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ROLE OF FODDER PRODUCTION SYSTEMS TO IMPROVE CARBON SEQUESTRATION AND ENVIRONMENTAL SUSTAINABILITY

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ABSTRACT

Fodder-based livestock production plays a key role in food security and poverty alleviation, but is considered a major contributor to agricultural GHG emissions. Fodder production with best management practices is important for the mitigation of rising atmospheric carbon dioxide concentrations via carbon storage in biomass and soil organic matter through a process termed carbon sequestration. The strategies of carbon sequestration in fodder production systems include: adoption of pasture based agro forestry practices, grazing management, adding fertilizers and water, sowing of improved forage species, restoration of degraded lands and inclusion of grasses. Moreover, management practices that sequester carbon will deliver other co-benefits such as increased productivity, reduced erosion, improved soil quality and nutrient and water use efficiency, resource conservation, reduced costs, and social and cultural benefits. However, there are challenges that hinder the practice to overcome the potential usage. The challenges include, lack of appropriate policy, disturbance of rangeland, deforestation and degradation, lack of institutional capacity, documentation problem on carbon stock, land tenure and governance issues problem. In general potential of carbon sequestration in fodder production system is highly focused on the effective management practice.

KEYWORDS: Carbon Sequestration, Fodder Production System, Climate Change, Management Practices, Environment Sustainability.

INTRODUCTION

The increase in concentration of green house gases (GHGs) in the atmosphere is a major threat to food-fodder security and climate change in 21st century. The atmospheric concentration of carbon dioxide (CO_2) has increased globally by 40 per cent from 278 ppm in the pre industrial era to around 391 ppm in 2012, in the recent years there has been a consistent and continues increase in the emission of green house gases (GHGs) into the atmosphere due to the anthropogenic activities *viz*. burning of fossil fuels for energy, deforestation, land use change, biomass burning and draining of peat and wetlands (Ciais *et al.*, 2013, WMO, 2012). Anthropogenic activities have lead to notable changes over the 20th century in the earth's climate including increase in global temperature by 0.6± 0.2ºC at an average rate of increase of 0.17 ºC/ decade. Since 1950, sea level rise over 20th century of 0.1 to 0.2 m, increase in precipitation of 0.5 to 1.0%/ decade, and the increase in frequency of extreme events and heavy precipitations by 2 to 4 % (IPCC, 2007). The GHGs emission should be reduced by 50 to 80% by 2050 to avoid adverse effect of climate change. Although oceans store most of the earth's carbon, soils contains approximately 75 to 80% terrestrial carbon pool and higher than the biotic pool (*i.e*. the increased amount stored in living plants and animals). Therefore, soils play a key role in maintaining a balanced global carbon cycle. Depending on the processes and technological innovations, there are three main types of carbon sequestration (i) those based on natural processes of photosynthesis and conversion of atmospheric CO_2 into biomass, soil organic matter or humus and other components of the terrestrial biosphere; (ii) those involving engineering techniques and (iii) those involving chemical transformations (Lal, 2008). Atmospheric enrichment of CO_2 can be moderated by reducing anthropogenic emissions and by adopting proper management practices in grassland and forage land which will enhance storing or sequestering carbon either in to plant or in to the soil.

Grassland including rangelands, shrub lands, pasture lands and forage crop lands, covered approximately 3.5 billion ha area, representing 26 percent of the world land area and 70 percent of the world agricultural area, and containing about 20 percent of the world's soil carbon stocks (Conant, 2010). From a global view, grasslands store approximately 34% of the global terrestrial stock of C, whereas forests store approximately 39% and agro ecosystems approximately 17% (WRI, 2000).Around 20% of the world's native grassland have been converted to cultivated crops but still a significant portion of animal products (i.e. milk & meat) in the world comes from grasslands. The disturbance of grassland by means of removing biomass continues heavy stocking rates and poor grazing management practices are an integral part of traditional grassland management system that influence grassland production and have led to the depletion of soil carbon stocks. Many management practices intended to increase forage production also have the potential to augment soil carbon stocks like adoption of agroforestry, fertilization, irrigations, grazing management, fire management and sowing of favourable forage grasses and legumes. Therefore, management systems determine the fate of an ecosystem to act as a source/sink of CO_2. The objective of this review is to briefly elucidate the main sources of GHG emission and particularly address the sustainable management of fodder production systems to improve carbon sequestration and environment sustainability simultaneously to mitigate the threat of the global climate change.

