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PERSPECTIVE

LivestockPlus: Forages, sustainable intensification, and food security in the tropics

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Abstract The increased use of grain-based feed for livestock during the last two decades has contributed, along with other factors, to a rise in grain prices that has reduced human food security. This circumstance argues for feeding more forages to livestock, particularly in the tropics where many livestock are reared on small farms. Efforts to accomplish this end, referred to as the 'LivestockPlus' approach, intensify in sustainable ways the management of grasses, shrubs, trees, and animals. By decoupling the human food and livestock feed systems, these efforts would increase the resilience of the global food system. Effective LivestockPlus approaches take one of two forms: (1) simple improvements such as new forage varieties and animal management practices that spread from farmer to farmer by word of mouth, or (2) complex sets of new practices that integrate forage production more closely into farms' other agricultural activities and agroecologies.

Keywords Forages · Livestock · Livestock plus · Sustainable intensification · Tropics

INTRODUCTION

During the last three decades, as the composition of the world's livestock population has shifted toward monogastric animals, such as pigs, poultry, and guinea pigs, livestock feeds have also changed (Herrero et al. 2013). Because monogastrics, unlike ruminants (cattle, goats, and sheep), have difficulty digesting pasture grasses and other roughage, growth in their numbers has led to commensurate changes in livestock feed, with farmers making more use of grain- and soybean-based concentrates to feed livestock (Rao et al. 2015). The use of feed concentrates, while remaining roughly the same in the developed world between 1980 and 2005, more than doubled in the developing world during the same period (FAO 2009). Because the feed concentrates have a grain basis and contain soybeans as well as oilcakes, their increased use to feed mostly confined livestock has created a competition between humans and animals for the same foods (Thornton 2010).

At the same time, grain prices have begun to increase in historically unprecedented ways. For more than 80 years beginning in 1920, the prices of basic grains declined relative to the prices of other goods and services. Beginning in 2005, grain prices began to increase more rapidly than the prices of other goods. Several factors, most prominently the American subsidies for corn-based ethanol, but also slowing rates of growth in grain production and the growing competition between livestock and humans for basic grains, have driven grain prices up over the last decade (Trostle 2008). In so doing, this competition has undermined the food security of billions of people.

These circumstances call for a decoupling of human food and livestock feed through a renewed emphasis on the production of forages for livestock. How do we do this? To answer this question, this paper first outlines the dilemma posed by the increasing reliance of humans and livestock on the same grains for food. Then it describes four recent agricultural research and extension efforts, sometimes referred to as the LivestockPlus program (Rao et al. 2015), which were created to increase the use of forages to feed livestock in the tropics. This review suggests two strategies for promoting the increased use of forages as livestock feed: one through the development and spread from farmer to farmer of more nutritious forages, and the other through tighter integration of forage production and other agricultural activities on farms.

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FORAGES FOR LIVESTOCK, SUSTAINABLE INTENSIFICATION, AND HUMAN FOOD SECURITY

Globally, grasses currently make up 48 % and grains 28 % of all biomass fed to livestock (Herrero et al. 2013). Crop residues represent a third major source of livestock feed. The reliance on grains as well as grasses for feeding livestock stems in part from the different digestive systems of ruminants and monogastrics. Ruminants have evolved to graze herbaceous plants and browse tree leaves that can be digested in their complex of four or five stomachs. Monogastrics, like humans, have a single stomach and are unable to digest large quantities of such forms of biomass and thus prefer grain- and soybean-based feeds (FAO 2014a). Ruminants eat what monogastrics cannot; they are uniquely able to convert plants from non-arable land into protein (Pitesky et al. 2009). They also transport themselves, and in well-managed pastures, they return 60–90 % of the plant nutrients they consume to the soil as urine and feces (Haynes and Williams 1993). Ruminants also produce 90 % of the greenhouse gases emitted by the livestock sector, mostly in the form of methane from cattle. Monogastrics convert biomass into meat more efficiently than ruminants, so they are less expensive to produce (Herrero et al. 2013) which, along with dietary preferences, has spurred the recent rapid expansion in their numbers and in the use of feed concentrates.

