International Renewable Energy Agency

# SUSTAINABLE PASTURELAND INTENSIFICATION

## MAKING ROOM FOR ENERGY CROPS WITHOUT HARMING BIODIVERSITY

WORKING PAPER

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# ABSTRACT

**Biofuels are an essential renewable energy resource, with 40% (90 exajoules) of renewable energy resources projected to come from biofuel sources by 2050. In order to meet these projected energetic demands, biofuel production must be increased from the current annual biofuel yield of 50 exajoules. Sustainable intensification of pastureland, or the increase of livestock yield in kilogrammes per hectare, is a key approach to making more land available for these bioenergy crops, like high-yielding grasses and short-rotation coppice wood, without incurring the carbon debt associated with conversion of farmland from forest. However, pastureland intensification is often criticised as a potential threat to pastureland biodiversity – there are cases of unsustainable intensification of pastureland leading to ecological degradation. This working paper reviews approaches to sustainable intensification of pastureland that have had a neutral or positive effect on biodiversity of the affected areas, and how some of these approaches have been implemented in several successful case studies.**


# 1. INTRODUCTION

With the Earth's average temperature continuing to rise, efforts to lower global carbon emissions have become progressively more intense (Raftery et al., 2017). Increased use of renewable energy resources, which are much lower in carbon emissions than fossil fuels, is key to winning the race, and bioenergy will play a key role. The International Renewable Energy Agency sees bioenergy accounting for about a third of total cost-effective renewable energy potential in 2050 (IEA/IRENA, 2017; Searle and Malins, 2015).

Achieving this goal requires intensively increasing the production of bioenergy resources. Intuitively, this may appear to require an increase in area of land used to grow such resources. However, substantial amounts of bioenergy can be obtained from crop and wood residues on farms and forestlands that are already cultivated. Additionally, bioenergy crops could also be grown on land freed up by reducing waste and losses in the food chain, restoring degraded lands to productive use, and raising yields on farmland used for growing crops or raising livestock.

There is an enormous bioenergetic potential that arises specifically from the intensification of pastureland; intensification could lead to the use of as many as 950 million hectares (Mha) of land for biofuel cultivation instead of livestock rearing (IRENA, 2016). Pastureland intensification is defined simply as an increase in agricultural output (kilogramme (kg) of livestock) per unit of input (UN, 2017). Input in this instance can be defined as anything that contributes to agricultural production, such as land, labour, time and fertiliser, among other resources (UN, 2017; FAO, 2009).

Suggestion of intensifying pastureland for the cultivation of biofuels is often met with controversy, as there are several potential complications, chiefly the potential to reduce local biodiversity (NERRS, 2017). This paper discusses pastureland intensification as a viable means by which to increase global biofuel production without increasing the demand for agricultural land, and without causing detrimental damage to surrounding wildlife communities. The intent is to assess the extent to which pastureland can be intensified without damaging the resiliency of local ecosystems.

Biodiversity is a reliable tool for assessing the health of any natural ecosystem. There is a clear consensus among ecologists that vibrant biodiversity is necessary for the maintenance of a healthy organismal community (USGS, 2017). Hence, biological diversity can be used as a proxy measure for ecosystem vibrancy.

There are three main facets of biodiversity that fall under the larger umbrella of the term. They are as follows: genetic diversity, ecosystem diversity, and species diversity. Each of these considers different scales of biological diversity, spanning from intra-species diversity to large-scale ecosystem-to-ecosystem diversity.

Genetic diversity refers to the variations in genetic traits within a specific species (Nevo, 1988). By virtue of its small-scale consideration of diversity, while exclusively dealing with variation within a single species population, it is not very useful for assessing the interspecies biodiversity that constitutes a community or ecosystem.

