Tropical Grasslands – Forrajes Tropicales (2013) Volume 1, 12−24

Global impacts from improved tropical forages: A meta-analysis revealing overlooked benefits and costs, evolving values and new priorities

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Keywords: Economics, social impacts, environmental impacts, landscapes.

Abstract

The wider use and improved performance of planted tropical forages can substantially change social, economic and environmental landscapes. By reviewing impact-related studies published in the past two decades, this paper shows how evolving development priorities have influenced the types of impacts being documented. A meta-analysis was used to examine 98 studies according to: (i) breadth of reported effects, as related to development goals of social equity, economic growth and environmental sustainability; (ii) extent of effects, ranging from intermediate to longer-term impacts; and (iii) measurement precision (identification, description or quantification) of impacts.

Impacts have been assessed for fewer than half of the documented 118 Mha with improved forages. Although Brazil accounts for 86% of the known planted area, widespread irregular reporting of technology adoption affects accuracy of global estimates. Over 80% of the impact-related studies reported economic effects, while fewer than 20% were quantitative estimates of longer-term economic impacts. Inconsistent valuation methods and assumptions prevented valid summation of total economic impacts. Social effects were reported in fewer than 60% of studies and emphasized household-level outcomes on gender and labor, with most reported effects being non-quantitative. Environmental effects were reported slightly more often than social effects, with recent increases in quantitative estimates of carbon accumulation. Few studies analyzed tradeoffs. Independent reviewers conducted approximately 15% of the studies. Newer development priorities of environmental sustainability, system intensification, organizational participation and innovation capacities require broader approaches to assess impacts. Increased marketing and coordination with development and environmental organizations can generate greater demands for improved forages.

Resumen

El uso más amplio y el desempeño mejorado de forrajes tropicales sembrados pueden cambiar sustancialmente los paisajes social, económico y ambiental. Mediante la revisión de estudios relacionados con el impacto de forrajes tropicales publicados en las últimas dos décadas, este artículo muestra cómo las prioridades de desarrollo cambiantes han influido en los tipos de impactos que se están documentando. Se utilizó un meta-análisis para examinar 98 estudios de acuerdo con: (i) la envergadura de los efectos reportados en relación con los objetivos de desarrollo de equidad social, crecimiento económico y sostenibilidad ambiental; (ii) el alcance de los efectos, que van desde impactos a mediano plazo a más largo plazo; y (iii) la precisión de medición (identificación, descripción o cuantificación) de los impactos.

Se han evaluado impactos para menos de la mitad de los 118 millones de hectáreas con forrajes mejorados que se encuentran documentados. Aunque Brasil representa el 86% de la superficie sembrada que se conoce, los informes de adopción de tecnología son, en general, irregulares, lo cual afecta a la precisión de las estimaciones globales. Más del 80% de los estudios relacionados con el impacto de forrajes tropicales reportaron efectos económicos, mientras que

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menos del 20% son estimaciones cuantitativas del impacto económico a largo plazo. Métodos y supuestos de valoración inconsistentes impidieron sumar, en forma válida, el impacto económico total. Se reportaron efectos sociales en menos del 60% de los estudios, y se enfatizaron los resultados a nivel de los hogares en cuanto a género y trabajo. La mayoría de los efectos reportados fueron no cuantitativos. Los efectos ambientales fueron reportados un poco más frecuentemente que los efectos sociales, con aumentos recientes en las estimaciones cuantitativas de la acumulación de carbono. Pocos estudios analizaron las ventajas y desventajas. Aproximadamente el 15% de los estudios fueron realizados por revisores independientes. Las prioridades de desarrollo más recientes − sostenibilidad ambiental, intensificación de sistemas, participación organizacional y capacidad de innovación − requieren de enfoques de mayor alcance para evaluar los impactos. Una mayor comercialización y coordinación con organizaciones de desarrollo y ambientales pueden generar una mayor demanda de forrajes mejorados.

Introduction

Increasing consumer demands for animal products are radically changing crop and livestock systems throughout the world (Delgado et al. 1999; FAO 2009). Despite reduced meat consumption per capita in some countries of Europe and the Americas (Kanerva 2011; Larsen 2012), the higher incomes of growing populations, especially in China and India, are stimulating greater global demand for and trade of livestock products (Delgado et al. 1999; Fu et al. 2012). In order to produce sufficient feed for more animals, an intensification process that improves the productivity of crop and livestock systems needs to continue – but at a more urgent pace (McDermott et al. 2010).

Two general strategies can intensify crop and livestock systems, namely the use of: (i) feed grain concentrates; and (ii) grass and legume forages (Herrero et al. 2010; Bouwman et al. 2011), while improving animal breeds and health status can improve feed efficiency. A dramatic and steady increase in the use of feed grains has already occurred (Delgado 2005; Thornton 2010). Now, one-third of all arable land is dedicated to crop production for use as animal feed (Goodland and Anhang 2009), although there is increasing demand for feed grains for use as food and biofuel (Dixon et al. 2010; Taheripour et al. 2010). Monocrop practices can cause environmental damage (Clay 2004), such as water and air pollution from high levels of chemical fertilizer and pesticide use (Steinfeld et al. 2006). Furthermore, the geographic isolation of grain-producing areas from livestock areas requires significant energy inputs for transportation and nutrient supplies (Pimentel and Pimentel 2007). Consequently, total net greenhouse gas (GHG) emissions associated with grain feedlot systems are estimated to be 15% higher than emissions from intensive forage grazing systems (Pelletier et al. 2010). In total, the production of livestock accounts for at least 51% of global anthropogenic GHG emissions (Goodland and Anhang 2009).

Often grown on non-arable lands, grass and legume forages can generate both positive and negative changes to economic, social and environmental landscapes. In striving to estimate global impacts of improved forages, a meta-analysis approach was used to review impact-related studies from the past 2 decades, associated with forage research, development, training and extension (RDTE) activities throughout the tropics, including Africa, Asia, Australia and the Americas. In addition to geography, the term global is interpreted as being comprehensive. Therefore, serving as a general framework for systematic analysis is a "triple bottom-line" concept (Elkington 1997) of social, economic and environmental changes caused by technological innovations, which has been employed by Embrapa (Avila 2001; Avila et al. 2008). In 2 ways, this paper is an extension of a review on adoption of tropical legumes conducted by Shelton et al. (2005), with: (i) the inclusion of sown grass pastures; and (ii) estimates of global impacts after adoption.

Methods

RDTE innovations of improved forages within a livestock supply chain

In order to substantiate causal relations between improved forages and a potentially wide range of different impacts, a generalized forage-livestock supply chain was developed. The supply chain with 4 links: input, production, transformation and marketing (Figure 1), can represent: (i) small-scale farmers who manage a diversity of crop and animal husbandry activities for home consumption and local markets; and (ii) large-scale operations specializing in meat and/or dairy production for national and international commodity markets. Forage innovations can change both products and processes of the supply chain. Products are improved forage *germplasm*, whereas processes are affected by *innovations* of farmers working with scientists and development workers. Improved forages are rarely a stand-alone off-the-shelf technology. In most cases, the technology input requires training and extension efforts to match forages with production systems, and develop or co-develop best practices of cultivation, harvest and optimal use as a feed for a particular type of animal (Horne et al. 2000; Peters et al. 2003). Stakeholders and beneficiaries of improved-forage RDTE include a diversity of participants along the supply chain, including suppliers of seeds or planting material, farmers and producer organizations, and marketers, traders and general consumers, who are affected positively by services or by negative externalities.

