Strategies leading to successful wide adoption of mixed grass-legume pastures for sustainable intensification of beef cattle production systems in the Brazilian Amazon

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Introduction

In the Brazilian Amazon, pasture-based cattle ranching is a source of environmental harm and hope for income and well-being improvement for more than 450 thousand rural households (IBGE, 2019). It is both the main deforestation driver (NEPSTAD, et al., 2014) and a key stable capital asset in the path of farmers towards improving their family's food security, income and well-being (GARRETT et al., 2017; VALENTIM; GARRETT, 2015).

Expansion of agriculture and cattle ranching until 2018 has occurred at the cost of deforestation of 14% (59 million hectares) of the Brazilian Amazon biome, with pastures occupying 90% of these areas (MAPBIOMAS, 2019). In 2017, the cattle herd in the region was 46 million animal units (1 AU = 450 kg of live weight), grazing in 45 million hectares of pastures, resulting in an average stocking rate of 1 AU/ha (LAPIG, 2019). In the Legal Amazon, 50% of the cultivated pastures are either degraded or in degradation process (DIAS-FILHO, 2011). Therefore, intensification of pasture-based cattle production systems is a key variable in solving the sustainable development equation in the Brazilian Amazon. However, current animal productivity of cultivated pastures in Brazil are only 32-34% of the potential. Increasing productivity to 49–52% of the potential would be enough to meet demands for meat, crops, wood products and biofuels until 2040, without additional deforestation and avoid emissions of up to 14.3 Gt CO2 Eq (STRASSBURG et al., 2014).

Intensification and long-term productivity of pasture-based cattle production systems depends on replenishment of soil nutrient reserves removed or lost by leaching, erosion and volatilization. There is a wide knowledge stock relevant towards the goal of sustainable intensification of cattle production systems in the Brazilian Amazon (BUNGENSTAB et al., 2019; DIAS-FILHO; ANDRADE, 2019; EMBRAPA, 2019). Of particular interest are those aspects related to nitrogen (N) supply, since this is the main nutrient required for plant and animal growth and production. Inputs of N into agricultural systems may be from fertilizers or derived from the atmosphere through biological N2 fixation (BNF). However, opportunities for intensification of livestock production systems in the Brazilian Amazon are limited because the majority of farmers can`t afford the high cost external inputs (VALENTIM; ANDRADE, 2004).

Forage legume technologies with effective BNF capacity are among the most promising options to supply N needed for sustainable intensification of livestock production systems in Brazil. Mixed with grasses, legumes provide a low cost supply of highly deficient nitrogen (N) to soil-plant-animal ecosystems in the tropics though BNF by soil bacteria of the genus *Rhizobium*. This contributes to increase the quantity and quality of forage produced and additionally, improves biodiversity and resilience of pasture ecosystems. With adoption of adequate management practices, grass-legume pastures can support higher stocking rates and increase productivity per animal and per area over longer periods (GRAHAM; VANCE, 2014; STRASSBURG et al., 2014; LATAWIEC et al., 2014; ANDRADE, 2012; SHELTON et al., 2005; VALENTIM; ANDRADE, 2004). These technologies are particularly relevant to improve food security and income of smallholders in the tropics who can`t afford buying expensive fertilizers to supply essential N for their livestock production systems (FAO, 2009; REARDON et al., 1999; VALENTIM; ANDRADE, 2004).

However, with a few exceptions, forage legumes have failed in delivering in their promise to improve productivity of livestock production systems in the tropics. Unsuccessful experiences in establishing and maintaining productive and persistent grass-legumes mixtures resulted in lack of credibility of this alternative among farmers and researchers. Unavailability of commercial cultivars adapted to the different environmental conditions and the high cost of commercial seeds in the market also contributed to restrict wide adoption of grass-legume pastures in the tropics. In many instances where these technologies were promoted, insufficient knowledge among farmers regarding adequate management practices, associated with low persistence of legumes in mixed pastures with grasses resulted in high rates of failure. Low use of fertilizers in pasture establishment and management, still predominant in pasture-based cattle production systems, is also an important factor limiting successful adoption of mixed grass legume pastures in the tropics. Other important factors restricting wide adoption of mixed grass legume in the tropics are the lack of farmers participation in research and development, promotion of technologies that do not meet farmers expectations of socioeconomic benefits, and unfavorable policies (ANDRADE, 2012; BARCELLOS et al., 2008; SHELTON et al., 2005; VALENTIM; ANDRADE, 2004).