At the other end of the spectrum, ecosystem biodiversity focuses on the diversity of whole ecosystems and the differences between them. To put it succinctly, it focuses on the diversity between entire biomes rather than between species (SEAFDEC, 1994). Just as genetic diversity focuses on too narrow a category, ecosystem diversity focuses on one that is too large; analysing ecosystem-level diversity does not provide species-level insight into each biome, so it is not very useful for analysing and interpreting individual ecosystem health.

Thus, the most useful measure of biodiversity for this paper is species diversity. Species diversity usually refers to some combination of species richness as well as species evenness, as the relative abundance of species and the absolute number of species both matter for determining species diversity (Duelli and Obrist, 2003). With its interspecies focus, species diversity is the most relevant biodiversity measure for studying diversity within an ecosystem.

Most commonly, the species biodiversity of a community is represented by an index number, consisting of different weighted combinations of species evenness (relative abundances) and species richness (absolute number of species). Among the most commonly used indices of diversity is Simpson's index, defined as in Simpson (1949):

$$D = 1 - \sum_{i=1}^{n} (p_i)^2 \quad (1)$$

Where D is a value between 0 and 1, denoting the probability that two randomly selected organisms out of a given biological community will fall into the same species category. Generally, a value of 1 indicates "infinite" biodiversity, in the sense that it is unbounded, and a value of 0 indicates no biodiversity, as in the presence of no species, in the sample. In the above equation, pi refers to the fractional abundance of the ith species, and n refers to the total number of species in the dataset, which, in this case, is the ecosystem in question.

The Shannon-Wiener index is similarly used as a different way to measure biodiversity:

$$\mathrm{H}' = - \sum_{i=1}^{n} p_i \ln p_i \quad (2)$$

Just like Simpson's index, the Shannon-Wiener index takes relative abundance and species richness into account. An increase in the value of H' corresponds to an increase in biodiversity. The values of H' and D are often compared with the absolute value of species richness (S) to provide a comprehensive overview of species abundance and evenness. Simpson's index of biodiversity and the Shannon-Wiener index prove to be among the most reliable over datasets of variable sizes when finding an intermediate measure of species evenness and species richness (Morris et al., 2014). The values serve as important comparative tools when assessing biodiversity of a community or ecosystem.

# 2. REDUCED BIODIVERSITY AS A POTENTIAL CONSEQUENCE OF PASTURELAND INTENSIFICATION

Amongst environmentalists, there has been considerable apprehension of the potential environmental ramifications of agricultural intensification, particularly concerning pastureland. One of the primary concerns is that the clearing of natural grasslands and the introduction of monocultural plant species can have detrimental effects on local biodiversity. Traditionally, agricultural intensification has relied on the exclusive growth of a crop monoculture (in the case of pastureland, this would be the cultivation of a single forage crop for livestock). This means that entire swaths of land become dominated by one specific species of plant, which can very clearly have a negative impact on biodiversity and, consequently, the surrounding wildlife community (Aragona and Orr, 2011).

However, presenting agricultural intensification as a matter of simply increasing the efficiency of monocultural farms is not entirely accurate. Biodiversity on agricultural plots, both cropland and pastureland, has benefits to the productivity of the farm. The 2nd International Crop Sciences Congress, consisting of various government-sponsored research institutions from Asia, Australia, Europe and North America, spent a considerable portion of their 1996 meeting discussing the benefits farmers gain from having a large biological variation of crops and wildlife: both factors contribute to increased agricultural productivity and lead to higher levels of soil resiliency. They point out that "agricultural intensification does not automatically trigger great harm to the environment" and that it can "save and enhance biodiversity." They conclude their discussion of agricultural intensification, biodiversity and the environment by suggesting several sustainable options: "An important step towards achieving sustainability in agriculture in coordination with nature will be to re-introduce crop rotation, inter-cropping, cover crops, biofertilisers like legumes, bacterial cultures, and integrated pest management techniques." (Srivastava and Mukhopadhyay, 2010).