Given the projected increases in human consumption of monogastrics, the growing reliance on grain–soybean-based feeds seems likely to continue during the next two decades (Herrero et al. 2013). The flows of grain and soybeans to monogastrics are large with substantial consequences to global food security. A recent modeling study (Cassidy et al. 2013) found that reducing the consumption of grain-fed animal products by 50 % would increase calorie availability enough to feed an additional 2 billion people. These trends in livestock feed and production have two important implications for poor people. First, by driving up the price of basic foods for humans, these trends make poor people more food insecure. Second, while a rise in agricultural commodity prices would ostensibly benefit poor rural producers of grains and livestock, the one billion rural poor whose livelihoods depend on small-scale crop—livestock production cannot take full advantage of the rising prices of animal products because they do not have the capital necessary to expand production (Thornton 2010).

In this context, intensified production of tropical forages would address issues of rural poverty and food security. First, it would enhance the resilience of the human food system by decoupling human and livestock consumption through an emphasis on roughage that humans do not consume but livestock do. This program, if sufficiently large in magnitude, would create downward price pressures on basic grains, which in turn would improve the food security of poor people. Second, a forage-focused pathway of intensification would emphasize innovations like more productive forages or forage—crop combinations that rural smallholders could adopt because these innovations require very little capital. In this sense, such an approach would benefit the rural poor directly, in a way that innovations in an industrialized livestock economy never could. Third, forage-based systems, especially those composed of grasses, legumes, and trees, are more resilient to weather stresses like drought and can thrive on less fertile lands which are unsuitable for grain–soybean cultivation. Fourth, a shift away from grain monocultures to diversified crop–livestock systems would reduce production and financial vulnerabilities that afflict many smallholder producers.

Forage intensification would occur in a global context in which the extent of pastures is slowly declining. From 2000 to 2011, permanent pastures and meadows, cultivated and uncultivated, declined 1.8 % (FAO 2014b). Most of the pasture losses occurred through the expansion of cropland into grasslands in regions like Brazil's Cerrado. In this instance, government regulations dissuaded landowners from converting rain forests into pastures and induced them to convert grasslands into croplands (Lambin et al. 2013). Given recent efforts to prevent the conversion of additional tropical forests into pasture, an increase in the supply of forages for livestock will most likely come, not from increases in the extent of pastures, but from sustainable intensification on existing pastures.

'Sustainable intensification' occurs when increases in agricultural productivity occur along with enhanced ecosystem services on lands that are already under cultivation. One influential report (Montpellier Panel 2013) argues that these seemingly incommensurate ends can be achieved through a more precise agriculture. Targeted applications of inputs, along with advances in the production potential of crop germplasm, would increase agricultural production at the same time that it reduces the extent and environmental impact of agriculture. In practice, observers use a looser definition, labeling changes as sustainable intensification whenever productivity increases without impairing ecosystem services. We will use this looser definition in the examples of forage-focused sustainable intensification presented below.

SUSTAINABLE INTENSIFICATION WITH FORAGES: CASE STUDIES

Farmers in large areas like sub-Saharan Africa and the Llanos of Colombia remain reluctant to adopt newly developed forages despite a wide range of potential benefits documented by nine decades of research and experience. Insufficient links between experiment station and on-farm work as well as a lack of interaction between scientists and farmers has limited wider uptake of forages (Peters et al. 2003). To clarify both the challenges of advancing forage-focused sustainable intensification and the conditions that facilitate its spread, we present four examples of it. The cases presented here, from Kenya, the Caribbean, Nicaragua, and interior South America, illustrate the range of settings in which this program of activities could be pursued and the recurring challenges of trying to induce innovations across highly varied, sometimes degraded agro-ecosystems in places with debilitated state structures for reaching smallholders.

The push–pull system in Kenya

The Lake Victoria Basin region of Western Kenya faces severe development challenges given the poverty of its predominantly agricultural population. The agro-ecology differs from the humid highlands north and south of Kisumu to the semi-arid, mid-elevation lands along Lake Victoria. Maize (*Zea mays* L.) is the major staple and cash crop but grain yields on farms are less than 25 % of the experimental station yields of 4–5 t ha^{-1}. *Striga* spp. (witchweed), stemborers and declining soil fertility have been shown to be the three most important production constraints for maize. *Striga* infestation alone can cause 30–50 % of yield losses. Yield losses due to stemborer have been estimated at 13 %. High population pressure has led to declines in fallowing, leading to diminished soil fertility and land degradation (Vanlauwe et al. 2008). Dairy is another important enterprise in the Lake Basin, with 30–50 % of smallholders keeping cows. Feeding systems range from pure grazing in paddocks and tethering to zero grazing systems with cut-and-carry fodder. Feed constraints, especially during the dry season, are commonly reported by farmers (Lukuyu et al. 2011).

