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MITIGATION OF CLIMATE CHANGE THROUGH FODDER PRODUCTION SYSTEMS–A REVIEW

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SUMMARY

Livestock production is a major source of GHGemissions, and reducing meat consumption or changing from ruminant to non-ruminant meat could have a number of environmental benefits. Improving management of grazing land has the greatest mitigation potential of all agricultural interventions, over 1.5 bt CO_2 equivalents/year, sufficient to offset all the emissions from livestock production. In our view, ignoring the importance of forage-based systems may leave 50-80 per cent of the mitigation potential of agriculture untapped. Thus, improved grassland management and sustainable intensification of forage-based systems (through improved resource use efficiency, improved carbon sequestration, and reduced emissions due to BNI) are key to mitigating GHG emissions from livestock production, and 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.

Key words : Climate change, fodder production system, food, by-products

Concern about climate change has been growing for the last two decades. Climate variability and change are not new phenomena, but the scale of climate change in recent decades is unprecedented. Even if we act decisively now, there will be an increase of temperature between 1.1°C and 6.4°C by 2100 (IPCC, 2016), threatening sustainable food production worldwide. This accelerated climate change is driven largely by emission of greenhouse gases mostly resulting from use of fossil fuels. Agriculture, animal husbandry and fisheries are highly dependent on weather and climate change for producing food and by-products necessary to sustain human life.Therefore, climate change is one of the greatest challenges to human development, in general, and to food security in particular in recent history.

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 per cent attributed to land use change and deforestation (IPCC, 2014).

Livestock systems are estimated to contribute about 10.8 per cent of global anthropogenic GHG emission and 70 per cent of all agricultural sector GHG emissions. In 2000, non-CO_2 emissions from livestock systems ranged between 2.0 and 3.6 Gt CO_2eq. These are expected to increase by 70 per cent by 2050. Large ruminants (cattle and buffalo) emit more GHG per kg of meat than monogastrics (pigs and poultry). Ruminants contribute 75 per cent of total livestock GHG emission (FAO, 2009). In addition to GHG from enteric fermentation and manure, large ruminants are also associated with land use changes such as deforestation.

Importance of Forage-based Crop-livestock Systems

Livestock plays a central role in global food systems and thus in food security, accounting for 40 per cent 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 per cent of total food energy and one-third of humanity's protein intake, causing obesity for some, while remedying undernourishment 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 (native grasslands and savannas). 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 per cent 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 per cent of the world's agricultural land (Foley *et al*., 2011).

The Role of Tropical Forages for Eco-efficient Production

Although tropical agriculture contributes to GHG emissions, it can also mitigate climate change by reducing emissions (abatements) and absorbing GHGs. Mitigation refers to any strategy or action taken to remove the GHGs released into the atmosphere, or to reduce their amount. Adaptation refers to adjustment in natural or human systems to a new or changing environment (IPCC, 2007).

Agriculture in 2030 could potentially offset 5500-6000 million metric tonnes of CO_2 equivalents per year. The mitigation potential of improved grassland and cropland management is about 1350-1450 million CO_2 equivalents per year each, which, together with 1350 million t CO_2 equivalents per year for restoring cultivated organic soils, and 650 million t CO_2 equivalents per year for restoring degraded land, is about 75 per cent of the global bio-physical mitigation potential. Improved management of crops and grassland and restoration of degraded land and organic soils offer the greatest opportunities for mitigation of GHG emissions (Smith *et al*., 2008).

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 per cent 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. It is these benefits of forage-based systems in the tropics that need to be recognized by the global community. The demand for livestock products must be reconciled with the environmental impacts of livestock. The aim should be greater eco-efficiency i. e. highly productive forage-based systems with a small ecological footprint that are economically sustainable and socially equitable (Keating *et al*., 2010). 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).

In this context, the development of adapted tropical forages and their integration into crop-livestock systems can play an essential role in their intensification and diversification, with multiple functions in terms of economic and environmental benefits such as : adaptation to biotic (pests and diseases) and abiotic stresses (soils of low fertility, soil salinity, drought and waterlogging) reducing risks in vulnerable environments; provision of sufficient feed of high quality year-round, enhancing productivity per animal and per area; sustain and enhance crop production; prevent and reverse land degradation, and mitigate GHG emissions. Synergies between crop and livestock production can lead to a more efficient use of resources not only at farm level but also at landscape and regional scales (Herrero *et al*., 2010).

Forages as a Means to Mitigate GHG Emissions

Agricultural production systems including improved forages can address mitigation of all major GHG. Forages 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).