An array of effects on social, economic and environmental landscapes

A common distinction, *outcomes* versus *impacts*, although not clear-cut, is often used to clarify the types of effects and the times at which they occur. Adapted definitions from OECD-DAC (2002) and CGIAR (Walker et al. 2008) illustrate the conceptual difference: *Outcomes* (or *intermediate* or *Stage I impacts*) are the short- and medium-term effects resulting from an innovation. They represent changes in behavior, goods and services, either on- or off-farm, which occur between the completion of a project or program and the achievement of impacts. Technology-focused studies typically assess outcomes at a geographically specific scale after adoption has occurred and there is evidence of effects, such as costs and benefits. *Impacts* (or *Stage II impacts*) are a longer-term concept. They are the positive and negative, macro-level effects on identifiable areas or population groups caused by an innovation, directly or indirectly, intended or unintended. These effects can be socio-cultural, institutional, economic, environmental, etc. Impact studies are conducted to assess 'bigger picture' impacts generated by large-scale adoption, which lead to notable changes in social, economic and environmental landscapes.

The *breadth of effects* describes the different outcomes and impacts of RDTE innovations on different landscapes. With respect to a *social landscape*, improved forages affect individuals, households, communities and nations. Intermediate outcomes include increases or decreases in labor use of family members. Other possible social effects include enhanced farmer participation in producer or community organizations. Fostered farmer participation in, and capacity building of, organizations along a supply chain can lead to significant institutional change, with greater influence in policy decisions that can ultimately result in improved well-being and equity. An *economic landscape* also changes in many ways as a result of forage RDTE innovations. At the farm level, savings in input use or factor efficiencies generate different outcomes, such as reduced requirements for labor, rainfall/water or fertilizer. Also, cultivation of improved forages can lead to greater productivity, typically measured in yield of biomass, energy or protein per unit area. Nevertheless, forages are an intermediate product and are typically used for other purposes such as animal feed. Improved forages can enhance efficiencies of product transformation that result in higher farm gross and net revenues (profits). At an international scale, economic impacts of improved forages can include changes to the performance of a livestock subsector with respect to its enhanced competitiveness and comparative advantage. Such analyses often include examination of government policy interventions (e.g. subsidies, taxes and tariffs on inputs, outputs, imports and exports) on sector performance.

Effects of improved forages on the *environmental landscape* are often both positive and negative, and can lead to tradeoffs with social and economic objectives. On-farm performance outcomes result from better abilities to withstand pests, diseases, flooding and drought. Improved forages can also cover soils faster and more completely, thereby reducing erosion and weed infestations. Deep root structures can access water during dry seasons and store carbon in soils. Leguminous forages, in particular, fix nitrogen in soils, thereby improving soil health and fertility. Such improvements in on-farm performance can generate potentially significant benefits by preventing losses of biomass production and improving overall farm resilience to weather shocks. At farm and landscape levels, negative impacts of improved forages include invasiveness of some species and loss of local biodiversity (Chudleigh and Bramwell 1996; Steinfeld et al. 2006; Stevens and Falk 2009). Other impacts can arise from a cumulative effect of better farm productivity at larger scales, including changes to downstream water flows, water quality and sedimentation. Whether off-farm environmental effects are beneficial or detrimental depends on specific site contexts and management practices, thereby posing challenges to accurate measurement of impacts.

A meta-analysis approach was used to examine diverse effects from improved forage germplasm and associated knowledge-sharing innovations. Although the task of identifying studies for inclusion could be considered simple, identification requires a clear operational definition of the phenomenon being examined (Rudel 2008). The process of reviewing the studies enabled the comprehensive specification of effects on landscapes (Figure 1), which, in turn, served as the analytical framework for case selection. Via web-based literature searches, reviews of references within papers, and communications

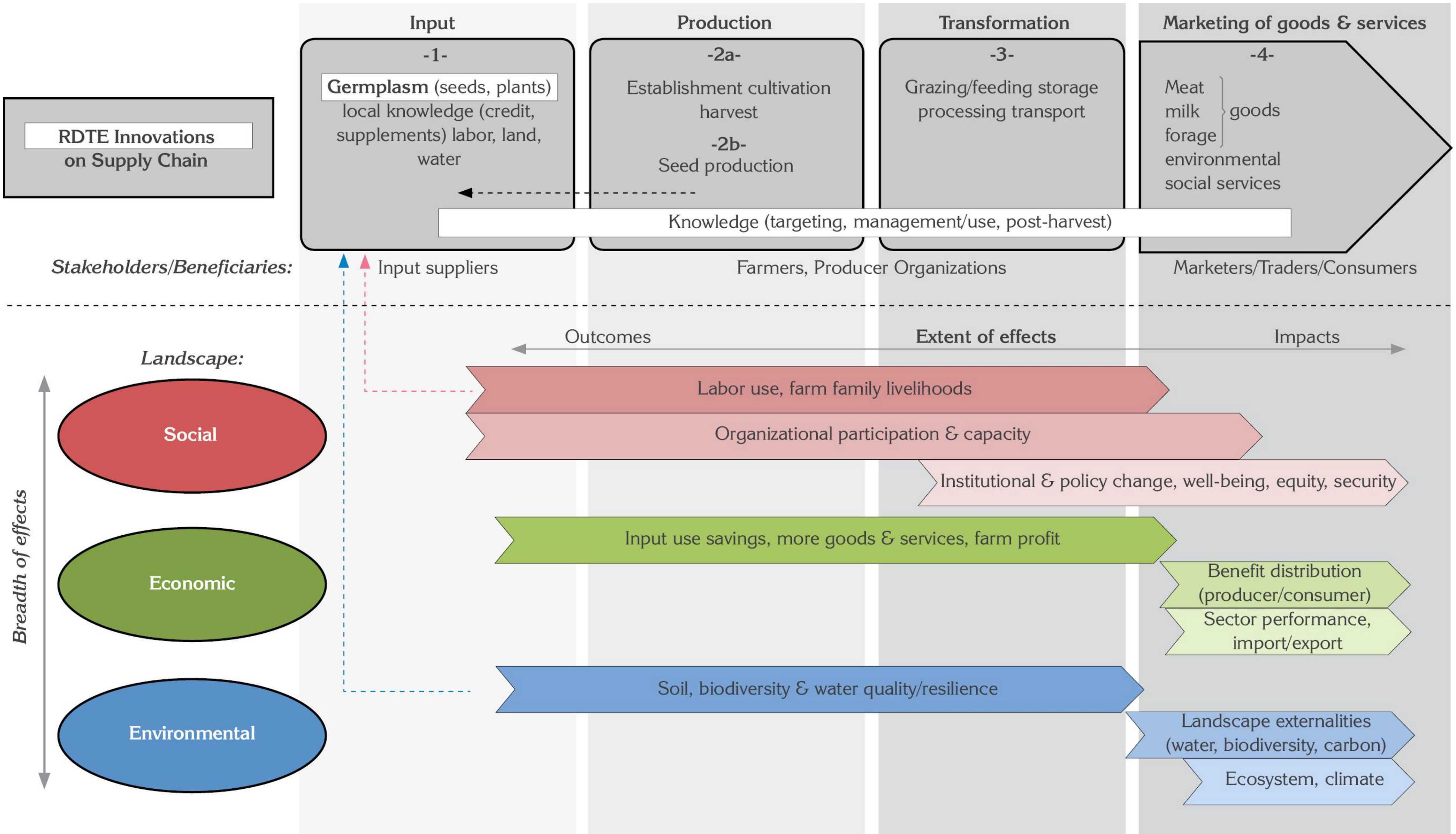

Figure 1. An array of effects on landscapes associated with RDTE innovations along a generic supply chain of improved forages.

with forage experts, a pool of over 170 studies was collected, and 98 were selected for use within the sample. Many disqualified studies were characterizations of existing forage-livestock systems or were studies of farm trials or adoption − without any description or quantification of impact. Although the search was conducted in 4 languages, most studies were written in English, with 4 in Spanish, 1 in Portuguese and none in French.

