Strategies to enable the use of legume silage in ruminant production

Odilon Gomes Pereira

Federal University of Viçosa, Department of Animal Science, Viçosa, Minas Gerais, Brazil

E-mail: odilon@ufv.br

André Soares de Oliveira

Federal University of Mato Grosso, Environmental and Agricultural Science Institute, Sinop, Mato Grosso, Brazil

Karina Guimarães Ribeiro

Federal University of Vales do Jequitinhonha e Mucuri, Department of Animal Science, Diamantina, Minas Gerais, Brazil

1. Introduction

The Brazilian livestock is based on pastures use, the ones which represent the more practical and economical way of ruminant feed. Despite having the biggest commercial herd in the world, approximately 200 millions of cattle, the productivity indexes obtained in Brazil in most of animal production systems in pasture are still low. This low productivity is related to the season pattern in feed supply which comes from pastures, responding to climatic changes, resulting in crop period and intercrop period of animal products.

Regarding to this, it shall proceed to the adjust between forage demand and supply, by an adequate feed planning, aiming to diminish the forage shortage in the dry period, making it possible this way, the uniform animal production all year long. The use of ensiled forage is a feasible alternative to guarantee the high quality forage supply, during the food shortage period. In this context, the sorghum and corn crops has been stood out as the most used species in ensiling process, by its ease of cultivation, high productivity and especially by the produced silage quality. However, recently, the interest for the use of legume silage in animal feeding system has been studied in several countries, being that, in Brazil, the soybean silage *(Glycine max L.* Merrill*)* has been of bigger interest.

It is aimed with the present text to discuss some aspects referring to the legume use as silage, to the fermentative pattern in legume silages, and to cattle feed supplementation with legume silages, as well as to show data related to the bioeconomic feasibility of legume silage use in ruminant feeding, pointing out the soybean silage.

2. Legume in the ensiling process

The legume use in pasture areas promotes increments in animal production, by the increase of nutritive value and forage supply resulting not only from the participation of legume in the animal diet, but also by indirect effects related to nitrogen biologic fixation. However, although these benefits, its participation in animal production system in pasture in our country is still insignificant, being the low persistence of legumes in pastures considered as the main cause of little use by the producers.

As for the use for silages production, historically, the legumes have always been considered inadequate to ensiling, due to high buffering capacity, low soluble carbohydrates and dry matter contents. Besides these restrictive characteristics to the fermentative process, it is important to stand out that the legumes in general present lower productivity of dry matter when compared to tropical grass. These factors together explain the reason of the low use of legumes as silage in tropical countries. However, these characteristics undesirable to fermentative process can be overcome by the additive use and forage wilting before ensiling.

The first studies about legume silage in Brazil are from the seventies (Faria et al., 1971; Tosi et al., 1973), being then approached in the lecture about Forage Preserving, approached by Dr. Tosi, in the 1º Symposium about Pasture Management, in 1973, in the city of Piracicaba, São Paulo. Farias et al. (1971) evaluated silages of perennial soybean (*Neonotonia wightii*), centrosema (*Centrosema pubescens*, Benth) and *Macroptilium atropurpureum* cv. Siratro and concluded that the silages of the three legumes were low quality, based on the high pH value and in the low lactic acid content. In the 80s or 90s the main goal of the studies was to increase the protein content of corn silages by consorting this grass with legumes of annual cycle, cultivated under different cultural arrangement (Evangelista et al., 1983; Obeid et al., 1985, 1992a,b). Actually, the consorted silages resulted in higher food intake and weight gain of animals compared to exclusive corn silage, due to higher protein content in corn x soybean consorted silages (Zago et al., 1985; Obeid et al., 1992b).

However, the corn x legume consort presents some limitations, highlighting the competition for light among species, the difficulty of these species to present the adequate growth stage to cut at the same time, besides the limits for fertilizations and weed control, since these ones have anatomic and physiologic differences, and also in the type and quality of fertilizer necessary for its adequate nutrition.

Knowing this, the exclusive legume planting, especially soybean, has been an interesting option by presenting high dry matter production per area, besides a higher facility in cultural practices and in harvest. In fact, more recently, it has been seen a growing interest in soybean cultivation for silage production in many countries, such as United States (Griffin, 2000; Blount et al. 2003; Seiter et al., 2004), Canada (Johnston & Bowman, 2000, Bello-Pérez et al., 2008), United Kigdom (Koivisto et al., 2003), Costa Rica (Tobia & Villalobos, 2004), Argentina (Castro & Andreo, 2008) and Brazil (Keplin, 2004; Melo Filho et al., 2005; Pereira et al. 2007 a,b; Rigueira, 2008). The interest for the soybean cultivation as forage is partly due to an improvement of ensiling process technology as well as the appearance of new varieties, with distinct length cycles, developed especially for forage. Nevertheless, the available information about silage production and use of this legume in ruminant feed are still scarce.

The new varieties are the results of old varieties crossing developed for haymaking with modern varieties developed for grain production, resistant to diseases such as root rot, caused by *Phytophtora*. From these crossings, some characteristics like plant height, shoot formations, lodging resistance, pods number, canopy, were selected, producing lineage of almost two meters high (Devine & Hattley, 1998; Devine et al., 1998 a,b). Pioneer work in soybean improvement for forage in Brazil was made by Melo Filho (2006), who evaluated 20 soybean variety, two lineage and 11 F2 segregate population originated from varieties crossing with the referred lineage, aiming to select progenitors and segregate lineage, for the use in improvement programs directed to silage production. In Brazil, technologies were developed which make the soybean cultivation possible all over the national territory, appearing new varieties and cultivars adapted to different soil, temperature and humidity conditions.

3. Fermentative pattern in legume silages

The ensiling process principle consists in producing enough lactic acid quantity to inhibit the growth of undesirable microorganisms, maximizing the forage nutrients preservation. During the stages of ensiling process there are biochemical changes of the carbohydrate and nitrogen compounds of fresh forage, under the enzymatic activities of the plant and microorganisms. The soluble carbohydrates are converted in organic acids and gases, while part of the protein is degraded to non-protein components. The magnitude of these changes can affect the food intake potential of nutritive attributes in the ensiled material (Van Soest, 1994).

