Potential of C4 Tropical Grasses to Contribute in Carbon Sequestration, Environmental Security and Livelihood Opportunities through Increased Fodder Availability

D. R. Malaviya
Indian Institute of Sugarcane Research, India

A. K. Roy
Indian Grassland and Fodder Research Institute, India

P. Kaushal
National Institute of Biotic Stress Management, India

The XXIV International Grassland Congress / XI International Rangeland Congress (Sustainable Use of Grassland and Rangeland Resources for Improved Livelihoods) takes place virtually from October 25 through October 29, 2021.

Proceedings edited by the National Organizing Committee of 2021 IGC/IRC Congress

Published by the Kenya Agricultural and Livestock Research Organization

Potential of C4 tropical grasses to contribute in carbon sequestration, environmental security and livelihood opportunities through increased fodder availability

D. R. Malaviya[1], A. K. Roy, P. Kaushal[2]

ICAR-Indian Grassland and Fodder Research Institute, Jhansi -284003, India

Present address: [1]ICAR-Indian Institute of Sugarcane Research, Lucknow, India; [2] ICAR-National Institute of Biotic Stress Management, Raipur, India

ABSTRACT

The world grasslands/rangeland ecosystems comprise 26% of earth's surface and have immense ecological and economic significance. Diversity of grasslands had been a key element for their sustainability. Grasslands in India have existed as natural ecosystems for millions of years. It is a major source of income, employment and livelihood to the rural families. Owing to heavy grazing pressure, coupled with other social/anthropogenic factors, the grazing resources have fast deteriorated. The country has many old and natural grasslands with ethnic and economic value. Comprehensive ecological studies including floristic compositions, dominant species, grazing pressure and the climax/sub-climax stages of ecological succession will surely provide prescriptions for developing and rejuvenating these grazing resources. Grasslands face challenges in arid, semiarid and the moist lowlands with trees, shrubs and many invasive species including alien trees and shrubs introduced intentionally or unintentionally. Fast degrading rangelands in dry areas is causing a threat to huge amount of carbon stored in the top soil on earth in addition to threat to global hotspots for biodiversity. In the context of fast changing climate, the grazing lands can play a significant role. High water use efficiency and productivity of most C4 tropical grasses make them suitable for coping with climate change along with quality fodder.

Introduction

The world grasslands/rangeland ecosystems comprise 26% of earth's surface and support the livelihoods of more than 38% of the global populations, mostly world's poorest (Nalule, 2010). This highly dynamic ecosystem, developed since Pleistocene, has immense ecological and economic significance since dawn of civilization. Natural grassland is an ecosystem in which the dominant species are perennial grasses, with few or no tress /shrubs.

By 2050, the agricultural sector has a challenge to produce 60% more food, feed and fibre (8.5 billion t/yr) (FAO, 2014). India and China contribute largely to the Asian grazing lands and both have tropical, temperate as well as alpine grasslands. Out of ~5.4 billion ha of global grasslands, the Asia-Pacific region accounts to 1.2 billion ha. Grasslands also provide an opportunity of *in-situ* conservation of large number of flora and fauna. Diversity of grasslands had been a key element for their sustainability in areas under high ecological and climatic stresses; and balance among species representing different photosynthetic pathways has played key role because the different affects factors such as productivity, resilience to climate, biomass decomposition and forage quality.

Although C4 species number accounts just 3% of the C3 species, they contribute ~25% of the primary productivity on earth (Sage et al., 1999; Edwards et al., 2010). These C4 plants dominate the grassland and savannah biomes of warm temperate to tropical latitudes. A small number of C4 species (mostly in the *Poaceae)*, contribute substantially global C3/C4 grassland vegetation (Lloyd and Farquhar, 1994). In fact, the C3/C4 ecosystems such as savannas, occurring in hot, humid or subhumid climates, typically have C3 trees at distance, C4 herbaceous grasses stratum and a few C3 grasses and forbs (Sage *et al*., 1999). Brazilian *cerrado*, Argentinean *chaco*, tropical savannas in Africa, *Prairies* of North America, *pampas* and *campos* of South America, *grassvelds* of South Africa and Northern Australia represent such C3/C4 ecosystem. Some C4 species also occur in cooler and drier climates such as *prairies* of North America and Mongolian *steppe*. Kangaroo grass, red grass and wire grass grasslands are referred as C4 grasslands. Tall grass *prairies* are a diverse mix of C3 and C4 plant species but C4 grasses dominate the ecosystem. The global coverage of C4 vegetation is reported to be 18.8 million km2 compared to 87.4 million km2 C3 vegetation (Still et al., 2003). Photosynthetic use efficiency of water of the C4 plants is often higher and probably this ability led to expansion of the grassland biome in warm climates dominated with C4 grasses (Edwards et al., 2010). Hence, such grasslands exhibit high productivity with low moisture; high light and temperature.