Indeed, the complete destruction of natural, native landscape for the development of agriculture has a negative impact on the productivity of the land. What is ultimately better for the agriculture sector is to promote sustainable intensification, since the preservation of a rangeland's ecosystem helps increase its productivity.

The correlation between agricultural productivity and biodiversity is intuitive: soil stability relies heavily on soil biota in addition to nutrients, and the reduction of biological diversity negatively impacts both of those factors (Doran and Zeiss, 2000). Of course, this is a simplified depiction of the complicated ecological processes underlying soil health, but it holds true as a basic model. In short, soil resiliency and stability rely on biodiversity. This is yet another reason why conserving biodiversity is so important to consider for pastureland intensification: it serves an important role in the balance of an ecosystem as well as in the maintenance of agricultural land, even land used for pasture. Thus, increased plant and bacterial biodiversity in pastureland increases its productivity (Srivastava and Mukhopadhyay, 2010; Tilman et al., 2001).

The incorporation of land-saving techniques and systems can make pastureland more productive and more biologically diverse. For example, on agriculturally intensive farms in Europe, butterflies and skylarks became more abundant as forage increased and crops became more varied (Benton, Vickery and Wilson, 2003). For this study, various plots of cultivated land were subject to different combinations of cultivars. The plots that had the largest number of species of cultivated crops also had the largest number of native, wild species. In light of studies like this one, the depiction of the conservation of ecosystem vibrancy and the intensification of agriculture as a guaranteed tradeoff is inaccurate. In fact, exclusive cultivation of a monocultural forage crop has the potential to throw the surrounding ecosystem off balance, leading to a loss of biodiversity as well as of soil stability and resiliency. Put simply, farmers have an economic incentive to avoid monoculture and the reduced biodiversity associated with it, as such methods of intensification result in lowered crop and livestock yields (Waggoner, 1995).

A good example of how pastureland intensification can go wrong is provided by the mountains of Tajikistan, where single-crop cultivation and poor land management have extensively damaged the ecosystem. In Central Asia, where Tajikistan is located, 27% to 68% of pastureland is in a degraded state (ELD and CGIAR, 2016). Use of pastureland in this region of the world is at best haphazard and at worst excessive. (Breckle et al., 2006) found that desertification of Tajik pastures has increased dramatically over the past few decades due to unsustainable agricultural practices, especially in pastureland management. Degradation of pastures results from excessive grazing and the replacement of long-term fodder plants with fast-growing annuals; the strong taproots in long-term fodder plants provide more soil support than the superficial root systems in fast-growing annuals. The development of a year-round grazing system, where land is neither given a rest period nor aided by the presence of long-term fodder plants, has led to a reduction of local biodiversity around the pasturelands of the region.

The Consortium of International Agricultural Research Centers (CGIAR) suggests that a major reason for land degradation and biodiversity loss in the Tajik mountains is that there is no governmental regulation of agricultural practices. This leaves the management of farmland completely up to the individual farm owners or companies. CGIAR has found that practices such as no-till technology and intensive gardening would make Tajikistan's agricultural land more productive (ELD and CGIAR, 2016). Government measures to promote such practices could therefore reduce land degradation and benefit farmers. The solution to land degradation in the Tajik mountains is not to stop pastureland intensification altogether, but rather to improve the efficiency of pastureland use sustainably. Problems were caused not by intensification as such, but the way it was carried out. Tajikistan serves as an example of the dangers of unsustainable land use.

Another point of contention in the discussion of pastureland intensification is that in certain scenarios, it may increase in deforestation and accelerate conversion of natural landscape to farmland (Nepstad et al., 2008). The argument is as follows: increased land productivity on frontier farmland leads to increased profit for farmers and producers; in turn, they push to deforest more natural land to further increase their yield and gain even more profit. A 2006 study shows that market prices for agricultural products are positively correlated with increased rates of deforestation in the Brazilian Amazon (Morton et al. 2006). This supports the argument that there is an economic incentive to convert natural biome to agricultural land, especially when land-use is intensified.