Although they present high nutritive value, in general, legumes have undesirable characteristics for the proper fermentation process such as high moisture content at the harvest moment, high buffering capacity, low soluble carbohydrates contents and tabulate and hollow stem, which prevent the complete air removal at the ensiling moment (McAllister et al., 1998). Besides that, because of higher crude protein (CP) of legumes compared to the grass, it normally presents high proteolysis extension in the ensiling process.

Between 7 and 87% of nitrogen compounds of legume silages is converted in non-protein nitrogen (NPN) in the silo (Papadopoulos & McKersie, 1983; Muck, 1987). The high proteolysis extension is presented as a potential depression factor of dry matter ingestion, efficiency of nitrogen compounds utilization and animal productive performance. Among the factors which affect the proteolysis extension, it is emphasized:

a) Specie: Remarkable differences are observed in the ensiled mass proteolysis among legume species. The proteolysis is high in alfalfa silages, intermediate in red clover silages (*Trifolium pratense* L.) and trefoil (*Lotus corniccuneata* L.) and low in *Onobrychis viciifolia* Scop. (Albrecht & Beauchemin, 2003). Between 44 to 87 % of CP in alfalfa silage was degraded in NPN in the silo, while the value for red clover silage varied from 7 to 40% (Papadopoulos and McKersie, 1983; Muck, 1987). The lowest value for clover silage was due to the action of polyphenol oxidase enzyme which converts o-diphenol, present in high concentration in clover, into reactive o-quinones (Jones et al., 1995). These compounds react rapidly with proteases and protein substrates, reducing the proteolysis extension in the ensiled mass (Hatfield & Muck, 1999).

The low proteolysis extension in the silo in legumes such as trefoil and *Onobrychis viciifolia* Scop is due to higher tannin content (Albrecht & Beauchemin, 2003). Tannins are secondary metabolic compounds of plants, composed by hydroxylated phenyl rings which might have esterification with simple sugar (hydrolysable tannins) or polymerization through carbon-carbon bounds (condensed tannins). These polyphenolic molecules have the capacity of making complexes with many nutritionally important substances, pointing out among them the proteins. Besides acting directly, making the nutrients not available, they can complex the enzyme, reducing or inhibiting its catalytic power, or bind to glycoproteins present in bacteria cellular envelop, making the nutrient transport for the interior of the cells difficult and, consequently, decreasing the microbial growth (Mcsweeney et al., 2001). This way, the protease action is reduced both in the silo and rumen.

b) Dry matter content (DM) of ensiled mass: Legumes in less advanced maturity stages, although having higher potential nutritive value, present higher proteolysis extension due to lower dry matter content. Merchen & Satter (1983) evaluated the composition of fresh alfalfa (20.8% DM) and dehydrate alfalfa containing 29, 40 or 66% DM, before and after the ensiling, and the effect on the digestion local, in dairy cows with mean milk production of 23.7 kg d^{-1}, fed with diets containing 65% alfalfa. A little effect was observed in the total nitrogen compounds content, but its composition was affected by DM content. After ensiling, the soluble N fraction increased 77% (407 to 721 g kg^{-1} of N), 64% (390 to 641 g kg^{-1} of N) and 13% (373 to 423 g kg^{-1} of N) in alfalfa with 29, 40 and 66% DM. Due to a reduction in the proteolysis and deamination in the silo with the increase of DM content, the non degradable protein intake in the rumen and the duodenal flow of non ammoniacal N were higher using alfalfa with 66% DM (357 and 920 g kg^{-1} of total ingested N) regarding to alfalfa with 29% DM (148 and 688 g kg^{-1} of total N ingested) and 40% DM (148 and 726 g kg^{-1} of total N ingested). However, the higher temperature in the ensiled mass with 66% DM, originated from the plant respiration, resulted in higher increase in ADIN (acid detergent insoluble nitrogen) fraction after ensiling, which implicated in lower total protein digestibility of alfalfa diet containing 66% DM (676 g kg^{-1}), compared to the alfalfa diets containing 29% DM (723 g kg^{-1}) and 40% DM (724 g kg^{-1}). There was no effect on the total digestibility of fiber in neutral detergent.

Tabacco et al. (2006) estimated reduction of 12.29 percentage units of NPN fraction (% of total N) for each increase of 10 percentage units in dry matter content in alfalfa silages without additive submitted to wilting. (Figure 1).

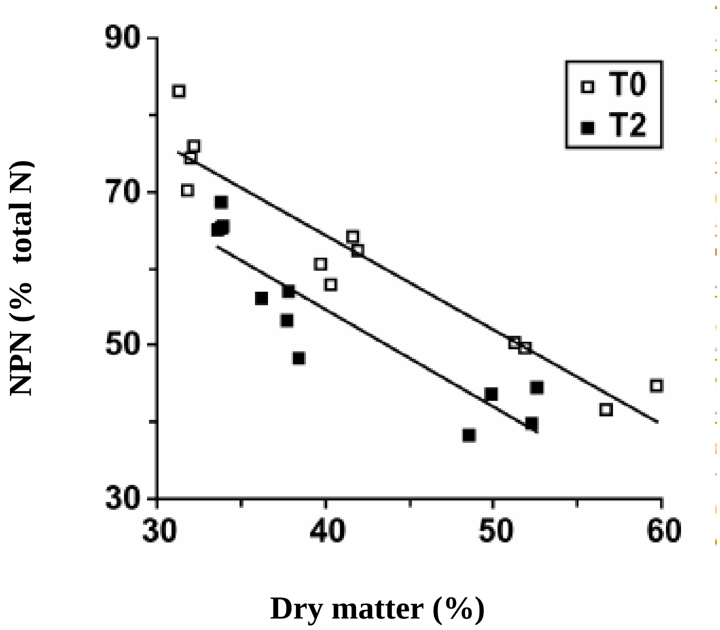

Figure 1 – Non-protein nitrogen content (NPN) of alfalfa silages without (T0) and with addition of 4% (dry matter basis) commercial hydrolysate tannin (T2), according to the dry matter (DM) of ensiled mass submitted to wilting. NPN-T0 (% total N) = 113 −1.229MS (r^2 = 0.90; MSEP = 4.1). NPN-T2 (% total N) = 105 – 1.269MS (r^2 = 0.81; MSEP = 4.8). PMSE = prediction mean square error.
Source: Tabacco et al. (2006).

c) Additive use: Some additives which inhibit protease activity of plant or bacteria have been effective in preserving protein fractions in legume silages with higher proteolysis potential, which can be highlighted the formic acid, formaldehyde, ammonium tetraformate (ATF) and commercial tannin (Nagel & Broderck, 1992; Tabacco et al., 2006; Broderick et al., 2007).