Indian grasslands/potential

Grasslands in India, a millions of years old natural ecosystems are a major source of income, employment and livelihood to the rural families especially nomadic and semi-nomadic tribes. The grazing resources includes degraded forest, degraded agricultural lands, saline sodic wastelands, ravines, rangelands and wastelands; also habitat to variety of wild animals and birds. The country supports 20 % of the world's livestock on only 2% of the world's geographical area with ~12.15 million ha permanent pastures. These natural grasslands have very high ethnic value; livelihood for many communities and reservoir of huge biodiversity (Malaviya *et al*., 2017). Ecological studies on the floristic compositions, dominant species and the climax/sub-climax stages over hundreds of years of ecological succession are ready prescriptions for developing and rejuvenating the grazing resources. Grasslands face challenges in arid, semiarid and the moist lowlands with trees, shrubs and many invasive species. Fast degrading rangelands in dry areas is causing a threat to huge amount of carbon stored in the top soil on earth in addition to threat to global hotspots for biodiversity. Some of the ecologically important, Indian grasslands, viz. Shola grasslands of Nilgiris; Sewan grasslands of arid Rajasthan; semi-arid grasslands of southern part; Rollapadu grasslands in the semi-arid Andhra Pradesh; Banni grasslands of Gujarat; and Alpine grasslands of Sikkim and Western Himalaya, are in various stage of degradation. Nomadic pastoralism, a traditional form of human-livestock-grassland interaction, is still predominant in the drylands of western India, the Deccan Plateau, and in the mountainous reaches of the Himalayas (Roy and Singh, 2013)

In the context of fast changing climate, the grazing lands can play a significant role. High water use efficiency and productivity of most C4 tropical grasses (such as *Panicum*, *Dichanthium*, *Heteropogon*, *Sehima, Cenchrus, Pennisetum*) make them suitable for coping with climate change along with quality fodder. Owing to heavy grazing pressure, productivity of grasslands in arid and semiarid region is low ranging from 0.5 to 1.0 t/ha dry matter. Even if 75% of the area under *Sehima- Dichanthium* cover is improved by controlled grazing and reseeding, the fodder availability will increase from 83 million tons to 224 million tons. A large number of fauna species such as Tibetan antelope, Gazelle, wolf, black necked Crane and Fox from cold deserts, Lesser Florican, Asiatic wildcat, Asiatic wild ass, desert fox, monitor, spiny tailed Lizards, Laggar Falcon, Red headed Falcon, steppe Eagle, Long legged Buzzard, red headed vultures form hot climate are threatened due to habitat degradation and anthropogenic pressures (Malaviya and Roy, 2021).

The grasslands are invaded by unpalatable, alien species like *Lantana*, *Eupatorium*, *Parthenium* etc. Plantations of trees/shrubs such as *Gliricidia, Azadirachta, Eucalyptus, Prosopis juliflora* and *Acacia auriculiformis* have also adversely affected the grasslands. The savannas of NE India are notable for the persistence of large herbivores. Managing grasslands outside protected area has been major constraint along with adversaries of topography, altitude, low moistures availability and high stocking rates. Plantation of *Prosopis,* human encroachment and lopping of woody species are also adversely affecting.

C3/C4 grasslands: climate change, carbon sequestration and the environment

Species with the C3 and C4 modes of photosynthesis coexist in grasslands. Balance between the two vegetation types affects productivity, water use efficiency and quality of forage, animal productivity, carbon storage and nitrogen (Lattanzi, 2010). It may be debatable whether that grasslands expanded because they included C4 species (Cerling *et al.* (1997) or C4 vegetation expanded because grasslands expanded (Edwards *et al.,* 2010) but it remains a fact that C4 species dominate the grasslands of tropical and sub-tropical climate.

The agricultural areas, including grasslands/wastelands, have a potential to sequester about a third of the 4.5–6.5 Gt C eq/year net GHG emissions. Emissions by various livestock production cycles on grasslands, although prove negative for environmental protection, can be reduced by adopting free animal grazing on rangeland. The grassland ecosystems have faced severe stresses including temperature, moisture and edaphic factors owing to continued grazing and poor replenishing majors done. Such stresses affect C3/C4 balance. Lattanzi (2010) believed that the C3/C4 balance should have moved during the last 50 years.

