence, exploring the potential of legume-based cropping systems, especially from a GHG emissions and environmental perspective is crucial. In particular, research comparing GHG emissions from soils and various on-and off-farm inputs between legume-based and N-fertiliser based monoculture, rotational and intercropping cropping

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systems is needed. This study should be essentially a life cycle analysis (LCA) of crops, estimating GHG emissions from seed to supermarkets. The specific objectives would include the estimation of GHG emissions from factors such as:

1. Flux of soil carbon;
2. Construction of buildings and building materials for specific purposes of the cropping industry;
3. Production and combustion of fossil fuels used for farm operations;
4. Production, packaging, storage and transportation of agrochemicals;
5. N_2O from soils due to use of N-fertiliser and production of biologically fixed N;
6. Production and use of electricity for irrigation;
7. Production of farm machinery used in the cropping;
8. Production and use of electricity for crops processing (cleaning, drying, etc.);
9. Production and transportation of crops packaging;
10. Transportation of crops from farms (or storage) to domestic markets;
11. Use of cold storage and processing facilities; and
12. Decaying crops wastes.

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