Although adoption in the tropics has been lower than expected, there are some successful histories of wide use of forage legumes in livestock production systems in the tropics (SHELTON et al., 2005). In Brazil, less than 2% of the cultivated pastures are mixed with legumes (EMBRAPA, 2019). Meanwhile, in the state of Acre, forage legumes were present in 29% of the 1.94 million hectares of cultivated pastures in 2014, mainly tropical kudzu (*Pueraria phaseoloides*) and forage peanut (*Arachis pintoi*) (Embrapa, 2019; AMARAL et al., 2018; VALENTIM; ANDRADE, 2005a; 2005b).

Here we describe and analyze an innovation framework implemented by Embrapa over the last 40 years to promote wide adoption of forage legume technologies for intensification of cattle production systems in the western Brazilian Amazon. We focus on assessing the importance of key adoption factors for the successful use of tropical kudzu and forage peanut in mixed grass-legume pastures in the state of Acre.

Description of the Innovation System for Mixed Grass-Legume Pastures

In 1973, the Brazilian Corporation for Agricultural Research (Embrapa) was established to provide knowledge support services to improve agriculture and livestock productivity and production in Brazil (CABRAL, 2005). One of the main knowledge gaps identified by farmers and the government was the need of adequate technologies for pasture reclamation and improvement to support the policies aiming at increasing pasture-based livestock production in the different Brazilian regions. This led to the establishment of the Project for Pasture Reclamation, Improvement and Management (Propasto) in the Legal Brazilian Amazon in 1976. The project had the main goals of developing improved cultivars of grasses and legumes with higher productivity of better quality forage and adapted to the different environmental conditions of the region; and, developing best management practices to establish and maintain productive and persistent pastures, thus contributing to increase productivity per animal and per area (EMBRAPA, 1980).

Propasto established a research network in 14 experimental fields, mostly on private cattle farms, in the main production areas of the states of Acre, Amazonas, Pará, Rondônia, Roraima and in a county of Goiás, currently part of the state of Tocantins. These farms were selected after consulting with farmers based on their strategic location and representativeness of the predominant cattle production systems in each state. The innovation framework implemented by Embrapa contemplated integration of governmental research, extension, regional development and financing organizations, the private sector, nongovernmental organizations and farmers. From 1976 through 1990, the Superintendence for Amazon Development provided financial support for Embrapa research activities. At the same time, the governmental Bank of Amazon provided credit to finance infrastructure improvements, and farm inputs for farmers collaborating with the Propasto Project (EMBRAPA, 1980).

On-farm research assessed nutritional needs, pest and disease resistance, and forage production and quality characteristics of large collections of introduced accessions of grasses and legumes. Pasture and animal productivity of the most promising accessions were assessed under grazing on large on-farm experiments pasture and animal productivity. Researchers and farmers continuously interacted and exchanged knowledge and information during the process of establishment of the experiments, data collection and analysis. The research network promoted annual meetings for assessment of results and planning of future activities. The technologies that were successfully validated were made available to the different stakeholders groups though technical publications, distribution of seeds or vegetative material of the most promising forage species for leading innovative farmers to establish their own seed producing areas and nurseries in order to promote wider adoption. On-farm field days allowed researchers and the collaborating farmers to share their knowledge with extensions agents, other farmers groups, policy makers and other relevant stakeholders for the private sector and nongovernmental organizations (EMBRAPA, 1980b).

In the state of Acre, on farm research activities established by the Propasto project started in 1976 and were conducted until 1982 (VALENTIM; COSTA, 1982; EMBRAPA, 1980). The relevance and saliency of Embrapa research outcomes in meeting farmers' knowledge needs, during its seven years of activities, contributed consolidate its credibility and assure commitment of local stakeholders with the continuity of this innovation framework. Over the last 40 years, the Research Group on Sustainable Cattle production Systems for the western Brazilian Amazon established by Embrapa in Acre in 1979 (CNPq, 2010) has been developing on-farm research and providing knowledge support services for sustainable intensification of beef and dairy cattle production systems in this region.