C3 and C4 plants also differ for light, water and nitrogen use efficiencies. Owing to difference in fibre content, the two types of plants also differ for the digestibility and decomposability. Under elevated CO2 increase in sugars, starch and fructan were reported among C3 grasses with reduction in protein content, however, among most C4 grasses protein content was least affected (Barbehenn et al 2004). Thus, the quickly degradable biomass of species contributes to ecosystem, whereas the less digestible species are left ungrazed due to selective grazing by animals. Consequently frequency and density of such species will increase. Grazing pressure is another important factor to be accounted in climate change studies and effects on the C3/C4 balance. Ungrazed C3/C4 grassland showed tall grasses replacing short ones but overall dominance of tall C4 such as *Brachypodium sylvaticum and Miscanthus sinensis* remained unchanged (Werger *et al.*, 2002). High regenerative capacity becomes important trait in order to minimize the overgrazing effect (Lemaire *et al.*, 2009). *Leymus chinensis* (C3) and *Chloris virgata* (C4) have shown major change in their competition magnitude and productivity as per precipitation and nitrogen availability (Niu et al 2008). Besides, this C4 grasses need to grow rapidly and survive under natural resource in order to dominate in the ecosystem. There has been limited study on grazing effect on C3/C4 vegetations in grassland at elevated CO2 (von Caemmerer *et al.*, 2001). Emissions by various livestock production cycles on grasslands, although prove negative for environmental protection, can be reduced by adopting free animal grazing on rangeland. Thus, the balance between C3 and C4 vegetation is responsive to climate change, and ecosystem function.

SOC sequestration potential per unit productivity is reported to be lower for C4 ecosystems because biomass derived from tropical C4 grasses will cycle through the soil faster than that derived from trees (Wynn and Bird 2007). Soil organic carbon (SOC) is important for sustaining agro-ecosystems, and is key for sustainable maintenance of soil health. Trees like *Ficus*, *Morus*, *Acacia* and *Leucaena* are reported to contribute 63 to 81% higher TOC than fallow land whereas the C4 grasses such as *Cenchrus*, *Panicum*, and *Chrysopogon* increased TOC by 77 to 91% (Ghosh *et al*., 2021).

Along with C4 species, CAM plants, such as cacti, adapted to dry environments are also contributing to grassland productivity. Both the C4 and CAM pathways have evolutionary advantage for adaptation to hot climates (Guralnick et al 2008) and efficient in the conservation of water. CAM plants show better adaptability because of plasticity between C3 and C4 modes (Ueno, 2004).

Prospects and strategies

Thus, the high biomass C4 or C3/C4 grasslands can play vital role in future to cope with climate change because of their high productivity even under resource constraint. These ecosystems also have relevance to maintain other infrastructure sustainable such as the dams by checking silting process. There are species like *Panicum maximum* which represent C3/C4 intermediate types along with many germplasm close to either C3 or C4 type (Malaviya *et al*., 2020). Such climate smart species are most suitable candidate for making grasslands climate resilient in auto mode. Further to mention, the high biomass producing C4 grass biomass of can be potential source for lignocellulosic ethanol production or combustion energy production. However, there is need to identify desirable stages of succession, based on ecological principles, for sustainability of the system. This requires an understanding of the eco-physiological basis of coexistence of the C3/C4 balance in grasslands. As a major source of forage from the C3/C4 grasslands and savannas, efficient recycling of natural resources and carbon sequestration need to studied. Recent advancement in C4 pathway and its evolution may open up further possibilities for introducing C4 pathway among some C3 species. The knowledge about the key genes controlling the expression of C4 photosynthesis may further boost by using the new C4 model species *Setaria viridis* (Sage and Zhu, 2011).

Acknowledgement: Authors are thankful to ICAR-IGFRI Jhansi for financial and logistic support.

References

Barbehenn RV, Chen Z, Karowe DN and Spickard A. 2004. C3 grasses have higher nutritional quality than C4 grasses under ambient and elevated atmospheric CO2. *Global Change Biology* 10: 1565–1575. doi: 10.1111/j.1365-2486.2004.00833.x

Cerling TE, Harris JM, MacFadden BJ, Leakey MG, Quade J, Eisenmann V and Ehleringer JR. 1997. Global vegetation change through the Miocene/Pliocene boundary. *Nature* 389: 153-158.

Collatz GJ, Berry JA and Clark JS. 1998. Effects of climate and atmospheric CO2 partial pressure on the global distribution of C4 grasses: Present, past, and future. *Oecologia* 114: 441–454.

Edwards EJ and Smith SA. 2010. Phylogenetic analyses reveal the shady history of C-4 grasses. *Proceedings of the National Academy of Sciences of the United States of America* 107: 2532-2537.

FAO. 2014. Building a common vision for sustainable food and agriculture: Principles and Approaches. United Nations Food and Agriculture Organisation, Rome.