The push–pull system, developed during the late 1990s by International Centre of Insect Physiology and Ecology (ICIPE), Rothamsted Research, Kenyan Agricultural Research Institute (KARI) and their partners, tries to reduce the damages to maize production by pests, weeds and declining soil fertility. Maize, sorghum or millet is intercropped with *Desmodium uncinatum* (Silverleaf), while Napier grass (*Pennisetum purpureum)* is planted as a border crop. *Desmodium* root exudates cause abortive germination of *Striga*. Napier attracts and traps stemborer moths while *Desmodium*, being a repelling plant, pushes them out of the field. On-farm studies from Western Kenya confirmed that stemborer damage and *striga* were significantly lower when smallholders adopted the push–pull system. Maize yields increased from 1 to 2 t ha^{-1} (Khan et al. 2008a). Smallholders cite reduced pest infestation, soil fertility improvement, increased maize yields and improved fodder and milk productivity as reasons for adopting the practice (Khan et al. 2008b). Economic analysis revealed that the push-and-pull system is highly profitable due to revenue generated by *Desmodium* and Napier fodder, although it requires relatively high initial investment especially for *Desmodium* seed and labor. The system was therefore recommended for areas with sufficient livestock and demand for fodder (De Groote et al. 2010). Moreover, *Desmodium* improves soil fertility through symbiotic N_2 fixation (110 kg ha^{-1} yr^{-1}), increases soil moisture and soil organic matter, and decreases erosion due to the *Desmodium* soil cover (Khan et al. 2011). Push–pull effects on soil fertility were similar to other soil fertility management technologies such as maize–bean intercropping or maize–soybean rotations (Vanlauwe et al. 2008). More recently, the push–pull system has been amended by using *Brachiaria* cv. Mulato II instead of Napier and *Desmodium intortum* (Greenleaf). Mulato II and Greenleaf *Desmodium* proved to be more drought-tolerant while still providing effective control of stemborers and *striga* weeds, resulting in significant grain yield increases (Khan et al. 2014).

Similar to many new agricultural technologies, the push–pull system has yet to be adopted on a massive scale. Nevertheless, to date, the push–pull system has been adopted by more than 28 000 smallholders in Kenya and 4000 in Uganda and Tanzania. The area covered by push-and-pull in East Africa is estimated to be around 15 000 ha (Khan et al. 2011). The smallholders' inability to obtain sufficient quantities of Desmodium seeds from private sector vendors has slowed the spread of the push–pull agro-ecology (De Groote et al. 2010).

Forages for monogastrics in Central America and Central Africa

Smallholders in the developing world have long raised livestock around their homesteads. In Central America, for example, many smallholders will raise 3–5 pigs on their farms. The sale of the pigs brings in income, and their slaughter provides the family with animal protein. Smallholders feed their livestock with leftovers from agricultural production and cuttings from nearby edible plants. In more urbanized districts, smallholders have sometimes fed small amounts of feed concentrates to these animals (Fujisaka et al. 2005). A recent research effort in Nicaragua, Colombia, and Democratic Republic of the Congo (DRC) has investigated the possibility of enhancing the diets of these monogastrics through on-farm cultivation of forages for their consumption (CIAT 2012). Suitable forage legumes would improve the availability of high-quality feed for these animals, thereby enhancing their weight gain. In addition, the legumes would improve soil fertility, raise overall farm production, and decrease the dependency of livestock on cereals (maize) and expensive feed concentrates (CIAT 2012).

Center for International Tropical Agriculture (CIAT) personnel put these expectations to a test with smallholders in Nicaragua and the DRC. Farmers replaced up to 50 % of their cereal-based feeds with fresh forage and silage of *Vigna unguiculata*, *Cajanus cajan* and *Lablab purpureus*. Pigs consuming forage-based feeds showed similar live weight gain as pigs that consumed conventional rations, but the costs for forage-based feeds were substantially lower than the costs of the grain- or soybean-based feeds. When smallholders fed their pigs silage from these forages, the pigs showed 20 % higher live weight gain and a 25 % improvement in the feed conversion ratio compared to soybean-based feeds (Artiles et al. 2012). Smallholders preferred the use of silage from forages for these reasons, but also because (1) silage does not require biweekly planting to guarantee a continuous supply of fresh forage, and (2) silage can be stored for months for dry season use, and, (3) when packed in plastic bags or buckets, silage can be stored and sold to other smallholders at a later date (CIAT 2012).