CONTRIBUTION OF AGRICULTURE AND LIVESTOCK TO CLIMATE CHANGE

Agriculture, including meat and milk production, produces three main greenhouse gases (GHGs): carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Agriculture is a major contributor to climate change, producing 14 per cent of GHG emissions at the global level, with a further 10 % attributed to land use change and deforestation (IPCC, 2014).

Livestock contribute 14.5% of the total annual anthropogenic GHG emissions globally (Gerber *et al.,* 2013). Livestock influence climate through land use change, feed production, animal production, manure, and processing and transport. Feed production and manure emit CO_2, nitrous oxide (N_2O), and methane (CH_4), which consequently affects climate change. Animal production increases CH_4 emissions. Processing and transport of animal products and land use change contributes to the increase of CO_2 emissions. The livestock sector is often associated with negative environmental impacts such as land degradation, air and water pollution, and biodiversity destruction (Bellarby *et al.,* 2013; Reynolds *et al.,* 2010; Steinfeld *et al.,* 2006; Thornton and Gerber, 2010). Increases in livestock production are expected to originate from a declining natural resource base, which will cause further environmental damage without proper natural resources management (Thornton and Herrero, 2010a, b).

IMPORTANCE OF FODDER PRODUCTION SYSTEMS AND THEIR ROLE TO IMPROVE ENVIRONMENTAL SUSTAINABILITY

Livestock plays a central role in global food systems and thus in food security, accounting for 40% of global agricultural gross domestic product at least 600 million of the world's poor depend on income from livestock (Thornton *et al*., 2002). Livestock products supply 17% of total food energy and one-third of humanity's protein intake, causing obesity for some, while remedying under nourishment of others (Steinfeld *et al*., 2006).

In the year 2000, livestock consumed nearly two-thirds of global biomass harvest from grazing lands and crop land (Krausmann *et al.,* 2008). In addition to perennial pastures for grazing, forages include herbaceous and woody plants, and perennial and short-lived forage crops for cut-and-carry system. Forage based systems include all systems that include forage plants as a component, including ley systems that include several years cropping before returning to pasture, agri-pastoral systems, and rangelands. They all contain a substantial component of animal production. Forage grass is the most consumed feed in the world (2.3 Gt in 2000), representing 48% of all biomass consumed by livestock; of this, 1.1 Gt are used in mixed systems and 0.6 Gt in grazing-only systems. Grazing lands are by far the largest single land-use type, estimated to extend over 34-45 Mkm². Grazed ecosystems range from intensively managed pastures to savannas and semi-deserts. Additionally, a substantial share of crop production is fed to livestock. In the year 2000, of the total of 15.2 Mkm² cropland, approximately 3.5 Mkm² provided feed for livestock. Thus, producing feed for livestock uses about 84% of the world's agricultural land (Foley *et al*., 2011).

Reducing agriculture's GHG emissions and increasing C stocks in the soil and biomass could reduce global GHG emissions by 5.5-5.9 Gt CO_2 equivalent/year. Eighty-nine per cent of the potential climate change mitigation of agriculture comes from terrestrial carbon sequestration, 9 per cent from CH_4 reduction, and 2% from reduction of N_2O emissions (Scherr and Sthapit, 2009). Sown forages, through their effects on livestock systems and cropping systems, can contribute to this potential in all of them. Of the overall carbon mitigation potential, 29 per cent will be from pasture land (Lal, 2010).

However, the potential to mitigate climate change and other co-benefits of forage-based systems are often not considered. Improved tropical forages *i.e.* species and varieties selected or bred for superior productivity and/ or quality, are an important component of crop livestock systems to achieve eco-efficiency in many tropical environments. Apart from their use as livestock feed, forage plants in well-managed mixed crop-livestock systems can also enhance crop production and contribute to other functions such as erosion control, soil improvement, restoration of degraded lands, and improving biodiversity. Furthermore, they have a huge potential to mitigate climate change and improve resource utilization and conservation, a concept we call LivestockPlus (Peters *et al*., 2013).

OPPORTUNITIES THROUGH FODDER PRODUCTION SYSTEMS TO MITIGATE GHG EMISSIONS

Reducing agriculture's GHG emissions and increasing C stocks in the soil and biomass could reduce global GHG emissions by 5.5−5.9 Gt CO_2-equivalent/yr (Olander *et al.,* 2013). Fodder production system can mitigate GHG emissions in three ways: by sequestering atmospheric CO_2; by reducing ruminant CH_4 emissions per unit livestock product as compared to a lower quality rangeland/degraded pasture and by reducing N_2O emissions (Scherr and Sthapit, 2009).