Nagel & Broderick (1992) observed that treatments with 2.8 g of formic acid/100g of DM or 0.31 g of formaldehyde/100g DM of alfalfa with 37% DM, decreased 32.5% and 17.6% the NPN fraction, regarding the alfalfa silage without additive (NPN of 430 g kg^{-1} from total N). According to the authors, the lower formaldehyde effectiveness to inhibit the proteolysis is because of lower application rate or the inability of it to reduce the forage pH quickly. However, because of the high cost and corrosive power of formic acid, other additives have been preferred.

The ATF is a buffer containing 1 mol of ammonia and 4 moles of formate. This compound is less corrosive and easier to handle than formic acid and presents potential to reduce proteolysis in legume silages. Broderick et al. (2007) verified that the addition of 7 liters of ATF/ton of alfalfa silage (fresh basis) reduced in 9.2% the NPN fraction (453 vs. 499 g kg^{-1} of total N) and in 23.4% the N fraction of free amino acids (301 vs. 393 g kg^{-1} of total N), compared to alfalfa silage without treatment. Besides, when supplying isonitrogen diets (180 g kg^{-1} DM) and isoenergetic (1.58 Mcal of liquid energy for lactation kg^{-1} of DM) for Holstein cows containing 40% of alfalfa silage (DM basis) without or with ATF addition, the authors verified that the ATF addition increased the dry matter intake in 4.2%, milk production in 8.6%, 3.5% fat-corrected milk production in 6.9%, milk protein production in 11.1% and non fat solids production in 10.0%, without affecting the urinary N excretion, indicating the efficiency increase in the N usage.

The commercial tannin use in low levels (lower than 5%, DM basis) has been adopted as silages additives because of its potential effect of proteolysis reduction during the ensiling process (Tabacco et al., 2006). The available commercial tannins can be divided in two main groups: condensed and hydrolisate, with several industrial usages. The tannin extracted from chestnuts (*Castanea sativa* L.) is the most hydrolyzed tannin, while quebracho and acacia tree extracts are the main commercial condensed tannins.

Tabacco et al. (2006), when evaluating the addition effects of four levels (0; 2; 4 and 6%, DM basis) of commercial hydrolyzed tannin (with 92% DM and 77% pure tannin, DM basis) originated from chestnut, in the fermentation quality in laboratory silos and ruminal degradation, concluded that the 4% tannin level (DM basis) was the most effective in reducing the proteolysis in the silo (13.9% reduction) and the ruminal protein degradation rate, without affecting the intestinal digestibility of rumen undegradable protein, indicating a possibility to increase the efficiency of using dietetic protein.

3.1.Ensiling and fermentative pattern in soybean silage

The soybean, besides restrictive characteristics to the fermentative process inherent to legumes, already pointed out, present high ether extract content which can inhibit the bacteria in the ensiled mass, affecting the fermentation process, resulting in silages with high pH. It is added to this a low autochthon population of bacteria which produce lactic acid (Pereira et al., 2007b).

According to Undersander et al. (2007), the soybean harvest for ensiling can be made from stage R_3 (start of pod formation) to R_7 (start of maturity). However, Muñoz et al. (1983) recommend the R_6 stage (full seed) as the most appropriate for the soybean harvest, due to nutritive aspects (high protein value and high dry matter digestibility) associated to the high dry matter production. Besides it provides higher silage acceptability by the animal regarding the ones harvested in a younger stage (Coffey et al., 1995a). Nevertheless, even in this development stage, the soluble carbohydrates content required for an adequate fermentation is low (Blount et al., 2003). This way, addition of a sugar source readily fermentable (molasses e.g) and/or, microbial additive use, can help for an adequate fermentation, when soybean is ensiled alone (Pereira et al., 2007 a, b; Pereira et al., 2008).

Opposing other forages, the nutrient contents and the forage quality of whole soybean plants do not change drastically with the maturity advance because the seed is rich in protein and energy (Willms, 2003).

Coffey et al. (1995b) evaluated the nutrient composition of soybean silage, obtained from the average of two varieties of maturation group IV and V, for two years, at the R_2, R_4 and R_6 growth stages, and found values varying from 16.0 to 20.6%; 38.3 to 48.3% and 27.3 to 37.3% for crude protein, neutral detergent fiber and acid detergent fiber, respectively.

Decrease in the pH and increase in the acid lactic/acetic acid ratio with the advance of growth stage were observed by Muck et al. (1996), cited by Panciera et al. (2003), for a grain cultivar and two forage lineage, according to Table 1. The authors also report that the fermentative characteristics of the soybean silages resemble to the ones from alfalfa silage.