Case Description

The initial focus of Embrapa research contemplated the introduction, selection and recommendation of forages adapted to the different socioeconomic and environmental conditions of the Legal Brazilian Amazon (EMBRAPA, 1980). However, most of the Propasto research network concentrated their focus on grasses, since this was the knowledge gap clearly identified by farmers which had no previous tradition of using forage legumes in their production system. Researchers recognized that N was an essential nutrient limiting productivity and sustainability of pasture-based cattle production systems in the Amazon (SERRÃO; FALESI, 1977). However, the costs and logistics of accessing nitrogen fertilizers made this option economically unviable to most farmers in the Amazon. This led to special focus by Embrapa in the state of Acre to a long-term commitment to promote use of forage legumes aiming as supplying low cost biologically fixed N to the soil-plant-animal ecosystem (VALENTIM; ANDRADE, 2004; VALENTIM; COSTA, 1982).

Key Technologies Promoted

a. Tropical Kudzu (*Pueraria phaseoloides*)

Tropical kudzu is a vigorous twining and climbing, deeply rooting legume, which can also root at the nodes. It is native from Southeast Asia (Malaysia and Indonesia) and currently widely cultivated throughout the tropics where it is considered a naturalized species (COOK et al. 2005; BOGDAN 1977). In Brazil, this legume was introduced for use as a ground cover in rubber tree plantations in the Amazon in the 1940`s, and with higher intensity in the 1970` and 1980`s (VALENTIM; 2010).

From the large collection of legumes introduced and evaluated by Embrapa in small plots at experimental stations and in farms between 1976 and 1982 only tropical kudzu showed good productivity of high quality forage, good seed production and excellent persistence in mixed grass-legumes pastures in the state of Acre (VALENTIM; COSTA, 1982). Embrapa Acre successfully promoted tropical kudzu since the early 1980s for use in mixed pastures with cultivars of *Panicum maximum*, *Brachiaria brizantha*, *B. humidicola* and *B. decumbens*. By 2005, this technology was adopted in over 5,400 farms reaching an area of 480,000 ha, with estimated economic benefits of US$ 33 million/year (SHELTON et al., 2005; VALENTIM; ANDRADE, 2004; 2005a).

b. Forage Peanut (*Arachis pintoi*) Cultivar Belomonte

Legumes of the genus Arachis are native from South America, where they are distributed in Peru, Bolivia, Brazil, Uruguay, Paraguay and Argentina. Forage peanut cultivars are being successfully adopted in the Nepal, Australia, Brazil, Colombia and the southern United States (SHELTON et al., 2005; COOK et al., 2005; VALENTIM; ANDRADE, 2004; KERRIDGE; HARDY, 1994). Research on experimental station with forage peanut started in Acre in 1990, with introduction and evaluation of accessions of *Arachis pintoi*, *Arachis glabrata* and *Arachis repens* (VALENTIM, 1996).

Since 1998, there was increasing degradation of pastures due to the occurrence of syndrome of death of Marandugrass (*Brachiaria brizantha* cv. Marandu) in poorly drained soils of the Amazon. This led farmers to search for forage alternatives to reclaim degraded pastures to maintain the productivity and profitability of cattle production systems. Tropical kudzu, the major forage legume used in mixed pastures in Acre, showed poor compatibility with some of the new grass species being established by farmers, such as African stargrass (*Cynodon nlemfuensis*), and also failed to persist when managed under rotational stocking at stocking rates above 1.5 AU per hectare (VALENTIM; ANDRADE, 2005b).