(i) Improving carbon sequestration : Carbon sequestration is known as carbon capture. The carbon can be stored (sequestered) in different ways : in plants and soil (terrestrial sequestration); underground (geological sequestration) and deep in ocean (ocean sequestration). 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). Carbon dioxide absorbed by grasses through photosynthesis is sequestered in the roots and surrounding soil. Each grass blade and iris leaf acts like a tiny vacuum, sucking carbon out of the air and transforming it into the solid structure of the plant's body. Rangelands are an ideal place to store carbon because much of the grasses' growth and hence the initial carbon sequestration is below the ground in the form of roots, where it can readily be transferred into more permanent storage in the soil. Trees and other plants also store carbon, but they grow more slowly. And they keep more of their biomass above the ground in the form of trunks, stems and leaves where it is vulnerable to wildfire and human uses, which return stored carbon more quickly to the air. Because most of our local (mostly non-native) rangeland grasses grow quickly, produce lots of roots, and die every year, they are particularly good at pumping carbon into the soil. When a plant decomposes, the remnants of its roots and leaves stay in the soil, breaking into tiny particles. As those particles work their way into the soil, they get trapped, and the deeper they are, the longer they tend to stay.

Grassland soils are a very significant store of carbon, with global carbon stocks estimated at about 343 Gt C, which is about 50 per cent more than the amount stored in forests globally (FAO, 2010). In addition to the significant stocks of carbon, grasslands also contribute to climate change mitigation by sequestering additional carbon. Lal (2004) estimated that the soil organic carbon sequestration potential of the world's grasslands was 0·01 to 0·3 Gt C/year.

Within a given grassland ecosystem, climatic and management related factors interact to influence GHG balance over a specified period of time (Liebig *et al*., 2010). Management practices that reduce carbon loss and increase carbon sequestration in grasslands include : avoiding soil tillage and the conversion of grasslands to arable use; moderately intensifying nutrient-poor permanent grasslands; using light grazing instead of heavy grazing; increasing the duration of grass leys; and converting grass leys to grass-legume mixtures or to permanent grasslands (Soussana *et al.,* 2010).

Well-managed forages have a huge potential to sequester C with values comparable to forest systems. However, degradation of pastures can substantially reduce this potential. Optimal grazing management can enhance accrual of soil carbon, highlighting the importance of grassland productivity in carbon sequestration. On the other hand, the inclusion of legumes in grass-legume mixtures (Soussana *et al*., 2010) and or the inclusion of a tree component such as in agroforestry systems can further enhance the C sequestration potential of forages. In addition, forages that are well adapted to edaphic and climatic stresses may have a higher potential to sequester C than field crops producing less biomass, in particular, in marginal conditions (Fisher *et al*., 1994).

Within established pastures, soil C can be increased by eliminating disturbances to the soil like tillage, fire, drought, disease or overgrazing, land use changes and by increasing primary production (Adams *et al.,* 2009). Potential C sequestration rates estimated for adoption of no tillage were 0.5-0.8 Mg C/ha/year. Forages are also key components of minimum and no-till cropping systems in Brazil and Colombia (Lal, 2004).

Guo and Gifford (2002) analyzed the results from 74 papers on the effects of land use changes on soil carbon stocks. While soil carbon stocks declined in conversion from pastures to plantations and from forests or pastures to crops, they increased when converting annual crops to plantations, crops to pastures, crops to secondary forest, and, interestingly, forest to pastures. Powers *et al.* (2011) reported increases in soil carbon stock when forest or savanna was converted to pastures (5-12% and 10-22%, respectively). In contrast to annual crops, well managed pastures maintain a cover of vegetation on the soil, which reduces fluctuations in soil temperature and adds organic matter (Brown and Lugo, 1990). Forages that are well adapted to edaphic and climatic stresses may have a higher potential to sequester C than field crops producing less biomass, in particular, in marginal conditions.

Most of the above-ground carbon invegetation is lost when forests are cleared for pastures, but soil carbon stocks are often the same over the long term or can increase substantially. Studies from the tropical rainforest of the Colombian region indicate that total carbon stocks are highest in native forests, followed by well managed sown pastures and silvi-pastoral systems, with degraded pastures and degraded soils having the lowest. In terms of C accumulated in the soil, improved, well-managed pasture and silvi-pastoral systems show comparable or even higher levels than the native forest, depending on local climatic and environmental conditions (Amézquita *et al.*, 2010).