Table 1 – Characteristics of soybean silage thirty days after ensiling[1]

Types	Harvest stage	DM (%)	pH	Lactic acid (%)	Acetic acid (%)
PA (Forage)	R_1	32.1	5.60	2.87	3.45
OR (Forage)	R_1	35.9	5.17	5.16	3.12
FS (Grain)	R_2	37.8	5.88	2.40	3.13
PA (Forage)	$R_{2.7}$	31.1	5.29	4.37	3.42
OR (Forage)	$R_{3.3}$	31.6	5.16	5.02	3.14
FS (Grain)	$R_{5.7}$	32.7	5.22	4.85	2.56
PA (Forage)	R_3	30.3	4.93	6.21	2.99
OR (Forage)	R_4	34.3	4.86	5.97	2.56
FS (Grain)	R_6	38.6	4.96	3.00	1.21

[1] Muck et al. (1996) cited by Panciera et al. (2003)

Pereira et al. (2007a) evaluated gases and effluent losses, dry matter recovery and fermentative profile in soybean silages (SS) submitted to the following treatments: exclusive SS, SS with inoculants (SSI), SSI with 2.5 % powder molasses (SSIM) and SS with 25% powder molasses (SSM), using 20 liter buckets. The authors registered lower value (P< 0.05) of pH in silage treated with inoculants and molasses (Table 2), probably by soluble sugar supply which stimulates lactic fermentation, associated with inoculants presence, suggesting that there was higher growth of lactic acid bacteria. In fact, when evaluating microbial population of soybean silage in different fermentation periods, submitted to the same treatments above (non published data) it was observed population with higher number of lactic acid bacteria on the day-7 (8.94 log CFU/g) and day-14 (62 log CFU/g) of fermentation, for the SSIM and SSM silages, respectively, while in SS and SSI silages the maximum population of these microorganisms was only registered on the day-28 of fermentation.

Table 2- Mean values of pH, effluent (EL) and gases losses (GL), dry matter recovery (DMR), ammonia nitrogen:total nitrogen ratio (N-NH_3), and lactic acid (LA), acetic acid (AA) and butyric (AB) content of soybean silage (SS) treated with different additives.

Item	Silages				VC (%)
	SS	SSI	SSIM	SSM	
pH	4.69^{a}	4.66^{a}	4.43^{c}	4.55^{b}	1.19
N-NH_3 (% DM)	21.64^{a}	15.75^{b}	12.38^{c}	12.58^{c}	8.51
LA (% DM)	4.69	4.79	5.12	6.51	18.9
AA (% DM)	3.70^{a}	3.30^{a}	2.32^{b}	2.84^{ab}	15.15
AB (% DM)	0.1768	0.2666	0.0287	0.0703	90.43
GL (% DM)	12.97^{a}	10.16^{b}	9.05^{b}	9.56^{b}	12.8
Effluent (kg/t OM)	18.5^{ab}	19.29^{a}	14.73^{bc}	11.31^{c}	13.1
DMR (%)	86.2^{b}	88.8^{ab}	9.6^{a}	91.9^{a}	2.39

Exclusive SS, SS with inoculant (SSI), SSI with 2.5% molasses (SSIM) and SS with 2.5% molasses (SSM).
Means in the same row followed by different letters differ ($P < 0.05$) by Tukey test

It is recognized that the soybean and other legumes silages stabilize in higher pH, as mentioned before. Melo Filho (2006) evaluated the direct and indirect effects of DM, carbohydrate soluble in water, CP and N-NH_3, inherent to soybean plants silage, on the pH of the referred silage. The factor which has most influenced the pH variation was the N-NH_3 concentration (% of total N), presenting positive and significant correlation (0.730) and positive direct effect (0.652); higher therefore than the residual effect (Table 3). Indeed, silages that present high values of N-NH_3, usually, present high pH, indicating low quality fermentation of the ensiled material.

Table 3- Direct (underline) and indirect effects of inherent parameters of whole plants soybean silage on its pH*

	Correlation effect*						Total effect
Parameters**	DM	WSC	CP	N-NH_3	ADF	EE	gc
DM	0.175	0.109	-0.033	0.009	-0.184	-0.003	0.073
WSC	-0.07	-0.273	0026	-0.239	0.028	-0.058	-0.586^{+}
CP	0.042	0.051	-0.136	-0.023	-0.103	0.027	-0.142
N-NH_3	0.002	0.1	0.005	0.652	-0.023	-0.006	0.730^{+}
ADF	-0.089	-0.021	0.039	-0.042	0.364	-0.05	0.200
EE	-0.003	0.086	-0.02	-0.02	-0.099	0.183	0.127

* R^2= 0.76, $P\varepsilon$= 0.49; ** DM, WSC, CP, N-NH3, ADF, EE, = contents of dry matter, water soluble carbohydrates, crude protein, ammonia nitrogen, acid detergent fiber and ether extract, respectively; gc = genotype correlation; +,Significant at 5%, through the bootstrap method, with 1000 simulations.
Source: Mello Filho (2006)

An interesting fact is related to the good aerobic stability of legume silages. Griffin (2001), evaluating research data from LEGSIL project (legume silage), conducted in the period of 1997-2001, in four countries of the European Community, relates that from 264 legume silages evaluated, none have presented heating or fungal deterioration when exposed to air for four days, and that 90% of silages were stable for seven days. The mixture of legumes and grass (50:50) also produced silages with high aerobic stability, while 90% of exclusively grass silages deteriorated in four days. The author also points that these results regarding preservation and aerobic stability were confirmed in field experiments, using both big bales and bunker silo.

4. Optimization of legume silage based diets for cattle

4.1 Nutrition characteristics of legume silages

Legume forages normally present high nutritive value for ruminants due to high protein content, lower neutral detergent fiber content (NDF), higher ruminal degradation rate of potentially digestible NDF and higher physical fragility of NDF particles when compared to the grass ones, which promotes higher animal dry matter intake, in spite of the lower digestion extension of NDF (Allen, 1996; Oba & Allen, 1999). However, the high proteolysis extension during the ensiling process, associated to the low starch content in legume silages challenges the nutritionists to minimize potential losses of nitrogen compounds in legume silages based diets for ruminants.

Several nutrition strategies have been researched aiming to maximize the efficiency of nitrogen utilization in legume silage based diets, mainly alfalfa silages, such as the combination of legume silages with higher starch content silages (corn silage) (Dhiman & Satter 1997; Brito & Broderick, 2007), use of legume silages with lower proteolysis potential (Hoffman et al., 1997; Broderick et al., 2007), and the use of additives that inhibit proteolysis at the ensiling moment (Messmann et al., 1997; Nagel & Broderck, 1992; Broderick et al., 2007).