Table 1. Reported effects (% of total) per type and extent of effect and measurement precision.

Type of effect	Outcomes			Impacts		
	mentioned	*described*	*quantified*	*mentioned*	*described*	*quantified*
Social	2	11	11	1	1	2
Economic	1	3	18	0	0	21
Environmental	7	5	8	1	4	7

Many impacts remain undocumented within the literature due to financial, technical and other restrictions, which often prevent a comprehensive assessment of forage innovations. In order to minimize publication bias (Rothstein et al. 2005) that would reduce estimates of global impacts, the dataset was expanded to include "non-impact" studies, such as project reports and other documents, which also describe impacts. For countries where only information on technology adoption or productivity increases was available, authors were contacted in an effort to obtain grey literature of impacts. Although the sample represents a diversity of countries from tropical Africa, Asia, Australia and Latin America, a paucity of the smaller, less-populous countries became evident.

Keywords pertaining to the types of effects, along with synonyms, were used to identify their presence or absence. Reported effects within a study sometimes represented more than one location or type of forage. Therefore, reported effects were larger than the number of studies. Review of the units of analysis and associated text permitted the determination of: (i) outcomes versus impacts; and (ii) the measurement precision used within the analysis. There were 3 categories of measurement precision: (i) simple mention or identification; (ii) narrative or qualitative description; and (iii) quantitative analysis. All economic estimates were adjusted according to inflation and are reported in 2005 US$.

Results and Discussion

Approximately 118 Mha planted with improved forages have been documented, with Brazil accounting for 86% of the known planted area (IBGE 2007; Landers 2007; CIAT 2013). Nevertheless in all countries, the irregular reporting of technology adoption and incomplete analysis of associated impacts (<50% of adopted area) distort the accuracy of global adoption and impact estimates.

Nearly 80% of the impact-related studies were published between 1999 and 2013. Within the sample, more than 200 different types of effects were reported. Nevertheless, approximately 2/3 of the effects were intermediate, not longer-term, larger-scale impacts. Although economic effects were most frequently reported, fewer than 20% of all reported effects were quantified economic impacts. Environmental and social impacts were even less frequently quantified, with 7 and 2%, respectively, of the total types of effects reported (Table 1). More than 34% of reported effects were mentions or brief descriptions of change. Although such results were not quantitative, the information provided aids in better understanding the global impacts of improved forages.

Earlier studies tended to report outcomes rather than impacts. The progression of extending analysis to longer-term impacts could be a consequence of increasing scientific capacity, availability of new assessment methods and policy priorities to understand larger-scale effects. In the face of multiple confounding factors, which hinder the substantiation of cause-and-effect arguments, studies are increasingly using mixed quantitative and qualitative methods, such as detailed narratives or diagrams of causal impact pathways, which typically acknowledge a broader array of effects (e.g. Cramb 2000; Pathak et al. 2004; Connell et al. 2010; Ayele et al. 2012). Nevertheless, fewer than 15% of studies were conducted independently of personnel affiliated with the program or project. Limited collaboration with evaluation experts and organizations may have prevented the use of new assessment methods and approaches.

Analyses of economic impacts employed inconsistent estimation methods and assumptions, thereby preventing a valid summation of total economic benefit of the studies. Review of economic impacts reported within the sample revealed 9 critical methodological shortcomings, many of which have been highlighted in other meta-analyses of economic benefits (Raitzer 2003; Raitzer and Lindner 2005; McClintock and Griffith 2010):

1. Estimates were based on the results employing different estimation methods, which include economic surplus models, cost-benefit accounting or unsubstantiated expert opinion.

2. Estimates of economic impacts represented different periods of time. Benefits were reported as annual estimates or the net present value (NPV) that represented different multi-year periods. Moreover, different rates (5 and 10%) were used to discount the future value of benefits, thereby substantially affecting the magnitude of NPV estimates.

3. Economic impacts were reported in terms of gross economic benefit or net of costs.

4. Costs were inconsistently defined across the studies. Reported costs included research and development (R&D), training and education (T&E) and adoption. R&D and T&E costs largely pertain to public sector organizations that finance such activities (though private companies produce and market seeds). Estimation of these costs often requires the use of numerous assumptions regarding staff time and other investments attributable to an improved forage. Meanwhile, farmers face a variety of costs related to adoption of technology. Such private costs include those pertaining to: (i) working capital associated with planting improved forages and purchasing more animals; (ii) capital investments such as infrastructure (e.g. corrals, barns, fencing); and (iii) opportunity costs of land and labor. Opportunity costs of land could be significant, if land previously produced crops or generated positive environmental externalities (e.g. biodiversity, carbon storage, water flow regulation). Labor costs of innovation, such as those related to advancing, acquiring, adapting and/or sharing knowledge were not included. While some studies discussed and analyzed a portion of these costs, no study addressed all potential costs.

5. Descriptions and types of data on technology adoption were inconsistent. Studies exhibited wide variation with respect to geographic scope, intensity of use per farm and duration of use. More than 50% of studies reporting economic impacts did not use empirical data on which to base estimates of adoption of technology, but instead depended solely on expert opinions (Table 2).

6. Transparency in the documentation of analytical methods was not consistent across the studies.

7. In the face of inherent uncertainty of costs, adoption and discount rates, sensitivity analyses of changes in parameter estimates were rarely performed.

8. Despite many economic estimates representing largely ex-ante, or a combination of ex-post and ex-ante, time horizons, scenario analyses were not included to examine the effects of assumptions employed to represent future conditions (e.g. yield improvement, input and output prices, climate change). In addition, economic analyses of substitute inputs, such as feed grain concentrates, were not conducted.

9. Economic analyses emphasized production performance with little acknowledgement or discussion of the economic values derived from decreased risk of crop, food and income failures. Furthermore, benefits associated with enhanced environmental conditions/resilience and improved social well-being/security remain largely unrecognized.

Despite the biases and limitations inherent to the sample, large-scale economic impacts from grasses were evident in Latin America (Table 2). In contrast, impacts from grasses and legumes were more evenly reported from Africa, South-east Asia and Australia. Consequently, the traditional biological distinction between grasses and legumes was replaced with a producer/market contrast of smallholder local market versus largeholder national/international market. The economic benefits from new spittlebug-resistant *Brachiaria* varieties in Latin America were the largest reported (Rivas and Holmann 2004; Costa et al. 2009). Benefits resulting from *Stylosanthes* varieties resistant to anthracnose disease were less substantial, perhaps due to less rigorous adoption and economic impact analysis. Other large-scale economic impacts from grasses were realized in Australia (Chudleigh and Bramwell 1996). Economic benefits from some forage species were estimated in different years. Economic benefits of *Stylosanthes* and *Leucaena* reported in Australia point to expanding use and economic impact (Rains 2005; Shelton and Dalzell 2007). For *Stylosanthes* in Brazil, the estimated value of nitrogen in soils exceeded the value as a feed (Costa et al. 2009). Despite substantial investment and reported adoption in South-east Asia (Phaikaew et al. 2004; Guodao and Chakraborty 2005; Stür et al. 2007) and South Asia (Ramesh et al. 2005), only one empirical analysis of economic impact has been conducted in Indonesia (Martin 2010).