Improving carbon sequestration

Carbon sequestration is known as carbon capture. The carbon can be stored (sequestered) in different ways: in plants and soil; underground and deep in ocean. Carbon sequestration with respect to agriculture sector refers to the capability of agriculture lands to remove CO_2 from the atmosphere. Forests and stable grasslands are referred to as carbon sinks since they can store huge amounts of carbon in their vegetation and root systems for long period of time (EPA, 2008). Tropical and temperate natural grasslands play a significant role in the global carbon cycle. Grassland soil carbon stocks amount to at least 10% of the global total, but other sources indicated it is up to 30% of world soil carbon. Comparisons of SOM stocks between biomes and different studies are complicated by divergent definitions and procedures, but at least it can be said that grassland soils represent a significant carbon pool, of the order of 200-300 Pg (Scurlock and Hall, 1998). The global potential of SOC sequestration is estimated at 0.6–1.2 Pg C /year, comprising 0.4–0.8 Pg C/year through the adoption of RMPs on cropland soils, 0.01–0.03 Pg C/ year on irrigated soils, and 0.01–0.3 Pg C/year through improvements of rangelands and grasslands(Lal *et al.,* 2007).The synthesis by Smith *et al.* (2008)suggest that adding manure or bio solids to soil could sequester C at the rates of between 0.42 and 0.76 t C /ha/ year depending on the region. An estimate has indicated that globally, 0.2-0.8 Gt CO_2 per year can be sequestered in grassland soils by 2030 (IPCC, 2007).

Grasslands are unique because besides being most sensitive and vulnerable to such changes due to their extensive soil carbon reserves (Korner, 2003), they are also promising targets for longer-term carbon uptake (Schimel, 1995). There is evidence that the soil carbon depends on combination of changes in floristic and community composition (biodiversity), land use and conservation practices which cause differences in quality and quantity of carbon input as well as in its decomposition rates. Although the carbon storage in grasslands has been studied worldwide but only a handful time restricted experiments have reported the influence of soil properties and biodiversity on the soil carbon fluxes (Adair *et al*., 2009). It was observed that introduction of *Macroptilium lathyroides* in natural grassland resulted in 1.29 times increase in TOC as compared to natural grassland. Other legumes also showed increased mixed biomass production and soil TOC (Table 1). Maximum increase in TOC and soil organic carbon (SOC) buildup rate was observed with *micropitilum lathyroildes* (42%) followed by *Stylosanthes guianensis*. Except *Alysicarpus ragouts* and *Clitoris tenanted* the rate of TOC buildup was higher in legume incorporated grassland than the natural grassland. It was observed that the land-use change from arable cropping to grassland results in an increase of soil C of 30g C/m^2/ year.

The capacity of agriculture lands to store or sequester carbon depends on several factors, including climate, soil type, type of crop or vegetation cover and different management practices (Goh, 2004). Farming forage crops has a remarkable capacity to sequester CO_2 and worldwide, farmers have the opportunity to offset their own emissions and those of other industries. Maintaining optimum levels of SOC is vital for soil quality, increased water retention capacity, nutrient enrichment, and soil faunal activity, thereby increasing soil fertility and crop productivity. Improving carbon sequestration in agricultural soils and making soil a net sink for atmospheric carbon can be achieved by adoption of the scientific management practices like proper soil and nutrient management (Jiang *et al*., 2006).

TABLE 1. Effect of range legumes on forage yield of natural grassland and organic carbon in the soil

Treatments	Forage DM yield (Mg/ha)	SOC build up rate (g/kg/yr)	TOC (g/kg)
Natural grassland	3.3	7.78	0.74
Alysicarapus rugosus	4.2	7.55	0.67
Atylosia scarabaeoides	4.1	9.22	1.22
Clitoria ternatea	4.4	7.47	0.64
Dolichos lablab	4.7	10.07	1.51
Desmodium tortusum	4.2	9.72	1.39
Glycine javanica	3.8	8.58	1.01
Macroptilium atropurpureum	4.1	7.99	0.81
Macroptilium lathyroides	4.9	11.05	1.83
Mimosa invisa	3.7	8.91	1.12
Stizolobium deeringianum	4.0	8.10	0.85
Stylosanthes guianensis	4.2	10.53	1.66
Stylosanthes humilis	4.0	8.22	0.89
Vigna luteola	4.2	9.15	1.20

Source: Rai *et al.* (2013)

Reducing nitrous oxide emissions

Current emissions of N_2O are about 17Mt N/year and by 2100 are projected to increase four-fold, largely due to increased use of N fertilizer (IPCC, 2014). The soil microbial processes of nitrification and denitrification drive N_2O emissions in agricultural systems. Nitrification generates nitrate (NO^{3-}) and is primarily responsible for the loss of soil nitrogen (N) and fertilizer N by both leaching and denitrification.