Sown forages alone could contribute 60-80 per cent of the total potential carbon sequestration on agricultural lands through their contribution to the management of crop and grazing land and to the restoration of degraded lands and cultivated organic soils (Smith *et al*., 2008). Sown tropical forages can sequester large amounts of carbon in soil, particularly in the deeper layers. Soil organic carbon (SOC) levels were as high as 268 t carbon/ha in the top 80 cm of soil under a *Brachiaria humidicola-Arachispintoi* pasture, with 75 per cent of the carbon found below 20 cm. Compared with the native savanna, a sown grass pasture sequestered an additional 26 t carbon/ ha in five years and increasing 2.7 fold with an associated legume (Fisher *et al*., 1994). Meenakshi *et al*. (2012) reported that the percentage of soil organic carbon sequestered by the fodder crops was found to be higher in black soils than in red soils and also the amount of carbon sequestered in the soil varied from 1.32 per cent by fodder cowpea, 1.34 per cent by fodder maize, 1.48 per cent by hedge lucerne and 1.45 per cent by hybrid napier. Bama and Babu (2016) conducted an experiment with three different perennial forage crops viz., legume fodder (Lucerne CO 1), grass fodder [Cumbu Napier hybrid grass CO(CN)4] and cereal fodder [sorghum CO(FS)29]. Among the different forage crops, Cumbu Napier grass had higher carbon sequesteration potential of above ground biomass which removed 336.7 t CO_2/ha than multicut fodder sorghum (148.7 t CO_2/ha). The higher below ground biomass in Cumbu Napier grass removed 7.73 t CO2/ha from the atmosphere than lucerne (4.21 t CO2/ha). Among the nutrient sources, the FYM favoured higher carbon fixation in the soil than poultry manure, integrated nutrient management and inorganics alone. In addition, the Cumbu napier fodder crop stored 9.2 g/kg of soil organic carbon over initial SOC status of 6.5 g/kg followed by multicut fodder sorghum accumulated (8.7 g/kg). Sown pastures of Brachiaria grasses have large potential for carbon sequestration in Latin American and Caribbean countries (Thornton and Herrero, 2010), with Central America having particular potential for carbon sequestration because of higher levels of land degradation.

A large part of the world's grasslands is under pressure to produce more livestock by grazing more intensively. About 7.5 per cent of the world's grasslands have been degraded by overgrazing (Reid *et al.*, 2004). Previous research has documented that improved grazing management could lead to greater forage production, more efficient use of land resources, and enhanced profitability and rehabilitation of degraded lands (Oldeman, 1994). Deforestation, degradation of native grasslands and conversion to crop land have prompted losses of biomass and soil carbon of 450-800 Gt per CO_2 equivalent to 30-40 per cent of cumulative fossil fuel emissions (DeFries e*t al.*, 1999).

Excessive grazing pressure is detrimental to plant productivity and may lead to decline in soil organic matter. Changes in grassland management which reverse the process of declining productivity can potentially lead to increased soil C. Thus, rehabilitation of areas degraded by overgrazing can potentially sequester atmospheric C. Universal rehabilitation of overgrazed grasslands can sequester approximately 45 Tg C/year, most of which can be achieved simply by cessation of overgrazing and implementation of moderate grazing intensity. Changes in soil C with conversion from heavy to moderate grazing ranged from a loss of 0.33 Mg C/ ha/year to sequestration of 1.83 Mg C/ha/year (Conant and Paustian, 2002). In the United States, agricultural conservation practices such as reduced tillage, improved fertilizer management, elimination of bare fallowing, the use of perennials in rotations, and the use of cover crops can potentially sequester large amounts of atmospheric C (Elliott *et al.*, 2001).

(ii) Reducing methane emissions : Enteric fermentation is the fermentation that takes place in the digestive systems of animals. In particular, ruminant animals (cattle, buffalo, sheep goats and camels) have a large "fore-stomach," or rumen, within which microbial fermentation breaks down food into soluble products that can be utilized by the animal. The microbial fermentation that occurs in the rumen enables ruminant animals to digest coarse plant material than monogastric animals. Methane is produced in the rumen by bacteria as a byproduct of the fermentation process. This CH_4 is exhaled or belched by the animal and accounts for the major portion of emissions from ruminants. Methane also is produced in the large intestines of ruminants and is expelled. In this first stage of digestion, the forage is acted on by the varied population of microorganisms, including bacteria, fungi and protozoa in the fore-stomach. This process releases hydrogen, while producing volatile fatty acids and microbial cells containing energy and essential proteins to be made available for the growth of the animal. In ruminants, the hydrogen is removed through the action of a group of microbes called methanogens that gain their energy through combining carbon dioxide with hydrogen to form methane.

CH_4 from enteric fermentation in ruminants accounts for 25 per cent of GHG emissions from livestock, or 65 per cent of non-CO_2 emissions. Beef and dairy cattle are the greatest methane emitters from enteric fermentation that are attributed to anthropogenic activities. Collectively, their effluences accounted for 95 per cent of methane emissions from enteric fermentation. Smaller ruminants, like sheep and goats, emitted less than or the same as non-ruminants, like horses and swine, because of their domestic population size. Overall, enteric fermentation from all major domestic livestock groups was responsible for 139 Tg CO_2eq (1.9% of total greenhouse gas emissions domestically) (Thornton and Herrero, 2010).