4.1.2 Alfalfa silages vs. corn silages

In Table 4 it is presented a research results compilation about substitution of corn silage (CS) for alfalfa silage (AS) in diets for lactating dairy cows. Comparing AS with CS as unique source of forage for lactating dairy cows, receiving diets with 60% AS, 60% CS or 79% CS, Broderick (1985) concluded that AS is comparable to CS for the milk production of approximately 25 kg day^{-1}, without affecting the dry matter intake, diet compounds digestibility and milk composition.

Dhimman & Satter (1997) evaluated the effect of different corn and alfalfa silage proportions (67:33; 33:67; 0:100) in diet (with 50% concentrate) in the productive performance and the efficiency of nitrogen compound utilization, in a complete lactation trial with 45 multiparous and 29 primiparous Holstein cows. The authors have not verified the effect on dry matter intake, milk production and composition. However, the ruminal ammonia concentration was lower and the N excretion on the environment was reduced between 6 and 15% with diets containing CS (33 and 67% of forage), which allowed the observation of an increase tendency between 6.8 and 13.6% in the efficiency of N utilization for milk production (N milk/N ingested). The authors concluded that CS can constitute one or two thirds of forage in diets containing AS for nutritional benefit maximization.

Brito & Broderick (2007), using 28 multiparous lactating Holstein cows, in a latin square design, investigated the effect of different proportions of AS:CS (100:0; 21:79; 47:53; 75:26) in diets containing 51% of concentrate and 16.7% of crude protein (mean), on milk production, efficiency of N utilization, digestibility and ruminal metabolism. The diet containing the highest CS proportion provided the lowest dry matter intake, neutral detergent fiber digestibility, ammonia concentration, ruminal acetate, milk production, 3.5% fat-corrected milk production, milk fat content and production. The effect in fiber digestion occurred, according to the authors, because of the increase in ruminal pH fluctuation and the time that ruminal pH was kept below 6 in the diet with higher CS level. The milk protein content and the efficiency of N utilization for milk production were higher in the diets containing higher CS proportions, but the milk protein production was not affected. The authors concluded that the best AS:CS proportion is 47:53, because it allows an increase in the efficiency of N utilization and support milk production.

Table 4 – Summary of research results on substitution of corn silage (CS) to alfalfa silage (AS) in lactating dairy cow's diet.

Author	CS:AS	FL (% DM)	DMI (kg/d)	MP (kg/d)	F (%)	P (%)	PUN (mg/dL)	NE (%)	N urine (g/dia)
Broderick	100:0	60	20.7	26.1 [a]	3.50	3.18			
(1985)	0:100	79	20.8	26.3 [a]	3.72	3.16			
	100:0	60	20.,0	23.9 [b]	3.74	3.21			
Dhiman &	67:33		21.1	31.4	3.65	3.19		33.5	
Satter	33:67	50	21,4	32.4	3.67	3.15		31.5	
(1997)	0:100		20.9	31.1	3.53	3.08		29.5	
Brito &	0:100		26.8 [a]	41.5 [a]			13.8	26.5[d]	217[a]
Broderick	21:79	51	26.5 [a]	42.0 [a]			13.9	28.5 [c]	215[a]
(2007)	53:47		25.4 [b]	41.5 [a]			14.1	30.0 [b]	201[b]
	75:26		23.7 [c]	39.5 [b]			14.4	31.7 [a]	188 [b]

Means followed by different letters in the same column and in the same trial are different ($P<0.05$)
FL= diet forage level; DMI= dry matter intake; MP= milk production; F= milk fat; P= milk protein; PUN = plasma urea-N; N= nitrogen compounds; NE= N efficiency (milk N secreted /N ingested); N urine= urine N excreted

4.1.3 Alfalfa silages vs. legume silages with lower proteolysis potential

Due to lower protein degradation extension in the silo for clover silages in relation to alfalfa silage, some researchers speculated that the substitution of alfalfa silage for clover silage (white or red) could increase the efficiency of N utilization and the productive performance in ruminants (Hoffman et al., 1997; Broderick et al., 2007).

Broderick et al. (2007) compared the productive performance and the utilization efficiency of the compounds (containing 50.3% forage, DM basis) in isonitrogen and isoenergetic diets (17.5% CP; 27.5% NDF; and 1.57 Mcal of ELp/kg DM), in Holstein cows with an mean initial milk production of 36 kg day^{-1} and 192 lactation days, containing alfalfa silage (41% DM; pH 4.94; 24.6 % CP containing 49% NPN; and 39.4% NDF) or red clover silage in initial stage (41.8% DM; pH 4.95; 23.3% CP containing 29.4% NPN; and 40.0% NDF) or at the end of maturity (43.4% DM; pH 4.86; 18.1% CP containing 27.1% NPN; and 41.4% NDF). The most advanced maturation stage of clover reduced diet DM, OM, CP and NDF digestibilities but did not affect dry matter intake, milk composition and production, intestine flow of rumen microbial protein and the efficiency of N utilization (N in milk/N ingested or milk production/N excreted in urine). The DM intake, the milk production and compound (fat, protein, lactose and total solids) were higher for diets containing alfalfa silages in relation to clover silages. The urea-N concentrations in plasma and milk, rumen ammonia and urinary excretion N were reduced with clover silages, suggesting better efficiency in N utilization, due to a lower NPN fraction. According to authors, the efficiency of apparent N utilization (N milk/N ingested) tended to be higher for cows fed corn silage, but there was no difference when the efficiency was expressed as kg of milk/kg of excreted N.

4.1.4 Soybean silage

The nutritive value of soybean plant can be comparable to the alfalfa one in the start of flowering. Lactation cows and growing calves have similar performance when fed soybean hay or alfalfa (Garcia, 2002).