This characterisation of the problem, however, lacks key nuances. Per Byerlee, Stevenson and Villoria (2014) increased rates of deforestation after agricultural intensification only occurred when the intensification was purely market-driven and on the frontier of farmland. In cases where it is done for increased productivity alone (referred to as technology-driven intensification), or done in areas far from natural landscape borders, then the deforestation rate does not increase at all (Ibid.). In fact, such intensification has the potential to make pastureland-available, non-livestock agriculture, like biofuel generation, thereby further increasing agricultural productivity while sparing natural forest (Kennedy et al., 2016). The relationship between pastureland intensification and deforestation rates is more nuanced than simple cause and effect. Indeed, a primary objective of pastureland intensification is to alleviate agricultural pressure on natural landscapes by using already-converted land more efficiently – most often, intensification efforts are undertaken for the purpose of protecting forests rather than increasing agricultural profits.

# 3. CASE STUDIES OF PASTURELAND INTENSIFICATION WITH INCREASED BIODIVERSITY

Perhaps the most successful examples of sustainable pastureland intensification are in Brazil and Colombia. The sustainable intensification of pastureland in these two countries has been facilitated by the adoption of a particular sustainable land management (SLM) practice referred to as agroforestry. Agroforestry, in the simplest sense, is a term that refers to several different land-use techniques involving the planting of woody plants on agricultural land used for growing harvest crops or maintaining livestock, with the woody plants arranged in some regular pattern (FAO, 2017a).

Agroforestry is a particularly effective land-use intensification method for cropland and pastureland alike, and it is associated with minimised biodiversity loss in areas of high-intensity land-use: in a fully developed agroforestry system, around 50% to 80% of native species are preserved at their native abundances (Noble and Dirzo, 1997). Part of agroforestry's success comes from its preservation of microbial biodiversity in the soil of agricultural land. By providing soil-level biological stability, the trees and shrubs incorporated onto agricultural land allow higher levels of biodiversity (birds and butterflies, for example) to flourish. Brazil and Colombia alike rely heavily on agroforestry techniques for the intensification of pastureland. There are many different agroforestry systems, such as windbreaks, alley-cropping, and riparian buffers, but the most useful in these countries is probably silvopasture (Nelson and Durschinger, 2015).

Silvopasture is the cultivation of forage crops, trees, and livestock on the same pastureland (FAO, 2017a). This type of pastoral farming has become increasingly common over the past few years. Unlike forms of pastureland intensification that rely on the over-sowing of forage crops or the excessive use of fertilisation, silvopastures increase the productivity of pastureland without any chemical intervention.

## 3.1. Colombia

**Pressure of pasture on forests:** There are 41 million hectares of pastureland in Colombia, and from 1990 to 2010, the average annual rate of deforestation of the Colombian Amazon was 310 345 hectares, most of which was used for pastureland (FAO, 2017b). As an area of the world with a unique combination of endemic species and naturally biologically diverse regions, the maintenance of Colombia's vibrant ecosystem diversity remains a pressing matter among environmentalists and agriculturists alike. Agricultural development naturally poses a risk to Colombia's natural landscapes. Stopping or limiting livestock cultivation is not a viable option, since many Colombians rely on agriculture for their food supply and income.

**Intensification approach:** The Colombian department (administrative region) of Valle del Cauca applied a silvopastoral intensification process. This involved cultivating Tithonia diversifolia (the Mexican sunflower) and Leucaena leucocephala (a leguminous tree that supports nitrogen-fixing bacteria) as fodder crops alongside the forage crops already growing on the pasture. The agricultural areas selected for the intensification process consisted of 3 700 hectares of previously degraded pastureland that had inefficient stocking and milk production rates, even with fertiliser use. Over 21 years, from 1990 to 2011, farmers have implemented intensive silvopastoral systems in designated farm areas.