Table 2. Summary information: economic impacts of improved forages.

Country/ region	NPV[1] (MUS$ 2005)	Annual (MUS$ 2005)	Forage(s)	Area ($x10^3$ ha)	Reference	Type of adoption data
Smallholder / local market						
W. Africa	19 (96)[2]		*Stylosanthes guianensis, S. hamata*	19 (52)	Elbasha et al. 1999	Statistics & survey
W. Africa	46[2]		*Stylosanthes* spp., *Centrosema pascuorum, Aeschynomene histrix*	32	Tarawali et al. 2005	Stats & survey
W. Africa	491[2]		*Vigna unguiculata*	1400	Kristjanson et al. 2002	Stats, survey & modeling
Indonesia	1010		*Pennisetum, Gliricidia, Leucaena, Sesbania*	n.r.	Martin 2010	1/3 value of future cattle sales
Kenya		7.9	*Calliandra calothyrsus*	~82	Place et al. 2009	Survey
Uganda, N. Tanzania, Rwanda		2.2	*Calliandra calothyrsus*	~103	Place et al. 2009	Survey
India		?	*Stylosanthes* spp.	>250	Ramesh et al. 2005	Experts
Thailand		0.75	*Stylosanthes*	>300	Phaikaew et al. 2004	Experts
China		22	*Stylosanthes*	>200	Guodao and Chakraborty 2005	Experts
Largeholder/ national, international markets						
Australia	1387	37[3]	*Cenchrus ciliaris*	6915	Chudleigh and Bramwell 1996	Stats, experts & extrapolation
Australia	244	7[3]	*Stylosanthes* spp.	1154	Chudleigh and Bramwell 1996	Stats, exp. & extrap.
Australia	659	17[3]	All improved pastures	7772	Chudleigh and Bramwell 1996	Stats, exp. & extrap.
C. America, Mexico	1790	243[4]	*Brachiaria* spp.	3287	Holmann et al. 2004	Seed sales
Colombia, C. America, Mexico	4413	497	*Brachiaria* spp.	4429	Rivas and Holmann 2004	Seed sales
Mexico		41[4]	Improved forages & technology	n.r.	Espinosa García and Wiggins 2003	Experts
Australia		~0.9	*Clitoria ternatea*	100	Conway 2005	Experts
Australia		2	*Centrosema pascuorum*	5	Cameron 2005	Experts
Australia		22.4	*Stylosanthes scabra, S. hamata*	1500	Rains 2005	Experts
Australia		15	*Stylosanthes scabra, S. hamata*	1000	Noble et al. 2000	Stats, expert
Australia		15	*Leucaena leucocephala*	100	Mullen et al. 2005	Expert
Australia		69	*Leucaena leucocephala*	150	Shelton and Dalzell 2007	% cattle offtake
Brazil	6269	1826[5]	*Brachiaria brizantha* cv. Marandu	23621	Costa et al. 2009	Seed sales
Brazil		13.5[5]	Seed production	n.r.	Costa et al. 2009	Seed sales
Brazil	5749	772[5]	*Panicum maximum* cv. Tanzania	4746	Costa et al. 2009	Seed sales
Brazil	4499	1640[5]	*Panicum maximum* cv. Mombasa	10074	Costa et al. 2009	Seed sales
Brazil	7	1.7	*Stylosanthes capitata + S. macrocephala* (cv. Estilosantes Campo Grande)	200	Costa et al. 2009	Seed sales
Brazil		33	*Pueraria phaseoloides*	480	Valentim and Andrade 2005a	Expert
Brazil		4	*Arachis pintoi*	65	Valentim and Andrade 2005b	Expert
USA		7	*Arachis glabrata*	8	Williams et al. 2005	Expert
USA		2.4[6]	*Aeschynomene americana*	65	Sollenberger and Kalmbacher 2005	Expert
USA		0.5[6]	*Desmodium heterocarpon*	14	Sollenberger and Kalmbacher 2005	Expert

[1]NPV = Net present value; [2]Net costs of RDTE and adoption (establishment and additional cattle); [3]Break-even cost to prevent negative impact from forage plants, being annual cost to reduce NPV of benefits to zero; [4]50% adoption rate assumption; [5]Estimate of final year of seed sale data (2006); [6]Estimates from Shelton et al. (2005).

Inquiry into environmental benefits of improved forages increased in sophistication from their on-farm productivity changes to include quantitative inquiry into nutrient cycling (Rao et al. 1996), direct seeding of crop-pasture rotations (Embrapa 2004), trade-offs between the use of forage legumes as fodder or green manure (Quintero et al. 2009a), conservation agriculture (Landers 2007; Kassam et al. 2010; Silici 2010) and the co-benefits associated with integrated management of striga weeds, insect pests and soil health (Khan et al. 2011). Analyses also expanded to examine off-farm impacts associated with environmental benefits of reduced erosion and downstream sedimentation and pollution (Quintero et al. 2006, 2009b; White et al. 2007) and carbon and biodiversity benefits from silvopastoral systems (Pagiola et al. 2007). Each of these analyses examined the effects of comprehensive farm management, which typically contains a component of improved forages. In addition, reporting of carbon storage and associated climate change mitigation continues to expand from analyses of deep-rooting *Brachiaria* grasses in Colombia (Fisher et al. 1994) to Brazil (Pinto et al. 1996; Tarre et al. 2001; Silva et al. 2004; Fisher et al. 2007; Marchão et al. 2009; Tonucci et al. 2011), *Leucaena* in Australia (Shelton and Dalzell 2007) and grasslands in Latin America (Mannetje et al. 2008) and worldwide (FAO 2010; Peters et al. 2012).

Attributing some off-farm environmental impacts to improved forages can be tenuous. For example, the adoption of improved forages cannot be considered a sufficient condition to avoiding deforestation. Other factors affecting the conservation of forests, such as local and national policies and their enforcement, are also needed for forest protection. Nevertheless, the contribution of improved forages to intensification and land/forest saving can be considered a necessary condition. Serving as a logical narrative to substantiate a causal technology-forest link is that intensification enables similar quantities of livestock products to be produced on smaller land areas (White et al. 2001; Kaimowitz and Angelsen 2008; Ewers et al. 2009; Connell et al. 2010; Cohn et al. 2011). Despite the challenges of attributing "saved" areas to improved forages, the magnitude, importance and value of ecosystem services from these original land uses can be substantial. Even without including emissions from land use change, estimates of a plausible mitigation potential of livestock and pasture management options in mixed and rangeland-based production systems of the tropics could contribute approximately 4% of global agricultural GHG mitigation, with a corresponding economic value of approximately US$1.3 billion per year at a price of $20 per ton CO_2-equivalent (Thornton and Herrero 2010).

The most commonly reported social impacts were at the family level, with savings in family labor, especially that of women and children (e.g. Connell et al. 2010; Ahmed 2012; Maxwell et al. 2012), and family nutrition and food security (Kassa et al. 2000). At the organizational level, social benefits included increased farmer and stakeholder participation and capacities along links of the supply chain (Khanh et al. 2011; Shiferaw et al. 2011; Ayele et al. 2012; Stür et al. 2013). Measurement of larger social impacts remains difficult, since many factors are likely to affect the functioning and status of political processes, national security, equity and well-being. Although estimates of economic benefits were disaggregated according to wealth/poverty by Rivas and Holmann (2004) and showed substantial purchasing power benefits accruing to the less-wealthy consumers of animal products, notions of development and associated social benefit are often considered to contain aspects of increased local capacity to achieve impact – not merely the results of technological change. In order to address measurement and valuation challenges that come with broader definitions of social benefit, quantitative analytical methods are being combined with or complemented by qualitative methods. Such analyses are part of a new breed of impact analyses that increasingly recognize processes of social change along the entire forage-livestock supply chain, from inputs and cultivation to feeding and marketing (Connell et al. 2010; Shiferaw et al. 2011; Ayele et al. 2012; Stür et al. 2013).