An interesting fact is regarded to the high ether extract content in soybean, approximately 10% (Muñoz et al., 1983, Griffin et al., 2000), once this nutrient inclusion, in levels higher than 6% in diets, can reduce the fiber digestion (Van Soest, 1994), by preventing the microorganisms adherence to feed particles (Devendra & Lewis, 1974) or by the toxic effect on cellulolytic organisms (Henderson, 1973). Besides, fat surplus in the diet can also reduce dry matter ingestion and passage rate (NRC, 2001). This way, soybean silage should not be offered only and exclusively in ruminant diets, once it compromises the assimilatory phenomenon. To avoid negative impacts of high ether extract content in diets, soybean as forage should not exceed 50% of the total dry matter (Wiederholt & Albrecht, 2002). Varner (1999) recommends that soybean silage should not exceed 30 or 40% of diets dry matter for dairy cows.

However, the information regarding to production and feeding with soybean silage are scarce. So that, in the text “A guide book for soybean silage production” (Undersander et al., 2007), the recommendations for silage production of this legume are based in farmer experiences who gave interviews about the silage production in the autumn 2005, in Wisconsin, United States. In these farms, the soybean silage constituted 15 to 20% of animal diets. It is observed, in Table 5, from the inspected farms, in only one there was an intake decrease. This way, although the soybean silage presents lower acceptability when compared to alfalfa or corn silage, it can be used in significant portion of diet, without influencing animal intake.

Table 5 – Soybean silage effects on milk production and food intake in eight farms of Wisconsin State, United States[1]

Number of inspected farms	Animal type	Food intake	Effects on milk production
6	Lactating cows	unchanged	None
1	Lactating cows	decreased	None
4	Dry cows and heifers	unchanged	Not aplly

[1] Undersander et al., 2007

Recently, Bello-Pérez et al. (2008) evaluated the nutritive value of soybean silage in relation to alfalfa silage, in diets for lactating dairy cows. Two isonitrogen diets (18.6 and 19% CP) and the same ether extract content (4.6 and 4.7%) were used, with forage:concentrate ratio of 48:52, being 72% from forage fraction constituted of soybean or alfalfa silages and, the other 28% from corn silages. The soybean silage resulted in lower ($P<0.05$) dry matter intake and milk production, in relation to alfalfa silage (Table 6), probably due to its lower ruminal NDF degradability (Table 7). Nevertheless, despite these negative effects of soybean silage, the 4% of fat-corrected milk production, milk composition (except fat content, higher for soybean silage), milk production efficiency and nutrients total digestibility were similar to both silages.

In Brazil, the first studies with soybean silage in animal feeding, soybean was consorted with corn, under different cultural arrangements, and its silage given to beef cattle as exclusive feed. It is observed on Table 8 that the mean weight gain of beef cattle fed these silages was 0.592 g day^{-1}. The greater weight gain in these animals compared to the ones fed only corn silage is due to the higher protein content of consortiated silages (Zago et al., 1985; Obeid et al., 1992b).

Table 6 - Performance and utilization efficiency of diet compounds in dairy cows fed soybean silage

Item	Diets		Significance level
	Soybean silage	Alfalfa silage	
Food intake (kg day^{-1})			
DM	23.5	25.1	0.033
CP	4.0	4.9	0.001
NDF	7.4	9.3	< 0.001
Production (kg day^{-1})			
Milk	35.5	37.2	0.002
Milk, 4% fat	34.3	34.8	0.31
Production efficiency	1.56	1.52	0.34
Milk composition (%)			
Fat	3.78	3.58	0.017
Protein	3.17	3.18	0.76
Lactose	4.69	4.69	0.89
Total solids	12.65	12.61	0.73
Digestibility (%)			
DM	71.1	70.9	0.88
OM	71.8	71.7	0.95
CP	70.6	69.5	0.74
NDF	57.8	53.5	0.27
Digestible energy, Mcal kg of DM^{-1}	3.11	3.01	0.17

[1]Adapted from Bello-Pérez et al. (2008)

Table 7 – *In situ* ruminal degradability of soybean and alfalfa silage nutrients

Item	Silages		Significance level
	Soybean	Alfalfa	
DM			
Soluble fraction, %	33.8	40.0	< 0.0001
Slowly degradable fraction, %	39.5	37.7	0.16
Degradability rate % h^{-1}	6.0	8.0	< 0.02
Latency time, h	0.62	0.54	0.69
Effective degradability, %	53.3	63.9	< 0.001
CP			
Soluble fraction, %	60.1	59.6	0.18
Slowly degradable fraction, %	30.4	31.2	0.73
Degradability rate % h^{-1}	6.5	9.4	0.034
Effective degradability, %	76.9	79.9	0.004
NDF			
Slowly degradable fraction, %	43.9	45.1	0.63
Degradability rate % h^{-1}	4.8	6.1	0.04
Latency time, h	1.0	0.8	0.85
Effective degradability, %	31.2	40.6	< 0.001

[1]Adapted from Bello-Pérez et al. (2008)

Table 8 – Dry matter intake (DMI), crude protein (CP) and weight gain of steers fed exclusive corn silage (CS) or in association with soybean silage (SS), sunnhemp (SuS) and velvet bean (VBS).

Treatments	Food intake (kg day^{-1})		Weight gain (kg day^{-1})	Author
	DM	CP		
CS[1]	10.6 c	0.662 b	0.265 b	Zago et al.(1985)
CS + SS[2]	14.1 a	0.979 a	0.596 a	
CS + SS[3]	13.1 ab	0.855 a	0.526 a	
CS + SS[4]	12.3 bc	0.873 a	0.566 a	
CS [1]	10.8 b	0.648 b	0.248 a	Obeid et al. (1992b)
CS + SS[5]	12.0 a	0.973 a	0.682 a	
CS + SuS[6]	12.8 a	1.152 a	0.698 1	
CS + VBS [7]	8.3 c	0.879 a	0.382 b	

[1] exclusive corn silage, [2] CS + SS (5:20 seeds m^{-1}), [3] CS + SS (5:30 seeds m^{-1}), [4] CS + SS (5:40 seeds m^{-1}), [5] CS + SS (6:20 seeds m^{-1}), [6] CS + SuS (6:10 seeds m^{-1}), [7] CS + VBS (6:6 seeds m^{-1}).