Some plants release biological nitrification inhibitors (BNIs) from their roots, which suppress nitrifier activity and reduce soil nitrification and N_2O emission (Subbarao *et al.,* 2012). This biological nitrification inhibition (BNI) is triggered by ammonium (NH_4^+) in the rhizosphere. The release of the BNIs is directed at the soil microsites where NH_4^+ is present and the nitrifier population is concentrated. Tropical forage grasses, cereals and crop legumes show a wide range in BNI ability. The tropical *Brachiaria* spp. has high BNI capacity, particularly *B. humidicola* and *B. decumbens* (Subbarao *et al.,* 2007). *Brachiaria* pastures can suppress N_2O emissions and carrying over their BNI activity to a subsequent crop might improve the crop's N economy, especially when substantial amounts of N fertilizer are applied (Subbarao *et al.,* 2012).

Improving the nitrogen use efficiency (NUE) of fodder crops allow lower fertilizer application and reduce nitrogenous emissions through the soil-plant-animal-soil cycle. Breeding forage crops capable of using fertilizer inputs more efficiently offer a clean technology route to increased sustainability of livestock production, via lowering recommended fertilizer rates, reducing the agricultural footprint with respect to pollution and reducing the wider consumption of non-renewable resources. Increasing the efficiency of N use in the ruminant animal reduce nitrous oxide emissions from ruminants. Rapid breakdown of herbage proteins in the rumen and inefficient incorporation of herbage nitrogen by the rumen microbial population are major causes of N loss and gaseous emissions.

Genetic improvement of the forage crops and legumes that constitute important components of the ruminant diet has the potential to reduce emissions to environment. Two possible strategies for increasing the efficiency of conversion of forage-N to microbial-N have been suggested: increase the amount of readily available energy accessible during the early part of the fermentation and provide a level of protection to the forage proteins, thereby inhibiting the rate at which their breakdown products are made available to the colonizing microbial population.

Reducing methane emissions

CH_4 from enteric fermentation in ruminants accounts for 25% of GHG emissions from livestock, or 65% of non-CO_2 emissions (Thornton and Herrero 2010a). Enteric CH_4 generated in the gastrointestinal tract of ruminants represents the greatest direct GHG released from the livestock sector and the single largest source of anthropogenic CH_4 at a global level (EPA 2012). About 75 % of total CH_4 emissions from livestock comes from cattle and this is expected to increase in the next decades, especially in developing countries (Tubiello *et al.,* 2013). Over the last five decades, global enteric CH_4 emissions from dairy cattle grew by 12%, with increases of 211% in developing countries and decreases of 48% in developed countries, thus highlighting a different contribution and a potential for reduction at a global level (Caro *et al*,. 2014). Interest in combating climate change has resulted in search for mitigation options to reduce GHG emissions from dairy cattle worldwide.

There are many factors that affect methane production in ruminant animals, such as the feed characteristics, the feeding level and schedule, the use of feed additives to promote production efficiency and the activity and health of the animal. It has also been suggested that there may be genetic factors that affect CH_4 production. Of these factors, the feed characteristics and feed rate have the most influence (USEPA, 1995).There are different strategies to reduce methane emissions such as forage diets with high digestibility plus high energy and protein concentrations, inclusion of forage legumes in diet and use of forages in mixed crop-livestock systems (Herrero *et al*., 2008). Forage diets with high digestibility plus high energy and protein concentrations produce less CH_4 per unit of meat or milk produced. Improving digestibility and protein content in forages could reduce CH_4 emissions from beef production by 15-30 per cent (Gurian-Sherman, 2011).

Forage and feed with a high proportion of easily digested carbohydrates such as starches and sugars usually move through the rumen faster and are used more efficiently than forage and feed with a high proportion of roughage such as cellulose. Grain has a higher proportion of easily digested carbohydrates, especially starch, than forage, and is therefore used more efficiently. Legumes contain less structural carbohydrates and more condensed tannins than does grass, and adding legumes to the diet can further reduce CH_4 emissions per unit of meat or milk produced. Use of forages in mixed crop-livestock systems cannot only reduce CH_4 emissions per unit livestock product but also contribute to the overall GHG balance of the system. Forages integrated in tropical agri-pastoral systems provide enhanced soil fertility and more crop residues of higher quality, giving higher system efficiency. Well drained soils resulting from enhanced rooting capacity in improved forages can also work as a sink for methane (Mosier *et al*., 2004), as consequence of its oxidation by aerobic microorganisms (methano trophs) that use this gas as a source of C and energy. Kammann *et al.* (2001) highlighted the importance of the top soil aerobic layer in oxidising methane and therefore reducing the amount released. In a comparison of arable land with grassland, the methane oxidation rate of grassland was about 10 times that of arable land (Willison *et al*., 1997).