In the beginning of 2000, farmers that traditionally collaborated with Embrapa Acre for on-farm validation of technologies demanded new legumes adapted for use in more intensive cattle production systems, which included pasture management under rotational stocking. At that time, forage peanut cultivar Belomonte was in pre-recommendation phase for the environmental conditions of Acre. In the year 2000, around 20 of these farmers established cultivar Belomonte in association with stoloniferous grasses such as African stargrass, tangolagrass (*B. arrecta* x *B. mutica*) and *B. humidicola* in the process of reclaiming degrading Marandugrass pastures. Both the legume and the grass were planted manually, using vegetative material (stolon pieces) supplied for farmers at no cost from a two-hectare nursery at Embrapa Acre. The initial success of this experience spreads rapidly by word of mouth among other farmers facing similar problems. In 2001, Embrapa Acre officially recommended forage peanut cultivar Belomonte for diversification of pasture ecosystems in Acre. The news of the success of this legume in the reclamation of degraded pastures, and in the improvement of other still productive grass pastures, rapidly spread among farmers. By March 2004, close to 1000 small, medium and large farmers of Acre had already peanut into their pastures (VALENTIM; ANDRADE, 2004; 2005b).

Mixed grass-forage peanut pastures results in higher pasture productivity of high quality forage thus increasing carrying capacity and animal performance. In the environmental conditions of Acre, mixed pastures of forage peanut and stargrass have the potential to support an average of 2.5 AU/ha/year and produce over 850 kg of animal live weight/ha/year (ANDRADE et al., 2015). Currently, cultivar Belomonte is adopted in over 79.6 thousand hectares of pastures, providing US$ 19.7 million of economic benefits for farmers in Acre (EMBRAPA, 2019).

However, vegetative propagation of cultivar Belomonte still limits wider adoption of this technology due to high labor demand for vegetative propagation. To overcome this challenge, Embrapa Acre developed a new forage peanut cultivar (BRS Mandobi) propagated by seeds (ASSIS et al., 2014). Mixed pastures of *B. humidicola* and forage peanut BRS Mandobi increase animal gains by 66%, compared with pure grass pastures, thus reducing steer slaughter aged from 33 to 25 months (SALES et al., 2019). This new cultivar has the potential to be adopted in the 45 million hectares of cultivated pastures in the Amazon biome (VALENTIM et al., 2017) and 36 million hectares in the Mata Atlântica biome (MABIOMAS, 2019).

Key Factors for Successful Wide Adoption of Mixed Grass-Legume Pastures

Adoption factors were assessed and ranked (Figure 1) according their contribution for successful wide adoption of mixed grass-legume pastures in the Brazilian Amazon. These factors are discussed as follows.

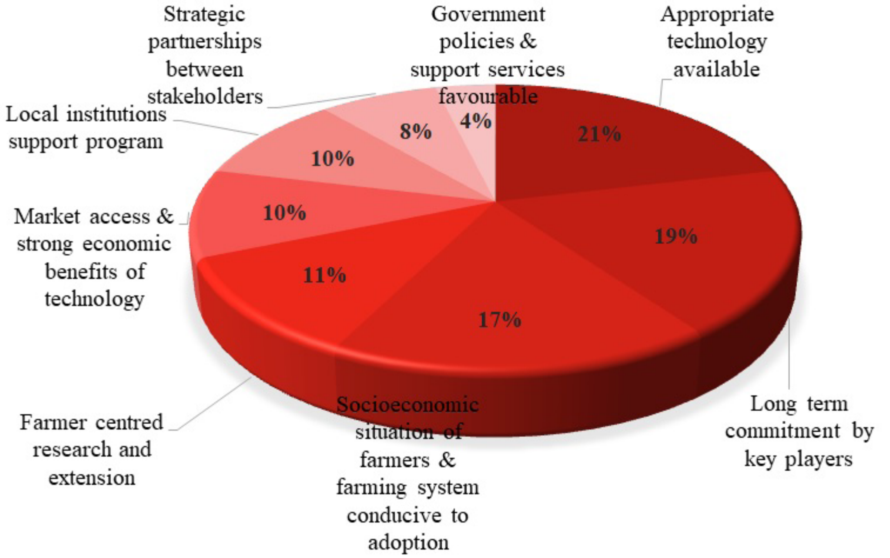

Figure 1. Ranking of key factors for successful wide adoption of mixed grass-legume pastures in the Brazilian Amazon state of Acre.

Appropriate Technology Available

Adoption of the grass-legume technology was relatively simple, although management of mixed pastures was somewhat more complex. However, in the early 1980`s, farmers in the Western Brazilian Amazon had no previous knowledge of the use of legumes as forages in animal production systems. Pastures consisted exclusively of cultivated grass species. Farmers perceived broad leaf plant species as undesirable species in their cultivated pastures and managed to control those using mechanical cutting methods, by burning the pastures or using agrochemicals. Convincing farmers to include a legume in association with grasses was very difficult in the beginning, particularly because of the aggressive growing behavior of tropical kudzu and the increased risk of accidental fires during the dry season.