Conclusion

Improved grass and legume forages have generated substantial impacts across uncountable social, economic and environmental landscapes. Past claims that the adoption of improved forages, especially legumes, is relatively poor across all tropical farming systems (Squires et al. 1992; Thomas and Sumberg 1995; Pengelly et al. 2003) may, however, continue to echo in some regions. Despite a broadening of inquiry to include outcomes identifying and describing a larger diversity of impacts, the limited sample of studies was probably biased with a tendency to report only larger, relatively homogeneous impacts, which are easier to measure. Consequently, impacts highlighted above are conservative and represent a fraction of the global impacts.

Impact evaluation continues to evolve in an attempt to improve aid and development processes (Stern et al. 2012). Results from the systematic meta-analysis of impact-related documents reveal how efforts changed to better understand cause-and-effect relationships between RDTE activities and impacts. Such an evolution corresponds to 3 general prescriptive approaches associated with the theory of evaluation that focus on: (i) analytical methods and experimental design; (ii) human and social values used in conducting evaluations; and (iii) users of the results of the evaluation (Alkin 2012). With regards to methods, the sample of impact-related documents shows increasing efforts to expand forage RDTE to address the performance of entire livestock supply chains. Furthermore, more analyses are recognizing and attempting to evaluate environmental and social benefits. This combination of expanded inquiry, in terms of extent and breadth of impact, is improving our knowledge of how forages affect change processes. Regarding human and social values, assessments of forage RDTE increasingly include stakeholder narratives. Such documentation efforts not only provide valuable contextual perspectives, but they also help to improve quantitative impact analyses by substantiating causal arguments of change. As for the use of results, many evaluations of impact are expanding the influence of forages by affecting policy decisions on research, development and conservation investment − ranging from site-specific to global contexts. Although the direct representation of many impact studies may be limited, generalizable accounts of lessons learned can help inform such decisions. Furthermore, additional inquiry into informational needs of diverse investors, from farmers to international organizations, can improve communication and targeting of improved forages, and thereby help achieve widespread beneficial impacts on social, economic and environmental landscapes.

Acknowledgments

The authors appreciate the insightful comments received from Bob Clements, responses from the case study authors and the financial support from ACIAR.

References

Ahmed I. 2012. Socio-Economic Impact of Forage Development on Farm Households Livelihood in Mieso District, West Hararghe Zone, Oromia National Regional State. M.Sc. Thesis. Haramaya University, Addis Ababa, Ethiopia.

Alkin MC, ed. 2012. Evaluation roots: A Wider Perspective of Theorists' Views and Influences. 2nd Edn. Sage Publications, Thousand Oaks, CA, USA.

Avila AFD. 2001. Avaliação dos Impactos Econômicos, Sociais e Ambientais da Pesquisa da Embrapa: Metodologia de Referência. Embrapa (Empresa Brasileira de Pesquisa Agropecuária), Secretaria de Administração Estratégica, Brasília, DF, Brazil.

Avila AFD; Rodrigues GS; Vedovoto GL, eds. 2008. Avaliação dos impactos de tecnologias geradas pela Embrapa: Metodologia de Referência. Embrapa (Empresa Brasileira de Pesquisa Agropecuária), Informação Tecnológica, Brasília, DF, Brazil. http://bs.sede.embrapa.br/2012/metodologiareferenciaavalimpactoembrapa.pdf

Ayele S; Duncan AJ; Larbi A; Khanh TT. 2012. Enhancing innovation in livestock value chains through networks: Lessons from fodder innovation case studies in developing countries. Science and Public Policy 39:333−346.

Bouwman L; Goldewijk KW; van der Hoek KW; Beusen AHW; van Vuuren DP; Willems J; Rufinoe MC; Stehfest E. 2011. Exploring global changes in nitrogen and phosphorus cycles in agriculture induced by livestock production over the 1900−2050 period. Proceedings of the National Academy of Sciences May 16, 2011. www.pnas.org/cgi/doi/10.1073/pnas.1012878108

Cameron AG. 2005. *Centrosema pascuorum* in Australia's Northern Territory: a tropical forage legume success story. Tropical Grasslands 39:219.

Chudleigh P; Bramwell T. 1996. Assessing the impact of introduced tropical pasture plants in northern Australia. Prepared for a CSIRO Task Force Interested in Introduced Pasture Plants. Agtrans Research, Toowong, Qld, Australia.

CIAT (Centro Internacional de Agricultura Tropical). 2013. Seed sales and royalties: Papalotla and Dow. Tropical Forages Program. CIAT, Cali, Colombia.

Clay J. 2004. World Agriculture and the Environment: A Commodity-by-Commodity Guide to Impacts and Practices. Island Press, Washington, DC, USA.

Cohn A; Bowman M; Zilberman D; O'Neill K. 2011. The Viability of Cattle Ranching Intensification in Brazil as a Strategy to Spare Land and Mitigate Greenhouse Gas Emissions. CCAFS Working Paper No. 11. CGIAR Research Program on Climate Change, Agriculture and Food Security CCAFS. Copenhagen, Denmark.

Connell J; Stür W; Horne P. 2010. Forages and farmers: case studies from South-East Asia. ACIAR Monograph No. 142. ACIAR (Australian Centre for International Agricultural Research), Canberra, Australia, and CIAT (International Centre for Tropical Agriculture), Vientiane, Laos.

Conway MJ. 2005. Butterfly pea in Queensland: a tropical forage legume success story. Tropical Grasslands 39:224.

Costa FP; Corrêa ES; de Melo Filho GA; Cardoso EE; Pereira MA; Miranda CHB. 2009. Avaliação dos Impactos Econômicos de Quatro Forrageiras Lançadas pela Embrapa. Documentos 174. Embrapa (Empresa Brasileira de Pesquisa Agropecuária) Gado de Corte, Campo Grande, MS, Brazil.

Cramb RA. 2000. Processes influencing the successful adoption of new technologies by smallholders. In: Stür WW; Horne PM; Hacker JB; Kerridge PC, eds. Working with farmers: the key to adoption of forage technologies.

ACIAR Proceedings No. 95. ACIAR (Australian Centre for International Agricultural Research), Canberra, Australia. p. 11–22.
http://www.aciar.gov.au/publication/PR095

Delgado C; Rosegrant M; Steinfeld H; Ehui S; Courbois B. 1999. Livestock to 2020. The Next Food Revolution. IFPRI (International Food Policy Research Institute), FAO (Food and Agriculture Organization of the United Nations), ILRI (International Livestock Research Institute), Washington, DC, USA.

Delgado C. 2005. Rising demand for meat and milk in developing countries: implications for grasslands-based livestock production. In: McGilloway DA, ed. Grassland: a global resource. Wageningen Academic Publishers, Wageningen, The Netherlands. p. 29−39.