Rigueira (2008) evaluated the productive performance of 32 HxZ steers, with 355 kg initial weight fed diets containing soybean silage (SS), soybean silage with microbial inoculant (SSI), soybean silage with inoculant and molasses (SSIM) and soybean silage with molasses (SSM). The inoculant used was Sil All C4 (Alltech, Brazil). The powder molasses was used in 2.5% proportion as fed. The isonitrogen diets, presented 13% crude protein. The forage:concentrate ratio was 70:30 (DM basis), being 40% soybean silage and 30% corn silage. Four reference animals were slaughtered after the adaptation period for carcass gain estimative. The intake of all analyzed nutrients was lower ($P<0.05$), in the diet containing soybean silage without additives compared to the one with soybean silage with inoculant and molasses (Table 9). This is probably due to better fermentation of soybean silage treated with inoculant and molasses when comparing with the others, resulting then, in a higher acceptability, mainly, regarding the control silage, which presented strong acetic acid and ammonia odor, characteristics of undesirable fermentations, as well as higher pH and N-NH_3/total-N values.

Table 9 – Mean dry matter intake (DM), crude protein (CP), ether extract (EE), neutral detergent fiber (NDF), non-fiber carbohydrate (NFC) and total digestible nutrients (TDN) of diets and respective variation coefficient (VC%)[1]

Item	Silages				VC (%)
	SS	SSI	SSIM	SSM	
	Intake (kg/day)				
DM	7.60b	8.46ab	9.55a	9.05ab	12.29
CP	0.80b	1.05a	1.24a	1.14a	12.78
EE	0.42b	0.50ab	0.56a	0.56a	12.80
NDF	3.03b	3.36ab	3.86a	3.65ab	12.65
NFC	2.74b	3.09ab	3.33a	3.17ab	11.70
TDN	4.72b	5.29b	6.60a	5.57b	11.45
	Intake (% BW)				
DM	1.83b	2.00ab	2.16a	2.10ab	9.54
NDF	0.73b	0.79ab	0.87a	0.85ab	9.98

[1]Adapted from Rigueira (2008)

Although it has been observed differences (P<0.05) in nutrients intake, this has not reflected in animal performance, once the weight and carcass gain, carcass dressing and feed conversion were not influenced by diets (Table 10). The author emphasizes that daily weight gain, which varied from 1.32 (exclusive soybean silage) to 1.68 kg day^{-1} (soybean silage with inoculant and molasses), can be considered high for the animal type applied. It is important to highlight also that the pH and ruminal ammonia concentration were not influenced (P>0.05) by diets. This study shows that soybean silage can become an interesting alternative when associated to other forage, in complete diets.

Table 10 – Obtained means for daily live weight gain (DWG), carcass gain (CG), carcass dressing (CD) and feed conversion (FC) for the different experimental diets and respective variation coefficient (VC%)[1]

Item	Silages				VC (%)
	SS	SSI	SSIM	SSM	
DWG(kg)	1.32	1.45	1.68	1.50	17.83
CG (kg)	0.84	0.87	0.99	0.96	15.70
CD (%)	54.41	53.62	53.59	54.69	2.54
FC	5.86	5.99	5.71	6.03	10.18

[1] Adapted from Rigueira (2008)

5. Economic evaluation of soybean silages based diets

On Table 11 is the chemical composition and forage income of soybean silage compared to corn and sorghum silages, most used forages for cattle feed in Brazil. The total digestible nutrients value (TDN) was obtained by prediction equations described at NRC (2001), from feed chemical composition (sorghum and corn silages) described in Valadares Filho et al. (2006) and Magalhães (2007) (soybean silage). The soybean silage is presented as a competitive forage option facing the traditional corn and sorghum silages, mainly in situations with high protein demand diets because of lower cost of crude protein production (Table 12).

Table 11 – Chemical composition and forage yield of selected forages

Forages	Chemical composition			Forage yield ($t\ ha^{-1} year^{-1}$)			
	DM (%)	CP (%DM)	TDNp est[1] (% DM)	OM	DM	CP	TDN
Corn silage	30.9	7.26	64.87	40.0	12.4	0.90	8.04
Sorghum silage	30.8	6.69	61.02	45.0	13.9	0.93	8.48
Soybean silage[2]	31.0	20.18	68.00	24.6	7.63	1.54	5.19

Source: Adapted from Pereira et al. (2007). [1/] TDNp estimated from chemical composition using the predictive equations describe at NRC (2001), considering DMI = 2.5 times the maintenance. [2]/ Mean forage yield (ton DM ha^{-1}) obtained from 22 varieties and 2 lineages, in the R6 stage, in Viçosa-MG, according to Mello Filho (2006).

Table 12 – Production costs per area, per organic matter (OM) unit, dry matter (DM), crude protein (CP) and total digestible nutrients (TDN) from the selected forages.

Forages	Total production costs				
	R$/ha/ year	R$/ton OM	R$/ton DM	R$/ton CP	R$/ton TDN
Corn silage	2.870,00	71.75	232.21	3.198,48	357.96
Sorghum silage	2.907,00	64.60	209.75	3.135,28	343.74
Soybean silage	2.511,17	10.08	329.32	1.631,91	484.29

Source: Adapted from Pereira et al. (2007c). Prices in July, 2008.

The economic analysis of soybean silage diets for feedlot beef cattle was performed, using data from the study of Souza et al. (2008). The authors evaluated the dry matter intake and the performance of 30 steers, weighing around 372.3 kg, during 84 days, receiving five diets with different substitution levels of corn silage to soybean silage (0, 25, 50, 75 e 100%, DM basis), both with 40% concentrate, DM basis. The DM intake, weight gain, carcass gain, carcass dressing and feed conversion were not influenced (P>0.05) by treatment (Table 13).

It is observed that the diet cost by carcass gain (R$ per each 15 kg) reduced as the corn silage was substituted by soybean silage, reaching the lowest value in the 75% level of substitution. However, total substitution was not beneficial because of the crude protein surplus in the diet when using soybean silage as an exclusive forage source.