**Improved productivity:** Development of silvopasture on agricultural land in Valle del Cauca has substantially increased its productivity. In the 21-year period, there was a 67% increase in milk yield (litres per hectare per annum) and a 29% increase in stocking rate (kg of livestock per hectare per annum) on pastureland, while the use of fertiliser was eliminated (Global Agenda for Sustainable Livestock, 2014). The observed changes in rate of fertiliser use, stocking rate, and milk production are shown in Table 1.

Table 1: **Yield Increases in Valle del Cauca Dairy Farming with Intensive Silvopastoral System Implementation 1990-2011**

| Year | 1990 | 2011 |
|---|---|---|
| Fertiliser use (kilogramme per hectare per annum) | 450–500 | 0 |
| Stocking rate (kilogramme per hectare per annum) | 1 575 | 2 025 |
| Milk Yield (litres per hectare per annum) | 9 000 | 15 000 |

Source: Global Agenda for Sustainable Livestock (2014)

Incorporating legumes into the forage cultivation of silvopastoral systems yields additional benefits to farmers. Per Lascano (1990), "The strategic use of small areas of sown grasses in association with legumes to complement native pastures was tested in a commercial farm in the Llanos of Colombia… with 5% of the area of the farm sown with improved grass-legume pastures." Large increases were obtained in a six-year period in terms of stocking capacity (kg per hectare (ha) per annum), which doubled, and cow weight, which increased by 40%" (Ibid.). The incorporation of silvopastoral systems into Colombian ranching has increased the productivity of pastureland and decreased biodiversity loss.

**Increased biodiversity:** Since silvopastoral systems in Valle del Cauca were incorporated over previously degraded pastureland, there has been marked improvement in avian biodiversity. The total richness of bird species has increased by 32.2%, and the number of endangered bird species has risen by 16.7%, following the integration of a silvopastoral system. Clearly, the benefits of silvopasture are not limited to increased productivity (FAO, 2010). According to the study results, the intercropping of trees with forage plants enhances the natural biota of soil, thereby increasing its ability to host forage crops and remain adequately nutrient-rich for native animals in the soil.

Additionally, a 2014 study shows that there was a marked increase in soil resiliency and nutrient content in Colombian pastureland subjected to silvopastoral intensification (Martínez et al., 2014). The study found that the integration of trees into pastoral systems leads to an unequivocal increase in soil nutrient content (phosphorus, potassium, calcium, and organic matter). They conclude that the soil enhancement resulting from silvopasture implementation bolsters microorganism functioning underground, with tree and shrub presence encouraging mycorrhizal network development between forage grasses.

## 3.2. Brazil

**Pressure of pasture on forests:** As of 2016, 198 Mha out of Brazil's 851 Mha were used for pastureland. For comparison, 38 Mha of land is used for urban areas, and 60 Mha of land is used for crop cultivation. Native ecosystem area takes of 554 Mha of land, with the Brazilian Cerrado and native forests occupying 200 Mha and 354 Mha, respectively (USDA, 2016). In the Cerrado region, 13 Mha of native land was converted to pasture between 2001 and 2013 (Graesser et al., 2015). Between 2010 and 2015, the average rate of deforestation of the Amazon rainforest in Brazil was 984 kilohectares (kha) per annum. This was 40% lower than the rate through the 1990s, which averaged around 1 640 kha per annum (Keenan et al., 2015).

Yet deforestation of 984 kha per year would still correspond to a loss of more than 25% of the existing Brazilian Amazon by 2117. Thus, deforestation rates have to be reduced further. Thus, even the maintenance of these reduced deforestation rates for the expansion of pastureland will have a detrimental impact on the natural Brazilian landscape, especially since the production of dairy and beef from Brazil is expected to increase by 58% and 73% by 2050, respectively.