Dixon J; Li X; Msangi S; Amede T; Bossio D; Ceballos H; Howeler R; Reddy BVS; Abaidoo R; Timsina J; Crissman C; Mares V; Quiroz R; Leon-Velarde C; Herrero M; Blummel M; Holmann F; Peters M; White D; Qadir M; Szonyi J. 2010. Feed, food and fuel: Competition and potential impacts on smallscale crop-livestock-energy farming systems. Project Report. CGIAR Systemwide Livestock Programme (SLP), Addis Ababa, Ethiopia.

Elbasha E; Thornton PK; Tarawali G. 1999. An ex post Economic Assessment of Planted Forages in West Africa. ILRI Impact Assessment Series 2. ILRI (International Livestock Research Institute), Nairobi, Kenya.

Elkington J. 1997. Cannibals with Forks: The Triple Bottom Line of 21st Century Business. New Society Publishers, Stony Creek, CT, USA.

Embrapa. 2004. Avaliação dos impactos econômicos, sociais e ambientais da pesquisa da Embrapa Agropecuária Oeste: relatório do ano de 2003. Documentos 66. Embrapa (Empresa Brasileira de Pesquisa Agropecuária) Agropecuária Oeste, Dourados, MS, Brazil.
http://www.infoteca.cnptia.embrapa.br/bitstream/doc/250713/1/DOC200466.pdf

Espinosa García JA; Wiggins S. 2003. Potential economic benefits of dual purpose livestock technology in the Mexican tropics. Técnica Pecuaria en México 41:19−36.
http://www.tecnicapecuaria.org.mx/trabajos/200304010380.pdf

Ewers RM; Scharlemann JPW; Balmford A; Green RE. 2009. Do increases in agricultural yield spare land for nature? Global Change Biology 15:1716−1726.

FAO. 2009. The State of Food and Agriculture 2009. Livestock in the balance. FAO (Food and Agriculture Organization of the United Nations), Rome, Italy.
http://www.fao.org/docrep/012/i0680e/i0680e.pdf

FAO. 2010. Grassland carbon sequestration: management, policy and economics: Proceedings of the Workshop on the role of grassland carbon sequestration in the mitigation of climate change. Integrated Crop Management. Vol. 11. FAO (Food and Agriculture Organization of the United Nations), Rome, Italy.
http://www.fao.org/docrep/013/i1880e/i1880e.pdf

Fisher MJ; Rao IM; Ayarza MA; Lascano CE; Sanz JI; Thomas RJ; Vera RR. 1994. Carbon storage by introduced deep-rooted grasses in the South American savannas. Nature 371:236−238.

Fisher MJ; Braz SP; Dos Santos RSM; Urquiaga S; Alves BJR; Boddey RM. 2007. Another dimension to grazing systems: Soil carbon. Tropical Grasslands 41:65–83.

Fu W; Gandhi VP; Cao L; Liu H; Zhou Z. 2012. Rising Consumption of Animal Products in China and India: National and Global Implications. China & World Economy 20(3): 88−106.

Goodland R; Anhang J. 2009. Livestock and Climate Change: What if the key actors in climate change are cows, pigs and chickens? World Watch (November/December). p. 10−19.
http://www.worldwatch.org/files/pdf/Livestock%20and%20Climate%20Change.pdf

Guodao L; Chakraborty S. 2005. Stylo in China: a tropical forage legume success story. Tropical Grasslands 39:215.

Herrero M; Thornton PK; Notenbaert AM; Wood S; Msangi S; Freeman HA; Bossio D; Dixon J; Peters M; van de Steeg J; Lynam J; Parthasarathy Rao P; Macmillan S; Gerard B; McDermott J; Seré C; Rosegrant M. 2010. Smart Investments in Sustainable Food Production: Revisiting Mixed Crop-Livestock Systems. Science 327: 822−825.

Holmann F; Rivas L; Argel P; Pérez E. 2004. Impacto de la adopción de pastos *Brachiaria*: Centroamerica y México. CIAT (Centro Internacional de Agricultura Tropical), Cali, Colombia.

Horne PM; Magboo E; Kerridge PC; Tuhulele M; Phimphachanhvongsod V; Gabunada F Jr; Bin LH; Stür WW. 2000. Participatory approaches to forage technology development with smallholders in Southeast Asia. In: Stür WW; Hacker JB; Kerridge PC, eds. Working with Farmers: The Key to Adoption of Forage Technologies. ACIAR Proceedings No. 95. ACIAR (Australian Centre for International Agricultural Research), Canberra, Australia. p. 23–31.

IBGE (Instituto Brasileiro de Geografia e Estatística). 2007. Census of Agriculture 1920/2006.
http://seriesestatisticas.ibge.gov.br/series.aspx?no=1&op=0&vcodigo=AGRO03&t=utilizacao-terras-ha

Kaimowitz D; Angelsen A. 2008. Will livestock intensification help save Latin America's forests? Journal of Sustainable Forestry 27:6−24.

Kanerva M. 2011. Main trends in meat consumption in Europe. University of Bremen, Bremen, Germany.
http://www.artec.uni-bremen.de/aktuelles/Fleisch_MKanerva.pdf

Kassa H; Ayalew W; Gabirel ZH; Meskel TG. 2000. Smallholder goat production and individual food security: The case of a women focused dairy goat development project in Eastern Hararghe of Ethiopia. In: Merkel, RC; Abebe G; Goetsch AL, eds. The Opportunities and Challenges of Enhancing Goat Production in East Africa. Proceedings of a conference held at Debub University, Awassa, Ethiopia, November 10–12, 2000. E (Kika) de la Garza Institute for Goat Research, Langston University, Langston, OK, USA. p. 164–174. http://www.luresext.edu/international/DairyHararghe.htm

Kassam A; Kueneman E; Kebe B; Ouedraogo S; Youdeowei A. 2010. Enhancing Crop-Livestock Systems in Conservation Agriculture for Sustainable Production Intensification: A Farmer Discovery Process Going to Scale in Burkina Faso. Integrated Crop Management Vol. 7. FAO (Food and Agriculture Organization of the United Nations), Rome, Italy. http://www.fao.org/docrep/012/i1437e/i1437e.pdf

Khan Z; Midega C; Pittchar J; Pickett J; Bruce T. 2011. Push-pull technology: conservation agriculture approach for integrated management of insect pests, weeds and soil health in Africa. International Journal of Agricultural Sustainability 9:162–170. http://www.tandfonline.com/doi/pdf/10.3763/ijas.2010.0558

Khanh TT; Nguyen NA; Stür W; Tiemann T; Duncan AJ. 2011. Enhancing Livelihoods of Poor Livestock Keepers through Increased Use of Fodder: Smallholder cattle fattening in Viet Nam. IFAD Technical Advisory Note. IFAD (International Fund for Agricultural Development), Rome, Italy.

Kristjanson P; Tarawali S; Okike I; Singh BB; Thornton PK; Manyong VM; Kruska RL; Hoogenboom G. 2002. Genetically Improved Dual-purpose Cowpea: Assessment of Adoption and Impact in the Dry Savannah of West Africa. Impact Assessment Series No. 9. ILRI (International Livestock Research Institute), Nairobi, Kenya.

Landers JN. 2007. Tropical crop-livestock systems in conservation agriculture: the Brazilian experience. Integrated Crop Management Vol. 5. FAO (Food and Agriculture Organization of the United Nations), Rome, Italy.

Larsen J. 2012. Peak Meat: U.S. Meat Consumption Falling. http://www.earth-policy.org/data_highlights/2012/highlights25

Mannetje L´t; Amézquita MC; Buurman P; Ibrahim M. 2008. Carbon sequestration in tropical grassland ecosystems. Wageningen Academic Publishers, Wageningen, The Netherlands.

