International Grassland Congress Proceedings | XXIV International Grassland Congress / XI International Rangeland Congress

Tree Legumes as Sustainable Ecosystem Services in Livestock Systems

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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

Tree legumes as sustainable ecosystem services in livestock systems

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Key words: tree; arboreal; legumes; leguminous; ecosystem services

Abstract

Arboreal legumes provide multiple uses in pastures and rangelands. Trees directly and indirectly feed, house, doctor, and warm humans at minimal environmental cost through forage (fodder), timber, biofuel, medicines, as well as edible leaves, pods, and seeds. Leguminous trees, because they foster biological nitrogen fixation (BNF) and acquire deep-soil nutrients and moisture, compete less with herbaceous plants for shallow-horizon soil moisture and nutrients. Their ecosystem services (ES) are generally less obvious and quantifiable. These include converting CO_2 to sequestered C and released O_2 in N-poor soils where trees without BNF do not thrive. Other ES include shade for animals (including humans), plants, and soil microorganisms that would not otherwise survive in direct sunlight, in dry seasons, or under human mismanagement (overgrazing). Arboreal legumes in semi-arid and arid environments also provide habitat and nutrition to insects (pollinators), mammals, and birds during crucial drought seasons and years, facilitating repopulation to the ecosystem when rainfall returns. Additional ES include crucial ecosystem biological diversity, climatic stability, as well as aesthetic and cultural values. Humans have long recognized their value in natural semi-arid and arid ecosystems such as rangelands but have been slower to incorporate them into cultivated pastures where herbaceous monocultures dominate. Incorporating arboreal legumes with greater regularity into restored rangelands or cultivated pastures would not only increase overall productivity by adding non-herbaceous aerial and deep-soil root biomass but also provide ES that herbaceous species cannot match.

Introduction

We can no longer afford to manage grasslands solely for forage production leading to animal products that feed humanity. Arboreal legumes, especially in warm climates, can contribute to diverse ecosystem functions (Dubeux et al., 2017). Beyond fixing atmospheric C and N that translates into meat, milk, fiber and draught power, legume trees also provide ecosystems services (ES) that sustain environmental health and compensate for unsustainable crop and forestry production. We will review key ES that perennial, deep-rooted arboreal and shrub legumes provide in grasslands. We will then expand on potential approaches where trees and shrubs can provide additional environmental and human health benefits from natural and managed ecosystems where grasses predominate.

Arboreal legume ecosystem services

Atmospheric N_2 fixation

Industrial fertilizer N in agricultural systems is ultimately regulated by economic considerations and the presence of effective infrastructures for fertilizer production and distribution. The legume family (Leguminosae or Fabaceae) is the third largest family of flowering plants, with approximately 650 genera and nearly 20,000 species (Doyle, 1994). Legumes often fix atmospheric N_2 that most plants cannot harness. Atmospheric N_2 can be fixed symbiotically by the association between *Rhizobium* species and legume roots. This represents a renewable source of N for agriculture (Peoples et al., 1995a,b). Including N_2-fixing legumes in livestock grazing systems cycles N into the soil as well as, via excreta from ruminants, thereby reducing industrial N fertilizer inputs with all their associated environmental issues.

Deep taproots

Deep-rooted arboreal trees can provide fodder year-round, especially during dry seasons and droughts, thereby sparing herbaceous layer overgrazing. Legume fodder trees are easier to grow in low-N soils, require little land, labor or capital, have numerous by-products and often supply feed within a year after planting. African farmers have fed tree foliage to their livestock for centuries, using wild browse or trees that grow naturally on their lands (Le Houé, 1980). Many farmers specifically grow fodder trees to feed their goats (Place et al., 2009) and studies confirm their significant impact on milk yields (Niang et al., 1996). Several other benefits of fodder shrubs, as cited by farmers, include the provision of products (firewood, stakes, bee forage and edible seed) and ES (fencing, soil fertility improvement, soil erosion control, and animal health and reproduction). Because of their high protein content, minerals and vitamins, and availability in dry seasons or droughts, fodder tree/shrub legumes have the capacity to complement crop-residues and natural pastures. Being deep rooted, fodder trees are less affected by seasonal and yearly climatic variability, cycles and changes.

Sequestering C into soil via root attrition and leaf litter

Leguminous taproots, whether arboreal or herbaceous legumes, cycle deep-soil horizon nutrients back into livestock systems via fodder-manure-soil microorganism-plant interactions thereby reducing fertilizer requirements. As deep-soil roots and surface leaf litter decompose, they also contribute to soil organic matter build-up (Vetaas, 1992). Besides raising cation exchange capacity that reduces surface and subsoil mineral and moisture losses, this soil component sequesters C, thereby mitigating harmful effects of gaseous C molecules such as CO_2 or CH_4.

Shade = temperature mitigation

Heat stress in livestock reduces appetite, weight gains, milk production and breeding efficiency (Haun, 1997; McDowell, 1968). Ideal conditions for beef and dairy cattle include a temperature range between 7 and 25 ºC (Henry et al., 2012). Leguminous trees on the grazing landscape have an advantage over barns and temporary structures because of the cooling effect that evapotranspiration provides, better ventilation and reduced reflection of sunlight rays (Karki and Goodman, 2010). Arboreal legumes likewise mitigate soil surface temperatures which, in warm environments, can benefit soil water-retention and protect microorganism or soil seed banks (Vetaas, 1992).