The case for on-farm cultivation of forages for livestock appears strongest for larger pigs with fully-developed digestive systems that can digest the fodder. Nevertheless, agri-businesses have, to date, shown little interest in distributing the forages or forage seed, so markets for the sale of forages or the purchase of seeds face two major challenges. One, because smallholders often do not sell household-reared animals in markets, they cannot easily recoup their expenditures for seed through the cash sale of animals, so they try to limit their expenditures for seed in the first place. Two, despite the recognized advantages of diversified feed sources and improved animal fattening, the technical and management aspects of this regimen are not well known to either extension agents or small-scale farmers. For these reasons, agricultural outreach by public and nonprofit organizations seems essential to insure the wide dissemination of the forages. Women and youth could benefit disproportionately from the greater use of fodder because they are usually responsible for both feeding and tending to animals in smallholder pig production. In addition, this work, although focused on the forage/feed component, has also stimulated smallholders to improve other components of their pork production systems, such as housing, genetics, and hygiene. Finally, political and economic stability is necessary for the promotion of these changes. The intermittent presence of armed groups who looted smallholdings and the related absence of extension personnel in the eastern DRC made it impossible to promote the spread of more nutritious forages after 1990 (Maass et al. 2012).

Grazing systems for goats: Mixed versus mono-grazing in the Caribbean

More than 90 % of the world's 972 million goats live on farms in the developing world (FAO 2014a, b). Like other ruminants, goats are important in rural development because they convert forages and crops and household residues into meat, fiber, leather, and milk (Torres-Acosta et al. 2012), and they are less costly than cows in terms of initial investment and feed requirements. Traditionally, smallholders with small numbers of goats and other livestock have grazed them together. When the size of cattle ranches increased and other livestock operations became more specialized during the last half century, ranchers began to graze each species of livestock in its respective own field.

A series of experiments conducted on agricultural experiment stations now suggest that synergies arise when different species of livestock graze together in the same fields. For example, goats confined to their own fields have suffered from infestations of a gastro-intestinal parasite, strongyles. Although intensive use of chemical anthelmintics (drugs that expel parasitic worms) can combat strongyles, the growth of resistant strains of the parasite has reduced the efficacy of such measures (Jackson et al. 2011). In this context, alternative strategies for containing the parasite, like mixed grazing, seem especially attractive.

A meta-analysis of experiments, in which sheep and cattle graze together, shows superior live weight gain per hectare among both species: 28.6 % for sheep and 25.1 % for cattle. In addition, both species demonstrate additional resistance to intestinal parasites in mixed grazing compared to mono-grazing systems. The mix of species, with different sensitivities to specific species of strongyles, reduces the transmission of the parasites between animals. In effect, cows in a pasture with goats act like vacuum cleaners of the strongyles that infest goats. Another study of mixed grazing showed superior average daily weight gain among the goats and more complete consumption of forages (D'Alexis et al. 2013). This finding holds for fields subjected to continuous grazing as well as rotational grazing. The larger consumption of biomass in the mixed grazing situations reflects the complementary feeding strategies of goats and cattle. Mixed grazing also reduces the amount of fencing on farms and decreases the associated costs. In addition, because cows are so large, they deter attacks by predators on sheep and goats. In these respects, mixed grazing provides adopters with a range of benefits (Coffey 2001).

What remains open to question is the actual adoption of these practices by people who raise livestock. Given the magnitude of the gains on parasitism, the growing ineffectiveness of chemical wormers, and the relative simplicity of the change in pasturing livestock, the prospects for expansion in mixed grazing practices would seem to be good.

The adoption of a new forage for cattle, *Brachiaria*, in interior South America

Despite the relatively infertile acidic soils that prevail in the extensive grasslands of interior Brazil and Colombia, planners and settlers have long regarded these places as a 'last frontier' for improving global food security through agricultural expansion (World Bank 1998). Poor soil quality, particularly low pH associated with aluminum toxicity and phosphorus deficiency, low soil organic matter, and poor physical structure are the main factors limiting primary productivity in these regions. Improvements in tropical forages for cattle in these regions have come in waves. During the 1970s and 1980s, Brazilians deforested extensive areas and planted recently introduced varieties of *Brachiaria*. During the same period, landowners in the eastern plains (Llanos) of Colombia replaced the naturally-occurring grasses with *Brachiaria* and achieved dramatic gains of more than ten times in the weight of the livestock supported per hectare of pasture (Rao et al. 2015). These gains in productivity soon faded as the planted pastures degraded through nutrient losses and overgrazing. The grasses became nutrient deficient, and pests like spittlebug became more prevalent.