Farmers had access to practical information and materials to support technology adoption. Embrapa made available an accompanying technology package encompassing specific technology requirements though videos, radio programs, technical bulletins, folders, and demonstration units in large, medium and small farms. Additionally, mixed grass-legume technologies were formally included in recommended beef and dairy cattle productions systems, collaboratively designed by researchers, farmers, extensions and financial agents of governmental and private organizations.

Embrapa also supported the establishment of local production and supply of affordable good quality tropical kudzu seeds. Small farmers use tropical kudzu as a fallow to reclaim degraded areas for a period of 2-3 years, after which they are converted to cultivation of annual (rice, corn, cassava) and perennial crops (coffee, orange, limes). This trailing legume grows over the regenerating native shrub and woody species and produce abundant seeds, which are harvested during the dry season and sold to local retailers (VALENTIM; ANDRADE, 2005a). In the case of forage peanut, Embrapa established two hectares of nursery to supply farmers with no cost plant material for vegetative propagation (VALENTIM; ANDRADE, 2005b).

Long-term Commitment by Key Players

Researchers of Embrapa Acre have a long commitment (around 40 years) in using participatory approaches of research and development and technology transfer activities regarding the use grass-legume technologies with farmers in cattle production systems in the State of Acre. In addition, Embrapa researchers and collaborating farmers became champions in advocating the advantages of using mixed grass-legume pastures as a lower cost, higher profitability strategy towards sustainable intensification of cattle production systems in the Brazilian Amazon.

Embrapa framework was successful in promoting grass-legume technologies among large farmers that account for 4% of the farms and 40% of the cattle herd in Acre. Although in smaller proportions, small and medium farmers also adopted tropical kudzu in their cattle production systems, not only in grass-legume pastures, but also in the process of reclamation of degraded land for agricultural production. This allowed farmers to become seed producers with tropical kudzu becoming a cash crop generating income for many small farmers that represent 96% of the properties and account for 60% of the cattle in the State of Acre.

Socioeconomic Situation of Farmers and Farming System Were Conducive to Adoption

One of the key drivers for wide adoption of mixed grass-legume pastures in the state of Acre was the socioeconomic situation of farmers and their farming systems. Since the late 1980`s farmers have been under pressure to stop deforestation for pasture establishment in the Brazilian Amazon. Additionally, incidence of pests and diseases, lack of maintenance fertilization and poor management led to increased pasture degradation, thus increasing costs and reducing profitability of cattle production systems. This established a socioeconomic environment conducive for farmers to become more receptive to technological changes in their production systems, favoring adoption of grass-legume pasture technologies (VALENTIM; ANDRADE, 2004).

Farmers Centered Innovation System

Farmers and other stakeholders were active participants in most of the phases of the innovation framework. In addition, a flexible approach was used to ensure that farmer innovations were absorbed and integrated into the technology package. Methods for seeding tropical kudzu and adjustments on seeding rate and planting density for pasture establishment or introduction of the legumes in existing pastures were developed with valuable insights from farmer's trial and error experiences.

Mixed grass-legume pasture technologies were developed and tested on large, medium and small beef and dairy cattle production farms. Farmers that participated in the development or were early adopters were active agents in the process promoting these technologies. These farmers acted as practical instructors in technology transfer activities for farmers, extension agents, students and researchers and their farms were used as demonstration units of successful use of mixed grass-legume pastures.

Market Access Available and Financial Benefits of Technology Strong

Global and national demand for livestock products has been increasing strongly, because of both population growth and increasing income, particularly in Asia, Latina America, and Africa (DELGADO, 2005). In addition, growing local and regional markets and improvements of infrastructure and logistics that occurred along the last four decades has made meat produced in the Western Brazilian Amazon increasingly competitive in Brazil and in the global market. This, associated with strong returns from mixed grass legume pastures were enough to support adoption costs of the technology in the state of Acre (VALENTIM; ANDRADE, 2005a; 2005b).