STRATEGIES FOR ENHANCEMENT CARBON SEQUESTRATION

Many management practices used to increase forage production and also have the potential to increase soil carbon stocks, thus sequestering atmospheric carbon in soils. Methods of improved management include fertilization, irrigation, intensive grazing management and sowing of favourable forage grasses and legumes. Improved grazing management leads to an increase of soil carbon stocks by an average of 0.35 Mg C /ha/year (Conant *et al.,* 2001).

Adoption of pasture based agro forestry practices

In many situations agroforestry practices like silvipasture system also offer excellent and economically viable potential for carbon sequestration (IPCC, 2000). Agro-forestry enhances carbon uptake by lengthening the growing season, expanding the niches from which water and soil nutrients are drawn and, in the case of nitrogen (N)-fixing species, enhancing soil fertility (FAO,2010).When silvipasture systems are introduced in suitable locations, carbon is sequestrated in the tree biomass and tends to be sequestered in the soil as well. Agroforestry systems are considered to have higher potential to sequester carbon than pasture or field crops (Kirby and potvin, 2007). The land use systems ranked in terms of their SOC content are in order of forest> agro forestry>tree plantations>arable crops.

Restoration of degraded lands and inclusion of grasses

Reversing of degraded lands enhances production in areas with low productivity, increasing carbon inputs and sequestering carbon (FAO, 2010). It is now well established that improved grazing management could lead to greater forage production, more efficient use of land resources, and enhanced profitability and rehabilitation of degraded lands and restoration of ecosystem services. Under favourable conditions improved pasture and silvopastoral systems can sequester 1–3 tonnes C/ha/yr. The introduction of grasses on arable lands can increase production return organic matter (when grazed as a forage crop), and reduce disturbance to the soil through tillage. Thus, inclusion of grasses into crop rotations can enhance carbon inputs and reduce decomposition losses of carbon, each of which leads to carbon sequestration.

Grazing management

Grazing management can be improved to reverse grazing practices that continually remove a very large proportion of aboveground biomass. Implementing a grazing management system that maximizes production, rather than off take, can increase carbon inputs and sequester carbon. Sustainable grazing management can increase carbon inputs and carbon stock without hampering forage production.

Direct Inputs of Water, Fertilizer or Organic Matter

Direct addition of water, fertilizer or organic matter can enhance water and N (nitrogen) balances, increasing plant productivity and carbon inputs, potentially sequestering carbon. Fertilizer application stimulated litter production of the tall grass prairie and resulted in an increase in soil C of 1.6 Mg/ha (Rice, 2000). Application of other nutrients, where they are deficient, also enhanced organic C storage (Conant *et al.,* 2001).Similarly, application of irrigation can enhance water and nitrogen balances leading to increase in plant productivity and carbon inputs.

Sowing of improved forage species

Such practice can lead to increased production through species that are better adapted to local climate, more resilient to grazing, more resistant to drought and able to enhance soil fertility. Enhancing production leads to greater carbon inputs and carbon sequestration.

Fire management

In some fodder production system, fire management also influence the amount of C stored in biomass. Burning of biomass produces charcoal, a form of C very resistant to decomposition, which can account for a significant portion of the C stored in some soils. Annual burning and grazing on the tall grass prairie were found to increase in soil C storage of 2.2 Mg/ha after 10 years (Rice, 2000).

CONCLUSION

Generally increasing Soil Organic Carbon (SOC) storage through changes in land use and land management is a low cost and environmentally beneficial way of sequestering substantial amounts of atmospheric CO_2. There is a need for strategies that allow for reducing GHG emissions through sustainable intensification of forage production systems to enhance productivity without compromising the ability of ecosystems to re-generate and provide many ecosystem services. The strategies are mainly management of fodder production systems such grazing management, restoration of degraded rangeland, sowing of grasses and legumes and fertilization etc. These practices have the potential to increase forage productivity, income generation and climate mitigation that change the herder and farmers livelihoods. The value of forages and their role in land use decisions to address environmental issues will remain an important challenge for agriculture.

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