In response, agronomists and plant breeders introduced spittlebug-resistant strains of *Brachiaria* and attempted to resolve nitrogen deficiencies in the soils by sowing legumes in pastures. The productivity gains have been large in test plots of the new pasture grasses and legumes. Meat production per unit area doubled when pastures were managed in a rotation with maize and soybeans (Rao et al. 2015). These innovations also have beneficial environmental impacts. When farmers adopt acid soil tolerant crop rotations of corn, rice, and *Brachiaria* in the region, they use chisels to inject fertilizers and seeds into the soils. These no-till technologies minimize the disturbances to the soils and enhance the already considerable below ground carbon sequestration capacity of *Brachiaria* grasses (Fisher et al. 1994). Carbon stocks increase yet again when trees are incorporated into *Brachiaria*-based pastures.

While promising as a productive and sustainable regimen for maintaining pastures, relatively few farmers have adopted this second phase of cultivation practices over the past two decades. The absence of easy access to distant markets in the Colombian Andes, the continuing insecurity in the Colombian countryside, the additional inputs of labor, lime, and fertilizer required by the new practices, and the lack of subsidies or credit to overcome investment cost barriers, have slowed adoption (Rao et al. 2015). In sum, the initial spread of the new varieties of *Brachiaria* during the 1970s and 1980s represented an unparalleled success in the rapid dissemination of a new, more productive forage, but the second generation, spittlebug resistant *Brachiaria* has not been as widely adopted. The initial adoption of improved forages was widespread, with almost 100 million hectares planted with improved *Brachiaria* pastures. The volume of seed sales suggests that the Colombian llanos contained about 1.1 million hectares of spittlebug resistant *Brachiaria* pastures at the beginning of the century (Rivas and Holmann 2004).

Ranchers in Brazil have had a similar experience. More recently developed regimens have delivered additional gains in pasture productivity. For example, *B. brizantha* cv. Marandu, occupies around 50 Mha, but efforts to integrate crops and trees into pasture management have only occurred on 4 Mha (Almeida et al. 2013; Jank et al. 2014). Figure 1 portrays one such silvo-pasture in Ecuador.

PATHS TO SUSTAINABLE INTENSIFICATION WITH FORAGES: A COMPARATIVE ANALYSIS

Two related and recurring conditions across locales, the complexity of the shift in forages and the range of agricultural organizations assisting farmers, seem especially important in explaining why farmers adopt one innovation and ignore others. Simple innovations have spread quickly. In the 1980s, the spread of *Brachiaria* essentially involved the substitution of one pasture grass for another. In many instances, would be cattle ranchers just began planting *Brachiaria* rather than some other pasture grass as they cleared away the forests. Rancher to rancher discussions and assistance spurred the use of the new cultivar. In these instances, the productivity gains were sufficiently large and the required investments and changes in agricultural practices were minimal enough, so the innovation 'sold itself.'

In contrast, other recent innovations in *Brachiaria*-based systems are more complicated. They involve the introduction of legumes, access to seed sources for the legume, a new variety of *Brachiaria*, and the introduction of crop rotations involving cereals and soybeans on some lands. In these instances, adoption may only occur when agricultural organizations like producer associations, groups of merchants, extension agents, and agricultural scientists can join forces with farmers to help them convert to the new crop varieties and adopt the associated regimens. In other words, complex technologies seem to require the creation of a strategic action field (Fligstein and MacAdam 2012) of people and organizations committed to facilitating the spread of the new technologies. Adoption occurs with the push–pull and Brachiaria–legume combinations when supporting organizations are present that can facilitate specific tasks, like the acquisition of seeds or the interplanting of legumes and pasture grasses. Once farmers have mastered these associated practices, the new practices become part of an agricultural routine and become easier to

Fig. 1 Brown Swiss cattle in a silvo-pasture in the Ecuadorian Amazon. Photo Credit: Diana Burbano

implement. The organizations that assist farmers do not spring up randomly. They are more likely to come into being where there are critical masses of cultivators and organizational practices that reward civil servants for engagement with the rural poor. For this reason, strategic action fields for forage-focused sustainable intensification are most likely to emerge in large, politically stable countries like Brazil.