**Policy response:** The Government of Brazil has enacted several laws protecting the natural Amazonian forests and encouraging agricultural intensification, especially on pastureland. The Brazilian Forest Code of 1965 provides guidelines for agriculture and food production. Comprehensive analysis of Brazil's rangeland show marked improvement in the productivity of beef and dairy production in the decade from 2000 to 2010 (Castelo, 2015).

**Intensification approach:** Brachiaria is a genus of grass crop that can be cultivated easily in the acidic soils of the Brazilian Amazon. It is considered a reliable and safe forage crop in tropical rangelands as it avoids degrading soils and grows well in soil of low-fertility (FAO, 2010). Brachiaria is particularly unique as a crop in that some strains (particularly Brachiaria humidicola) inhibit heavy nitrification of soil, which poses a huge threat to many sustainable pastureland intensification efforts. High rates of nitrification in pastureland soil, a by-product of ammonia-based fertilisers, lead to accelerated nitrate leaching of soil, which thereby decreases its resiliency and fertility over time.

Some Brachiaria hybrids alleviate nitrification stress on soil through a process referred to as biological nitrification inhibition; this is a useful asset for land-use intensification, as it reduces the amount of fertiliser required and improves the longevity of the soil (Rao et al., 2014). Brachiaria also has the benefit of growing resiliently even under heavy grazing conditions commonly found in intensified pasture (Shelton and Stür, 1990). These traits of the crop make it an ideal candidate for use in pastureland intensification efforts, particularly in tropical areas.

**Improved productivity:** In the decade from 2000 to 2010, the productive yield (kg product per hectare) of beef and dairy farming in Brazil's rangeland improved markedly (Castelo, 2015). Brachiaria has raised beef and dairy production on pastureland where it is cultivated: its use as a forest crop has increased the weight of livestock supported per hectare of pasture by a factor of ten (Rudel et al., 2015). Certain rangelands have also turned to incorporating silvopastoral systems to Brachiaria plots, which lead to even further increases in productivity (Rao et al., 2015).

**Increased biodiversity:** the introduction of silvopasture in Brazilian pasture has led to increased soil resilience and a decreased need for fertiliser use which, in turn, leads to increased maintenance of biodiversity levels (Rao et al., 2015). The use of silvopasture and carefully managed Brachiaria forage cultivation serves as a reliable means of increasing the productivity of agricultural land while minimising damage to forests and other features of Brazil's various ecosystems (Latawiec et al., 2014).

The productivity of pastureland can be increased while simultaneously reversing previous damage to degraded land. This is possible by introducing techniques such as rotational grazing and incorporating legume crops in addition to maintaining a silvopastoral system. A 2016 study on agricultural intensification in Brazil demonstrated that sustainable intensification has the potential to increase agricultural profits while improving species diversity and water quality when compared to current land use (Kennedy et al., 2016).

**Reduced deforestation:** The most substantial impact of the increased productivity of Brazil's pastureland is that the amount of land utilised for beef and dairy production actually decreases. A study conducted a comprehensive study on Brazil's land-use practices and deforestation rates. They found that destruction of the Brazilian Amazon for pastureland formation decreased drastically from an average rate of 18 200 square kilometres (km2) per annum between 1988 and 2006 to 4 700 km2 per annum in 2012 (Barretto et al., 2013). Similar results were found in the Cerrado biome, where deforestation rates fell from 14 200 km2 per annum in 2008 to 6 500 km2 per annum in 2010 (Beuchle et al., 2015). The reduction in deforestation rates is directly correlated with land-use intensification practices (Latawiec et al., 2014).