Marchão RL; Becquer T; Brunet D; Balbino LC; Vilela L; Brossard M. 2009. Carbon and nitrogen stocks in a Brazilian clayey Oxisol: 13-year effects of integrated crop-livestock management systems. Soil & Tillage Research 103:442–450.

Martin G. 2010. ACIAR investment in research on forages in Indonesia. ACIAR Impact Assessment Series Report No. 65. ACIAR (Australian Centre for International Agricultural Research), Canberra, Australia.

Maxwell TW; You S; Boratana U; Leakhna P; Reid J. 2012. The social and other impacts of a cattle/crop innovation in Cambodia. Agricultural Systems 107:83–91.

McClintock A; Griffith G. 2010. Benefit-cost meta-analysis of investment in the International Agricultural Research Centres. ACIAR Impact Assessment Series Report No. 68. ACIAR (Australian Centre for International Agricultural Research), Canberra, Australia.

McDermott JJ; Staal SJ; Freeman HA; Herrero M; van de Steeg JA. 2010. Sustaining intensification of smallholder livestock systems in the tropics. Livestock Science 130:95–109.

Mullen BF; Shelton HM; Dalzell SA. 2005. Leucaena in northern Australia: a forage tree legume success story. Tropical Grasslands 39:226.

Noble AD; Orr DM; Middleton CH; Rogers LG. 2000. Legumes in native pasture – asset or liability? A case history with stylo. Tropical Grasslands 34:199–206.

OECD-DAC (Organization for Economic Co-operation and Development, Development Assistance Committee). 2002. Glossary of Key Terms in Evaluation and Results Based Management. OECD, Paris, France. http://www.oecd.org/dataoecd/29/21/2754804.pdf.

Pagiola S; Ramirez E; Gobbi J; de Haan C; Ibrahim M; Murgueitio E; Ruiz JP. 2007. Paying for the environmental services of silvopastoral practices in Nicaragua. Ecological Economics 64:374–385.

Pathak PS; Ramesh CR; Bhatt RK. 2004. *Stylosanthes* in the reclamation and development of degraded soils in India. In: Chakraborty S, ed. High-yielding anthracnose resistant *Stylosanthes* for agricultural systems. ACIAR Monograph No. 111. ACIAR (Australian Centre for International Agricultural Research), Canberra, Australia. p. 85–96.

Pelletier N; Pirog R; Rasmussen R. 2010. Comparative life cycle environmental impacts of three beef production strategies in the Upper Midwestern United States. Agricultural Systems 103:380–389.

Pengelly BC; Whitbread A; Mazaiwana PR; Mukombe N. 2003. Tropical forage research for the future – better use of research resources to deliver adoption and benefits to farmers. Tropical Grasslands 37:207–216.

Peters M; Lascano CE; Roothaert R; de Haan NC. 2003. Linking research on forage germplasm to farmers: the pathway to increased adoption – a CIAT, ILRI and IITA perspective. Field Crops Research 84:179–188.

Peters M; Rao I; Fisher M; Subbarao G; Martens S; Herrero M; van der Hoek R; Schultze-Kraft R; Miles J; Castro A; Graefe S; Tiemann T; Ayarza M; Hyman G. 2012. Tropical forage-based systems to mitigate greenhouse gas emissions. Chapter 11. In: Hershey C; Neate P, eds. Eco-Efficiency: From Vision to Reality. CIAT (Centro Internacional de Agricultura Tropical), Cali, Colombia. p. 171–190. www.ciat.cgiar.org/.../chapter_11_eco_efficiency.pdf

Phaikaew C; Ramesh CR; Kexian Y; Stür W. 2004. Utilisation of *Stylosanthes* as a forage crop in Asia. In: Chakraborty S, ed. High-yielding anthracnose-resistant *Stylosanthes* for agricultural systems. ACIAR Monograph No. 111. ACIAR (Australian Centre for International Agricultural Research), Canberra, Australia. p. 65–76.

Pimentel D; Pimentel MH. 2007. Food, Energy and Society. 3rd Edn. CRC Press, Boca Raton, FL, USA.

Pinto AS; Bustamante MMC; Regina MS; da Silva S; Kisselle W; Brossard M; Kruger R; Zepp RG; Burke RA. 1996. Effects of Different Treatments of Pasture Restoration on Soil Trace Gas Emissions in the Cerrados of Central Brazil. Earth Interactions 10:1−26. http://journals.ametsoc.org/doi/pdf/10.1175/EI146.1

Place F; Roothaert R; Maina L; Franzel S; Sinja J; Wanjiku J. 2009. The impact of fodder trees on milk production and income among smallholder dairy farmers in East Africa and the role of research. ICRAF Occasional Paper No. 12. World Agroforestry Centre, Nairobi, Kenya.

Quintero M; Estrada RD; García J. 2006. A Manual for ECOSAUT: A Model for the Economic, Social, and Environmental Evaluation of Land Use. Centro Internacional de la Papa (CIP), Lima, Peru.

Quintero M; Estrada RD; Holmann F; Rao I; Martens S; Peters M; Van der Hoek R; Mena M; Douxchamps S; Oberson A; Frossard E. 2009a. Realizing the benefits of cover crop legumes in smallholder crop-livestock systems of the hillsides of Central America: Trade-off analysis of using legumes for soil enhancing or as animal feed resource. Presentation CGIAR Systemwide Livestock Programme Livestock Policy Group, 1 December 2009. http://www.slideshare.net/ILRI/realizing-the-benefits-of-cover-crop-legumes-in-smallholder-croplivestock-systems-of-the-hillsides-of-central-america-tradeoff-analysis-of-using-legumes-for-soil-enhancing-or-as-animal-feed-resource

Quintero M; Wunder S; Estrada RD. 2009b. For services rendered? Modeling hydrology and livelihoods in Andean payments for environmental services schemes. Forest Ecology and Management 258:1871−1880.

Rains JP. 2005. Stylos: The broad-acre legumes of N Australian grazing systems. Tropical Grasslands 39:225.

Raitzer DA. 2003. Benefit-Cost Meta-Analysis of Investment in the International Agricultural Research Centres of the CGIAR. Prepared on Behalf of the CGIAR Standing Panel on Impact Assessment. CGIAR Science Council Secretariat. http://www.sciencecouncil.cgiar.org/fileadmin/templates/ispc/documents/Publications/1b-Publications_Reports_briefs_SPIA/SC_SPIA_Benefit-Cost_Meta-analysis_Sep2003.pdf

Raitzer DA; Lindner R. 2005. Review of the Returns to ACIAR's Bilateral R&D Investments. Impact Assessment Series 35. ACIAR (Australian Centre for International Agricultural Research), Canberra, Australia. http://aciar.gov.au/files/node/679/final%20lo-res.pdf

Ramesh CR; Chakraborty S; Pathak PS; Biradar N; Bhat P. 2005. Stylo in India – much more than a plant for the revegetation of wasteland. Tropical Grasslands 39:213.

Rao IM; Boddey RM; Thomas RJ. 1996. Nutrient cycling and environmental impact of brachiaria pastures. In: Miles JW; Maass BL; Valle CB do; Kumble V, eds. Brachiaria: Biology, Agronomy and Improvement. CIAT (Centro Internacional de Agricultura Tropical), Cali, Colombia. p. 72−86.

Rivas L; Holmann F. 2004. Impacto de la Adopción de Híbridos de Brachiarias Resistentes al Salivazo e Colombia, México y Centroamérica. CIAT (Centro Internacional de Agricultura Tropical), Cali, Colombia.