Table 1 summarizes these patterns. The numerical equivalents for low, medium, and high numbers of adopters are as follows: 'low' would imply hundreds or thousands of adopters; 'medium' would imply tens of thousands of adopters, and 'high' would mean hundreds of thousands or more adopters.

NEXT STEPS—MORE INTEGRATED AND TARGETED APPROACHES TO FORAGE-FOCUSED SUSTAINABLE INTENSIFICATION

The four cases underscore the importance of the fit between the complexity of the new technologies and the organizational capacity of the agricultural community. New forages and associated management practices have spread when there is an approximate fit between complexity of the new technologies and the organizational capacity for outreach to farmers. A new, more productive forage variety without new management practices does not require intensive, repeated outreach efforts, whereas complicated new integrated practices for sustainable intensification like the push–pull system require organizational fields dedicated to reaching and serving farmers who embrace such innovations.

Farmers are in the best position to decide how to fit the cultivation of forages into their crop–livestock systems. They can grow forages as a free standing crop to be cut and carried to livestock, as a pasture, or as boundary crop along the edge of fields. The versatility of forage crops underscores the importance of using participatory farming systems approaches because farmers are in the best position to assess how to integrate new forages into agro-ecological systems (Thomas and Sumberg 1995; Peters et al. 2003). For this reason, farmer-to-farmer conversations can be extremely important in the dissemination of new forages. These links between farmers have become even more important in the spread of innovations in recent years as extension services in the Global South have deteriorated (Settle and Hama Garba 2011).

Table 1 Adoption of improved tropical forages: Patterns across the cases

Case studies[†]	Number of changes in agricultural practices	Density of supporting organizations/networks	Number of adopters
Push–Pull system for cattle—Kenya—2000s	Multiple	High	Medium
Mixed grazing for goats	One	Variable	Low (to date)
Forage for pigs: Nicaragua	One	High	Low (to date)
Forage for monogastrics: DRC	One	Low	Low
Improved forage for cattle: Amazon and Llanos—1980s	One	Low	High
Improved forage for cattle: Llanos, Colombia—2000s	Multiple	Low	Low
Improved forage for cattle: Amazon, Brazil—2000s	Multiple	High	High

[†] *Sources* References for each case study

CONCLUSION

The sustainable intensification of livestock operations in the tropics through improved use of forages seems plausible based on the admittedly small number of cases reviewed above. A larger role for forages in the feeding of livestock would restore some agro-biodiversity to the global food system, and in so doing, increase its resiliency. In addition to enhancing the food security of poor consumers by reducing global demand and prices for grains, forage-focused sustainable intensification would improve the productive capacity of poor producers who raise crops and livestock on small landholdings in rural South Asia, sub-Saharan Africa, and Central America.

To date, most research on the livestock sector has focused on the biological productivity of animals and grasses (Sumberg 2002). The adoption of new forages has been fitful, sometimes occurring rapidly as with *Brachiaria* during the 1980s, but often occurring only in specific locations and too slowly to produce noticeable changes in aggregated economic or environmental indicators. A more integrated approach in designing interventions would explicitly consider the existing agro-ecology, current agricultural practices, and the capabilities of participants in the innovation process. This kind of systematic integration would lead to both better coordinated and targeted interventions. The multiple considerations inherent in an integrated approach usually require identifying key leverage points for achieving widespread change and justify, in some instances, precise interventions. A focus, for example, on forages for guinea pigs in the eastern DRC seems most likely to maximize the gains for the poorest smallholders.

Because smallholders often depend on livelihoods that barely meet their needs, outside interventions like LivestockPlus could have potentially disruptive effects if they do not fit well into the array of other smallholder activities. In these instances, specific information about planting and management requirements of forages could help farmers select the most advantageous way to use the new forages. These typologies would assign farms to categories within which similar forage interventions might prove effective. A mapping of these agro-ecological categories would inform outreach and smallholder efforts about when, where, and how to use new forages (Notenbaert et al. 2009).

Efforts by forage experts to coordinate with other development and conservation agencies and NGOs can help motivate appropriate use of forages throughout rural landscapes (Rao et al. 2015). The array of potential interventions associated with the more complex of these management innovations with forages also presumes some central coordination by larger organizations with national or international mandates to achieve sustainable intensification. The mandates would provide the impetus behind the assembly of a strategic action field organized around forages. In this context, forage-focused sustainable intensification would represent part of a larger trajectory of desirable agricultural changes that would enhance human food security and make for a more resilient agro-ecological system.

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