There are a variety of 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). Increasing the WSC content in perennial ryegrass by 33 g/kg reduces methane production by 9 per cent (Lovett *et al*., 2004). 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. Methane emissions are also commonly lower with higher proportions of forage legumes in the diet, partly due to lower fibre content, faster rate of passage and, in some cases, the presence of condensed tannins (Waghorn and Clark, 2004). Another such approach is the use of tannin containing forages and breeding of forage species with enhanced tannin content. Forage legumes such as *Lotus corniculatus* (Birdsfoot trefoil) and *Lotus uliginosus* (Greater trefoil) possess secondary metabolites known as condensed tannins (CTs) in their leaves. CTs are flavonoid polymers which complex with soluble proteins and render then insoluble in the rumen; yet release them under the acidic conditions found in the small intestine, reducing bloat and increasing amino acid absorption (Woodward *et al*., 2004). Forage legume species such as clover and alfalfa are usually higher-quality forage than grass species, because they often contain less cellulose and other structural components and more protein.

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).

(iii) Reducing nitrous oxide emissions : Current emissions of N_2O are about 17 M t 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.

Controlling nitrification in agricultural systems is thus critical to reduce both N_2O emissions and nitrate contamination of water bodies largely due to increased use of N fertilizer. Some plants release biological nitrification inhibitors (BNIs) from their roots, which suppress nitrifier activity and reduce soil nitrification and N_2O emission. 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. have high BNI capacity, particularly *Brachiaria humidicola* and *Brachiaria decumbens*.Nitrification inhibitor in *Brachiaria* grasses is brachialactone, a cyclicditerpene**.** *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). This exciting possibility is currently being researched and could lead to economically profitable and ecologically sustainable cropping systems with low nitrification and low N_2O emissions. Field studies in CIAT headquarters (Cali, Colombia), on a Mollisol, indicated a 90 per cent decrease in the oxidation rates of soil NH_4^+in *Brachiaria humidicola* plots, largely due to low nitrifier populations.

Improving the nitrogen use efficiency (NUE) of fodder crops allow lower fertilizer application and reduce nitrogenous emissions through the soil-plant-animal-soil cycle. In agronomic terms, NUE is the product of NUpE and NUtE, where NUpE is the N uptake efficiency (the ratio between the amount of N absorbed by the plant and that supplied/available in the soil) and NUtE is the utilization efficiency [the unit dry matter (DM) produced per unit N in the dry weight, or the DM flux per unit N flux in a whole stand in units of g biomass/mol of N].

NUEs from soil to crop are generally lower for grass-based livestock production compared with arable crop production ranging from 10-40 per cent for whole dairy systems compared with 40-80 per cent for arable systems, on a whole-farm basis. Quantitative trait loci (QTL) for traits associated with NUE have been identified in *Arabidopsis*, maize, barley and ryegrass (Wilkins *et al.*, 2000). 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.When sheep and cattle are given fresh forages they can waste 25-40 per cent of forage protein (Ulyatt *et al.*, 1988). Genetic improvement of the forage grasses and legumes that constitute important components of the ruminant diet has the potential to reduce emissions to air. 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 reducing the rate at which their breakdown products are made available to the colonising microbial population.

One approach is to develop forage species with a better balance between water soluble carbohydrate (WSC) and crude protein (CP) by increasing the WSC content of the grass or the clover component or reducing the protein content of the legume.The most advanced of these approaches is the development at IGER of high WSC ryegrasses where more N is partitioned into meat and milk and less is available for nitrogenous emissions through excreta (Miller *et al*., 2001).

Another approach is increasing the content of compounds that affect protein breakdown in the rumen. Opportunities also exist within forages to select for other specific traits that can reduce protein loss. A good example of this approach is the emerging research on the enzyme polyphenol oxidase (PPO), which is at a particularly high level of activity in red clover in comparison with other species and has a role in protein protection (Owens *et al.,* 2002). This enzyme converts phenols to quinones which subsequently bind to protein and slow the rate of protein degradation. Thus, in silo, the protein made available for diffuse pollution of nitrogen e. g. as ammonia, is reduced. Ensiling alfalfa (lucerne) leads to the degradation of 44 to 87 per cent of forage protein to non-forage protein (NPN). In comparison, red clover has up to 90 per cent less protein breakdown. Increasing the level of PPO is a target for genetic improvement in red clover as a route to reduced nitrogenous pollution.

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