Plant, microorganism, or animal diversity and refugia

Tree legume growth form, physiological, and reproductive characteristics provide habitat and nutrition to a variety of insect, mammal, and bird species during critical drought periods. Lateral roots close to the soil surface capture shallow soil moisture, while tap roots access water deep within the soil profile (Ansley et al., 2014). Many woody legumes increase soil water uptake through reductions in tissue water potential and accumulation of osmotic substances. These characteristics support pollen, seed and leaf production during drought periods when herbaceous species are dormant (Fagg and Stewart, 1994). Seed pods from woody legumes may provide a crucial food source for humans, wildlife, and livestock. Tree legumes are also highly attractive to a variety of generalist and specialist arthropods. Herbivorous insects utilize tree foliage, pollen, nectar, extra-floral nectaries, and pods as food resources. Other insects bore into the wood to deposit their larvae. Stands of woody legumes are preferred foraging sites for insectivorous mammals due to high arthropod abundance and richness (Hackett et al., 2013).

Leguminous trees foster a spatial mosaic of herbaceous composition and soil nutrient distribution under their canopies that is different than that beyond the canopy (Zhou et al., 2018; Ansley et al., 2019). Transitions from grasslands to savannas or woodlands result in alterations to primary production, litter inputs, and input chemistry, which subsequently change soil C and N storage and dynamics along with microbial composition and activity. Woodland soils under tree legumes often have greater populations of gram-negative bacteria, while grassland soils have a greater abundance of gram-positive bacteria and actinobacteria (Creamer et al. 2016). Soil fungal communities differ under tree legumes compared to open grasslands as well (Hollister et al. 2010). Growth of some herbaceous species, especially C_3 species, benefits from the nutrient enrichment and ameliorating effects of the woody canopy on air and soil temperature. McCleery et al. (2018) reported decreases in animal diversity when African savannah woody canopy cover was less than 10% or surpassed 65%. Reductions in animal diversity associated with homogenization of vegetation structure may indicate subsequent reductions in ecosystem stability, resilience, and services.

Plant secondary compounds.

Leguminous tree fodder, pods, and bark often contain plant secondary compounds containing useful environmental health benefits beyond simple feed for ruminants. Condensed tannins are the best known and are particularly abundant in shrubby and arboreal legumes (Tedeschi et al., 2014). They provide environmental services not only by suppressing internal parasites and rumen methane emission, but also reducing the need for pharmaceuticals that often have unintended negative environmental effects (Iglesias et al., 2006).

Multiple uses (fuel, lumber, honey, pulses, leafy vegetables) contribute to human nutrition and reduce need to exploit more land.

Tree legumes are well known for their multiple uses. Fuelwood and charcoal have been incorporated in bioenergy systems worldwide. Their wood is dense and has a high heating value (Fagg and Stewart, 1994). Since most woody legumes are smaller trees or shrubs, they are not typically used for large-scale timber production. However, their hard and durable wood is valued for local furniture construction, flooring, beams, and fence posts. Leguminous trees yield numerous products that contribute directly to human nutrition, including honey, flour, and jelly (Fagg and Stewart, 1994; Bovey, 2016). The foliage of some species is eaten as a leafy vegetable. Leguminous trees also produce gums for food additives and in pharmaceuticals. Woody legumes have been used green manure in agroforestry systems producing cereal grains, pulses, vegetables, and forages (Viswanath et al., 2018).

Enhancing arboreal legume ecosystem services in grasslands

We hypothesize that arboreal legumes provide more ES in grasslands than currently recognized. We propose these, along with the ES already well documented, justify protecting leguminous trees in rangeland and or actively including them in cultivated pastures to enhance not only ruminant productivity but also ecosystem health, environmental resilience and, ultimately, human health benefits.

Selective rangeland brush clearing

By selectively thinning or clearing grasslands with excessive tree cover, thereby sparring arboreal and shrub legumes with fodder and ES potential, plant and animal diversity will be conserved (Lima et al., 2018). This may not be as straightforward as it seems. Indiscriminate herbicide application or bulldozing is far easier than removing only invasive or undesirable species in a savannah or pasture. It also requires an understanding of which tree species should be left and why. Even in areas dominated by undesirable legume species, some parcels should be left undisturbed for wildlife habitat and landscape heterogeneity (Park et al., 2012).

Enhancing multiple canopies

Including multiple canopies in grasslands can increase forage production with positive effects on harvestable animal product (Muir et al., 2015). This in turn enhances a wide gamut of animal diversity, both domesticated and wild ruminants as well as those that simply augment ecosystem stability and resilience during climate fluctuations as well as human mismanagement.

Include in cultivated pastures

Including arboreal legumes in cultivated pastures can increase sunlight capture with consequent forage biomass production. Greater animal production follows, especially when multiple herbivore species are used to harvest vegetation diversity (Muir et al., 2015). This practice, however, is not a widespread management technique, especially in temperate regions.

Maintain natives and avoid exotics

Many landscapes, especially arid and semi-arid tropical and subtropical grasslands, have native arboreal legumes that can be protected and increased (Viswanath et al., 2018). Experience with invasive arboreal legumes around the world indicate that utilizing natives in restoration or production-enhancing interventions is generally beneficial because they avoid introducing disruptive invasive species selected for aggressive traits (Bradshaw et al., 2008). Sustainable management will avoid fostering native invasives (Ansley et al., 2019).

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