Thus, due to the competitive production cost of soybean silage crude protein (R$ 1,631.91/ton of CP) compared to soybean meal (R$ 2.193,32/ton of CP), currently it is seek the potential use of it in partial substitution (between 50 to 75%) to corn silage.

Table 13 – Diet ingredients, animal performance and feed costs for finishing beef cattle fed diets with different substitution levels of corn silage to soybean silage (DM basis)

Items	Substitution levels (%) of corn silage to soybean silage					Costs R$/ t DM[2]
	0	25	50	75	100	
Diet[1]						
Soybean silage		15.00	30.00	45.00	60.00	329.32
Corn silage	60.00	45.00	30.00	15.00		232.21
Finely ground corn	27.68	32.71	37.74	39.60	39.70	526.99
Soybean meal	11.13	6.14	1.14	0.00	0.00	1096.66
Urea/ammonia sulfate (9:1)	0.60	0.60	0.60	0.00	0.00	1,249.50
Mineral premix	0.59	0.55	0.52	0.40	0.30	1,365.00
Total	100.00	100.00	100.00	100.00	100.00	
Diet CP (% DM)	13.57	13.57	13.57	13.57	15.53	
Diet EE (% DM)	2.89	3.94	4.98	5.95	6.87	
Animal performance[1]						
DM intake, kg/d	8.96	8.92	8.95	8.75	8.67	
DM intake, % BW/d	2.17	2.12	2.02	2.07	2.09	
Daily weight gain, kg/an/d	1.17	1.10	1.21	1.14	1.21	
Daily carcass gain, kg/an/d	0.678	0.698	0.690	0.688	0.665	
Feed conversion ratio	7.77	8.13	7.45	7.65	7.30	
Feed costs (diet)						
Fed diet, R$/t DM	422.80	408.61	394.44	397.17	410.90	
Animal - R$/an/d	3.79	3.64	3.53	3.48	3.56	
R$/@ of body weight	97.14	99.40	87.53	91.45	88.33	
R$/@ of carcass	83.81	78.33	76.74	75.77	80.36	

[1]Data obtained from Souza et al. (2008). *P* value (>0.05) from F test.
[2]Prices in July, 2009.

However, it is important to point out that the present economic evaluation was made considering soybean meal price of R$ 1,096.66/ton DM, which represents 3.33 times the cost of the soybean silage DM ton. As the bioeconomic value of diets depends on the used feed prices, in Figure 2 the feed costs per 15 kg produced of the five diets are presented with five different DM prices ratio of soybean meal DM:soybean silage DM.

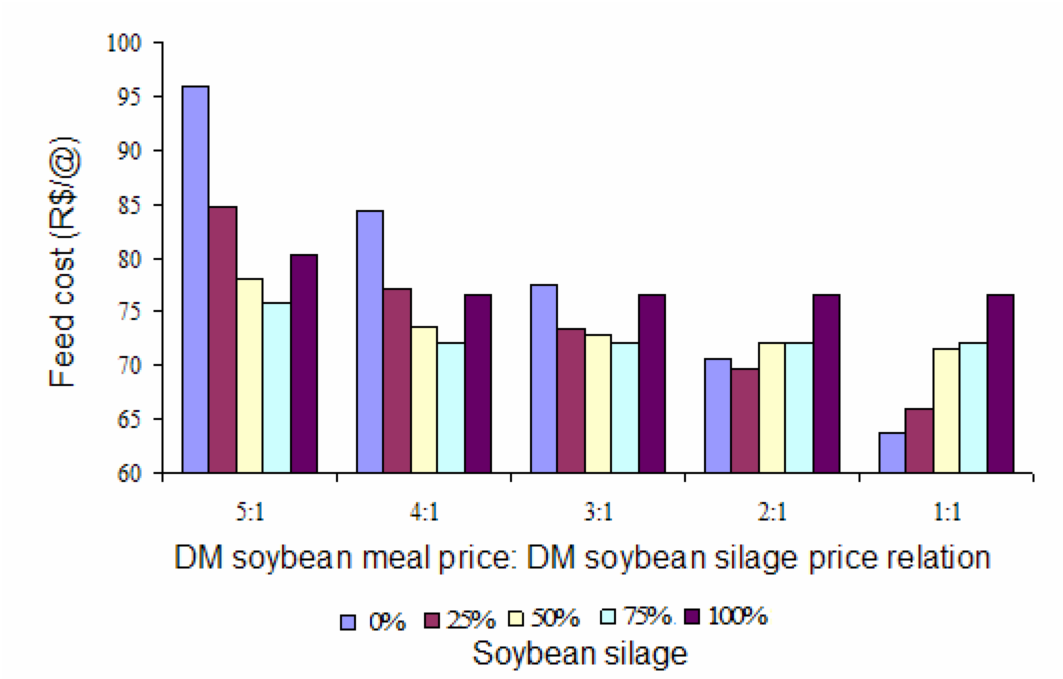

Figure 2 - Diet costs (R$/@ carcass gain) with different levels of corn silage substitution to soybean silage (0, 25, 50, 75 e 100%), according to different DM soybean meal price: DM soybean silage price ratio (@ = 15 kg).

It can be seen that as the price of soybean meal DM is reduced compared to soybean silage DM, the optimum level of corn silage substitution by soybean silage is affected. In price range of soybean meal DM between 5 and 3 times the price of soybean silage DM, the 75%level of substitution presented the lowest cost per 15 kg of carcass. When the price ratio reduced to 2:1, 25% was the optimum substitution level. Nevertheless, with 1:1 price ratio, the substitution of corn silage to soybean silage increased the cost per 15 kg of carcass, in all levels, not making the use of soybean silage economically possible.

6. Final Remarks

The harvest in adequate growth stage associated to the use of additive are strategies that enables producers to obtain good quality legume silage.

Legume silage should not be the only source of forage in ruminant diets, once it can limit the intake and, consequently, the animal performance. This way, the best strategy for legume silage use in ruminant feed is it association with other forage feed such as corn silage, to promote diet bioeconomic optimization.

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