## 3.3. Eastern Africa: Ethiopia and Kenya

**Intensification approach:** In Kenya and Ethiopia, farmers employ some different SLM practices to intensify pastures. The most prominent are the push-pull system and the adoption of multiple vegetation and livestock stocking techniques. A major problem for pastureland intensification in East Africa is posed by pests (Rudel et al., 2015), including a variety of native animal species. There is much contention over how to make pastureland more productive without harming local biodiversity, of which pests are a part. A push-pull system for cereal and livestock production has proven to be a practical solution to this problem. On the borders of agricultural lands, Napier grass is planted to attract pests like stemborers. The Napier grass acts as a "pull" for the stemborers, which preferentially forage on this crop. On the rest of the land used for farming and pasture, farmers maintain a crop such as Desmodium legume, which serves as a natural repellant to stemborers. This serves as the "push" part of the system (Khan et al., 2011).

**Improved productivity:** Use of this system has increased the agricultural potential of pastureland, allowing for more agricultural output to come from an unchanged input (Khan et al., 2011). The International Centre of Insect Physiology and Ecology 2015 report stated that farmers utilising the push-pull system in Eastern Africa doubled their maize yields. The system also improved soil resiliency and resistance to erosion (ICIPE, 2015).

**Resilient biodiversity:** A 2016 study of four different agroecological regions in Eastern Kenya explored the impacts of small-scale sustainable agriculture on the natural ecosystem. Four adjacent regions were sampled, where the number of vegetative species – and number of organisms belonging to each species present – were recorded. Following the data collection, several diversity indices, namely Simpson's index and the Shannon-Wiener index, were calculated. The study was conducted as a means of determining how agrobiodiversity impacts agricultural productivity, although the index calculations provide additional insight into biome resilience. The Shannon Index, Shannon-Wiener Index, and Species Richness values are provided in Table 2 (Mburu et al., 2016).

Table 2: **Diversity Measures in Four Agroecological Regions of Eastern Kenya**

| Diversity Measure | Embu Upper Midland Zone | Embu Lower Midland Zone | Tharaka-Nithi Upper Midland Zone | Tharaka-Nithi Lower Midland Zone |
|---|---|---|---|---|
| S | 31 | 34 | 27 | 32 |
| D | 1 575 | 2 025 | | |
| H' | 9 000 | 15 000 | | |

Source: Mburu et al., 2016

Comparing these Shannon and Simpson index values with typical results in Kenya's agricultural areas shows how well sustainable intensification efforts have also safeguarded biodiversity: typical crop and rangeland in Southern Kenya has an average Shannon-Wiener index value of 0.967 (Jawuoro et al., 2017). As demonstrated in the table, the biodiversity of agricultural land in Eastern Kenya has remained plentiful in species richness and evenness, despite intensification efforts, especially compared with species diversity in regularly maintained farmland in Kenya's southern rangelands. The SLM practices adopted by small-scale farmers in Kenya have mitigated environmental damage while yielding high levels of food production, as a result of grazing animals and crops, with higher H' values corresponding to increased food security among the sampled farms (Mburu et al., 2016). Sustainable pastureland development in Kenya has led to obvious gains in productivity as well as biodiversity maintenance in the areas on and around the pasture.

# 4. CONCLUSION

Looking forward, there are several methods that could help further progress sustainable pastureland intensification such as in the examples above. Legislative intervention is perhaps the most effective option. Legislation in Brazil has led to reduction in native biome conversion, which has consequently led many farmers in the country to adopt sustainability practices (Azevedo et al., 2017). Laws actively promoting intensified use of land will lead to lower rates of natural habitat loss. Going beyond the issue of simple land conversion, policy that promotes SLM practices would incentivise well-managed intensification efforts, which reduce the likelihood of biodiversity loss.

As the world progresses in its transition from fossil fuels to sustainable sources for the procurement of energy, biofuels remain an important yet underutilised resource. To increase biofuel yields around the world, either current land-use practices must become efficient or more land has to be used for cultivating biofuels. The importance of maintaining ecosystem biodiversity to the natural world as well as to farmers/ranchers makes the former a more palatable alternative to the latter. There is sufficient evidence that employing SLM practices in intensification efforts reaps benefits for biodiversity and productivity of the land alike.

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