Farms are diverse, therefore, farmers are looking for technologies with multiple benefits, which makes mixed grass-legume pastures very attractive. These technologies contribute to reduce costs associated buying and applying nitrogen fertilizers and agrochemicals for weed suppression (VALENTIM; ANDRADE, 2004). In addition, these technologies increase pasture carrying capacity and animal gains, which results in higher production per animal and per hectare, thus increasing profitability of cattle production systems in the Brazilian Amazon (ANDRADE et al., 2015).

Local Institutions Have Capacity to Support Program

Throughout the last four decades, promotion of sustainable intensification of cattle production systems using mixed grass-legumes pastures has been one of the main R&D focus of Embrapa Acre. In addition, researchers have been committed and available to solve problems as they occurred and adopted an interactive on-farm research framework involving farmers in the technology development process.

Strategic Partnerships Between Stakeholders in Place

Strategic partnerships between Embrapa, farmers and private enterprises were in place. However, there has been a lack of continuity (change of staff, lack of financial resources) of activities of extension agencies. This has prevented them from developing personnel with expertise in establishment and management of grass-legume pastures in the region. If more investments were made in capacity building of extension and development agencies, wider adoption would have been possible.

Government Policy Settings Conducive and Support Services Favourable

Research services were available to solve problems as they occurred and to progress technology with farmers, such as management strategies, new grass and legume varieties. Additionally, financial credit was available for reclamation of degraded pastures and for intensification of cattle production systems.

Challenges and opportunities for wider adoption of mixed grass-legumes pastures

Increasing Availability of Low Cost Forage Peanut Seeds in the Market

The myths that apparently limited successful adoption of mixed grass-legume pasture technologies in the Brazilian Amazon have been overcome by long-term successful on-farm experiences. Research has identified forage peanut as the most persistent and compatible tropical legume, highly adapted for use in more intensive pasture-based cattle production systems. However, current use of this legume in mixed grass pastures is far from fulfilling their potential area of adoption of 45 million hectares of cultivated pastures in the Amazon biome and in the 36 million hectares of pastures in the Mata Atlântica biome.

Restriction for wider adoption of this legume in mixed grass pastures due to dependence of vegetative propagation of cultivar Belomonte was partially solved by development of the seed producing cultivar BRS Mandobi (ASSIS et al., 2013). This cultivar will be released to the market in 2019, with seeds at a price of US$ 25.00/kg. Brazilian seed producing companies are still dependent of the development of a more efficient forage peanut seed harvester to make a decision to invest in large-scale seed production.

Expanding the Network of Mixed Grass-Legume Demonstration Farms

Expanding a network of demonstration farms and champion farmers with successful use of mixed grass-legume pastures is an essential step to increase awareness of farmers, researchers, extension agents, and public and private decisions makers to promote wider adoption of mixed grass-legume pastures as a strategy to intensify cattle production systems in the Amazon and Mata Atlântica biomes.

Improvement in the Rural Credit System

Another important step is to assure that Brazilian agriculture policies consider establishment of mixed grass-legume pastures and the introduction of legumes into existing pastures that are productive or in degradation as an investment in soil quality improvement and pasture productivity and resiliency. As such, this practice would be eligible as part of rural credit framework, particularly the Brazilian Low Carbon Plan (Plano ABC), and the National Program for Strengthening Family Farming (PRONAF).

Regulation of the Forest Code

The Brazilian Forest Code (BRASIL, 2012) is in the process of regulation in the National Congress. Article 41 establishes a Program to Support and Encourage Environmental Preservation and Recovery. The federal government is authorized to institute a program of support and incentive for environmental conservation, as well as for the adoption of technologies and good practices that reconcile agricultural and forestry productivity, with reduction of environmental impacts. The program establishes payments or incentives for ecosystem conservation and improvement activities that generate environmental services, such as: 1) soil conservation and improvement; 2) sequestration, conservation, maintenance and increase of stock and reduction of carbon flow; 3) conservation of water and water services; and, 4) conservation of biodiversity.

Considering that legumes provide several of these environmental services when mixed in grass pastures, as discussed previously, there is a great opportunity to include this practice among those that enable farmers to get payments for environmental services.

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