Rothstein HR; Sutton AJ; Borenstein M. 2005. Publication bias in meta-analysis: Prevention assessment, and adjustments. John Wiley, Hoboken, NJ, USA.

Rudel TK. 2008. Meta-analyses of case studies: A method for studying regional and global environmental change. Global Environmental Change 18:18−25.

Shelton HM; Franzel S; Peters M. 2005. Adoption of tropical legume technology around the world: analysis of success. Tropical Grasslands 39:198−209.

Shelton M; Dalzell S. 2007. Production, economic and environmental benefits of leucaena pastures. Tropical Grasslands 41:174−190.

Shiferaw A; Puskur R; Tegegne A; Hoekstra D. 2011. Innovation in forage development: empirical evidence from Alaba Special District, southern Ethiopia. Development in Practice 21:1138−1152.

Silici L. 2010. Conservation Agriculture and Sustainable Crop Intensification in Lesotho. Integrated Crop Management Vol. 10. FAO (Food and Agriculture Organization of the United Nations), Rome, Italy.

Silva JE; Resck DVS; Corazza EJ; Vivald L. 2004. Carbon storage in clayey Oxisol cultivated pasture in the "Cerrado" region, Brazil. Agriculture, Ecosystems and Environment 103:357−363.

Sollenberger LE; Kalmbacher RS. 2005. Aeschynomene and carpon desmodium: legumes for bahiagrass pasture in Florida. Tropical Grasslands 39:227.

Squires VR; Mann TL; Andrew MH. 1992. Problems in implementing improved range management on common lands in Africa: an Australian perspective. Journal of the Grassland Society of Southern Africa 9:1−7.

Steinfeld H; Gerber P; Wassenaar T; Castel V; Rosales M; de Haan C. 2006. Livestock's Long Shadow: Environmental Issues and Options. FAO (Food and Agriculture Organization of the United Nations), Rome, Italy. www.fao.org/docrep/010/a0701e/a0701e00.HTM

Stern E; Stame N; Mayne J; Forss K; Davies R; Befani B. 2012. Broadening the Range of Designs and Methods for Impact Evaluations. Working Paper 38. Department for International Development (DfID), London, UK. www.dfid.gov.uk/r4d/Output/189575/Default.aspx

Stevens J; Falk DA. 2009. Can Buffelgrass Invasions Be Controlled in the American Southwest? Using Invasion Ecology Theory to Understand Buffelgrass Success and Develop Comprehensive Restoration and Management. Ecological Restoration 27:417−427.

Stür W; Horne PM; Phengsavanh P; Gabunada F; Khanh TT; Connell J. 2007. Planted forages – the key for making money from smallholder livestock production: Experiences from CIAT's forage R&D in Southeast Asia. In: Hare MD; Wongpichet K, eds. Forages – A Pathway to Prosperity for

Smallholder Farmers. Proceedings of a Forage Symposium, Faculty of Agriculture, Ubon Ratchathani University, Ubon Ratchathani, Thailand. p. 313–331.

Stür W; Khanh TT; Duncan A. 2013. Transformation of smallholder beef cattle production in Vietnam – technology, innovation and markets: A case study. International Journal of Agricultural Sustainability, DOI: 10.1080/14735903.2013.779074. http://www.tandfonline.com/doi/abs/10.1080/14735903.2013.779074#

Taheripour F; Hertel TW; Tyner WE. 2010. Implications of the Biofuels Boom for the Global Livestock Industry: A Computable General Equilibrium Analysis. Global Trade Analysis Project (GTAP) Working Paper No. 58. Purdue University, West Lafayette, IN, USA. https://www.gtap.agecon.purdue.edu/resources/download/4632.pdf

Tarawali SA; Thornton P; De Haan N. 2005. Planted forage legumes in west Africa. Tropical Grasslands 39:211.

Tarre R; Macedo R; Cantarutti RB; de Rezende CP; Pereira JM; Ferreira E; Alves BJR; Urquiaga S; Boddey RM. 2001. The effect of the presence of a forage legume on nitrogen and carbon levels in soils under *Brachiaria* pastures in the Atlantic forest region of the south of Bahia, Brazil. Plant and Soil 234:15–26.

Thomas D; Sumberg JE. 1995. A review of the evaluation and use of tropical forage legumes in sub-Saharan Africa. Agriculture, Ecosystems and Environment 54:151–163.

Thornton P. 2010. Livestock production: recent trends, future prospects. Philosophical Transcripts of the Royal Society Biological Sciences 365(1554):2853–2867. http://rstb.royalsocietypublishing.org/content/365/1554/2853.full.pdf+html

Thornton PK; Herrero M. 2010. The potential for reduced methane and carbon dioxide emissions from livestock and pasture management in the tropics. Proceedings of the National Academy of Sciences 107:19667–19672.

Tonucci RG; Nair PKR; Nair VD; Garcia R; Bernardino FS. 2011. Soil Carbon Storage in Silvopasture and Related Land-Use Systems in the Brazilian Cerrado. Journal of Environmental Quality 40:833–841.

Valentim JF; Andrade CMS. 2005a. Tropical kudzu (*Pueraria phaseoloides*): successful adoption in sustainable cattle production systems in the western Brazilian Amazon. Tropical Grasslands 39:221.

Valentim JF; Andrade CMS. 2005b. Forage peanut (*Arachis pintoi*): a high yielding and high quality tropical legume for sustainable cattle production systems in the western Brazilian Amazon. Tropical Grasslands 39:222.

Walker T; Maredia M; Kelley T; La Rovere R; Templeton D; Thiele G; Douthwaite B. 2008. Strategic Guidance for Ex Post Impact Assessment of Agricultural Research. CGIAR Science Council Secretariat, Rome, Italy. http://impact.cgiar.org/sites/default/files/pdf/7-Strategic-Guidelines.pdf

White D; Holmann F; Fujisaka S; Reátegui K; Lascano C. 2001. Will intensifying pasture management in tropical Latin America protect forests (or is it the other way around)? In: Angelsen A; Kaimowitz D, eds. Agricultural Technologies and Tropical Deforestation. CABI, Wallingford, UK and New York, USA. p. 91–111.

White D; Rubiano J; García J; Andersson M; Jarvis A. 2007. Análisis de oportunidades de inversión en conservación por ahorros en tratamiento de aguas. Sitio del estudio: Páramo Chingaza, Colombia. CIAT, Universidad Nacional de Colombia - Palmira, The Nature Conservancy – Programa Andes Tropicales del Norte, Cali, Colombia.

Williams MJ; Quesenberry KH; Prine GM; Olson CB. 2005. Rhizoma peanut – more than a 'lucerne' for subtropical USA. Tropical Grasslands 39:228.

White DS; Peters M; Horne P. 2013. Global impacts from improved tropical forages: A meta-analysis revealing overlooked benefits and costs, evolving values and new priorities. Tropical Grasslands – Forrajes Tropicales 1:12–24.
DOI: 10.17138/TGFT(1)12-24

This paper was presented at the 22nd International Grassland Congress, Sydney, Australia, 15−19 September 2013. Its publication in *Tropical Grasslands – Forrajes Tropicales* is the result of a co-publication agreement with the IGC 2013 Organizing Committee. Except for adjustments to the journal's style and format, the text is essentially the same as that published in: **Michalk LD; Millar GD; Badgery WB; Broadfoot KM, eds. 2013. Revitalising Grasslands to Sustain our Communities. Proceedings of the 22nd International Grassland Congress, Sydney, Australia, 2013. New South Wales Department of Primary Industries, Orange, NSW, Australia. p. 169–178.**