Ghosh A, Kumar RV, Manna MC, Singh AK, Parihar CM, Kumar S, Roy AK and Koli P. 2021. Eco-restoration of degraded lands through trees and grasses improves soil carbon sequestration and biological activity in tropical climates. *Ecological Engineering* 162: 106176.

Guralnick LJ, Cline A, Smith M and Sage RF. 2008. Evolutionary physiology: the extent of C4 and CAM photosynthesis in the genera Anacampseros and Grahamia of the Portulacaceae. *Journal of Experimental Botany* 59(7): 1735-1742. http://dx.doi.org/10.1093/jxb/ern081.

Lattanzi FA. 2010. C3/C4 grasslands and climate change. In: *Grassland in a changing world.* Vol 15. Schnyder H, Isselstein J, Taube F, Auerswald K, Schellberg J, Wachendorf M, Herrmann A, Gierus M, Wrage N and Hopkins A. Proc. 24th General Meeting of the European Grassland Federation and Arbeitsgemeinschaft Grünland und Futterbau der Gesellschaft für Pflanzenbauwissenschaften. Kiel Germany pp 3-13.

Lemaire G, Da Silva SC, Agnusdei M, Wade M and Hodgson J. 2009. Interactions between leaf lifespan and defoliation frequency in temperate and tropical pastures: a review. *Grass and Forage Science* 64: 341-353.

Lloyd J and Farquhar GD. 1994. ^{13}C discrimination during CO2 assimilation by the terrestrial biosphere. *Oecologia* 99: 201-215.

Malaviya DR and Roy AK. 2021. Let's green the grasslands. In: State of India's Environment 2021. A Down To Earth annual, India. pp 290-296.

Malaviya DR, Roy AK and Kaushal P. 2020. Comparative leaf anatomical investigations suggestive to 'photosynthetic pathways type' in guinea grass (*Panicum maximum* Jacq.) accessions and its interspecific lineage. *Current Science* 119 (5): 808-816.

Malaviya DR, Roy AK and Kaushal P. 2017. Rangelands/grasslands of India: current status and future prospects. In: Grasslands of the World: Diversity, Management and Conservation Victor R Squires, Jürgen Dengler, Haiying Feng and Limin Hua (Eds.) CRC Press, Boca Raton.pp 223-240.

Nalule AS. 2010. *Social Management of Rangelands and Settlement in Karamoja Subregion.* European Commission, Humanitarian Aid and FAO.

Niu S, Liu W and Wan S. 2008. Different growth responses of C3 and C4 grasses to seasonal water and nitrogen regimes and competition in a pot experiment. *Journal of Experimental Botany* 59: 1431–1439. doi:10.1093/jxb/ern051

Roy AK and Singh JP. 2013. Grasslands in India: Problems and perspectives for sustaining livestock and rural livelihoods. *Tropical Grasslands – Forrajes Tropicales* 1: 240−243.

Sage RF, Wedin DA and Li M. 1999. The biogeography of C4 photosynthesis: patterns and controlling factors. In: *C4 Plant Biology* (eds Sage RFand Monson RK). Academic Press, San Diego, USA. pp. 313-373.

Sage RF and Zhu X. 2011. Exploiting the engine of C4 photosynthesis. *Journal of Experimental Botany*. 62: 2989–3000, doi:10.1093/jxb/err179.

Still CJ, Berry JA, Collatz GJ and DeFries RS. 2003. Global distribution of C3 and C4 vegetation: Carbon cycle implications, Global Biogeochem. Cycles, 17(1), 1006, doi:10.1029/2001GB001807.

Ueno O. 2004. Environmental regulation of photosynthetic metabolism in the amphibious sedge *Eleocharis baldwinii* and comparisons with related species. *Plant Cell Environ* 27: 627–639.

von Caemmerer S, Ghannoum O, Conroy JP, Clark H and Newton PCD. 2001. Photosynthetic responses of temperate species to free air CO2 enrichment (FACE) in a grazed New Zealand pasture. *Australian Journal of Plant Physiology* 28: 439-450.

Wang C, Guo L, Li Y, Wang Z. 2012. Systematic Comparison of C3 and C4 Plants Based on Metabolic Network Analysis. *BMC Systems Biology* 6 (Suppl 2): S9.

Werger MJA, Hirose T, During HJ, Heil GW, Hikosaka K, Ito T, Nachinshonhor UG, Nagamatsu D, Shibasaki K, Takatsuki S, van Rheenen JW and Anten NPR. 2002. Light partitioning among species and species replacement in early successional grasslands. *Journal of Vegetation Science* 13: 615-626.

Wynn JG and Bird MI. 2007. C4-derived soil organic carbon decomposes faster than its C3 counterpart in mixed C3/C4 soils. *Global Change Biology* 13: 1–12, doi: 10.1111/j.1365-2486.2007.01435.x