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Incorporating leucaena into goat production systems

Integrando leucaena en sistemas de producción de caprinos

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Abstract

The integration of leucaena into goat production systems in the tropics and subtropics is reviewed. Goats are well adapted to leucaena, and able to be productive on diets containing up to 100% leucaena as a result of bacterial and hepatic detoxification. Incorporation of leucaena into goat production systems can improve liveweight gains, milk production, worm control and reproduction. Successful feeding systems for goats can be based on both grazed silvopastoral systems and cut-and-carry intensive systems, although there is a lack of farming systems research examining the integration of leucaena into goat production systems, or documentation of the practicalities of these practices.

Keywords: *Caprus aegagrus hircus*, cut-and-carry, grazing, silvopastoral systems, tree legumes.

Resumen

La integración de leucaena en los sistemas de producción de caprinos en el trópico y subtrópico es revisado en este trabajo. Los caprinos están bien adaptados al consumo de leucaena y son capaces de ser productivos en dietas que contienen hasta un 100% de leucaena como resultado de la detoxificación bacteriana y hepática. La incorporación de leucaena en los sistemas de producción caprina tiene el potencial de mejorar las ganancias de peso vivo, la producción de leche, el control de parásitos internos y la reproducción. Sistemas de alimentación exitosos para caprinos pueden basarse tanto en pastoreo en sistemas silvopastoriles como en sistemas intensivos de corte y acarreo. Sin embargo, hay una escasa investigación sobre sistemas agropecuarios que examinen la integración de leucaena en los sistemas de producción caprina, y de documentación de aspectos prácticos de esta integración.

Palabras clave: *Caprus aegagrus hircus*, corte y acarreo, leguminosas arbóreas, pastoreo, sistemas silvopastoriles.

Introduction

Goat production systems in tropical and subtropical regions of Southeast Asia, Africa and South America are often characterized by a high seasonal variability of forage biomass availability and low protein concentration in herbaceous pasture species, preventing goats from meeting maintenance and production requirements (Mtenga and Shoo 1990; Clavero and Razz 2003) and from expressing their genetic potential (Leketa 2011). The high protein concentration in *Leucaena leucocephala* (leucaena) makes it a valuable feed resource for ruminants in tropical and subtropical conditions to fill these gaps. The nutritional benefits of feeding leucaena to ruminants extend to goats, and have been well studied, as has the toxicology of leucaena's most significant secondary compound, mimosine, and its primary metabolites, the dihydroxypyridones (DHP). However, the practicalities of using leucaena in goat management systems have been poorly documented.

Goats have physical and behavioral characteristics which cause them to rely much more on the browsing of shrubs than other ruminants, and grazing leucaena would appear to be a natural fit for goat production systems. However, this production system brings with it the risk of ring-barking of trees. Therefore, in several countries, leucaena is integrated into goat production systems as a cut-and-carry fodder.

Leucaena is fed to goats across a large range of tropical and subtropical regions. An analysis of research articles published on the topic reveals that the majority of research

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on feeding leucaena to goats is published in Asia, Africa and South America, regions in which leucaena is commonly used as a feed resource for goats (Table 1).

Table 1. Countries in which research on goats and leucaena has been recently published. Derived from Scopus database 2013–2018.

Region/Country	No of publications
Asia	
India	10
Thailand	4
Vietnam	4
Malaysia	2
Japan	3
Philippines	2
Africa	
Nigeria	5
Mozambique	2
Cameroon	1
Cote d'Ivoire	1
Ethiopia	1
Gabon	1
South Africa	1
Tanzania	1
Uganda	1
Americas	
Venezuela	4
Mexico	2
United States	3
Pacific	
Samoa	3
Australia	2
Middle East	
Israel	1
Palestine	1
Europe	
Germany	2
Netherlands	2
Belgium	1
Sweden	1

Adaptation to leucaena toxicity

Some of the earliest research on leucaena toxicity was reported on goats fed leucaena. The first experiments indicating a role for rumen bacterial metabolism of mimosine and DHP were conducted in goats in Hawaii and Australia (Jones 1981; Jones and Megarrity 1983). *Synergistes jonesii* was first isolated from the rumen fluid of goats (Jones 1981; Allison et al. 1992) and subsequently formed the main focus of leucaena detoxification research. Surveys of the presence of *S. jonesii* in leucaena-fed goat populations in Southeast Asia indicates that it is not ubiquitously present at high levels in goats fed leucaena, ranging from 32% of sampled goats in Thailand to 67% in Vietnam and 95% in eastern Indonesia, despite the long history of feeding leucaena to goats and cattle in these locations (McSweeney et al. 2014). More recent developments in understanding of leucaena toxicity have shown that not only are there a wide range of bacterial genera able to detoxify mimosine and DHP in the rumen (Derakhshani et al. 2016) but also hepatic conjugation pathways play an important role in the detoxification of DHP (Halliday 2018). *Synergistes jonesii* has now been shown to be indigenous to all ruminants, whether or not previously exposed to leucaena, although often at very low levels, which are insufficient to completely detoxify all DHP, especially where intake levels of leucaena are high. DHP, which is not completely detoxified from 3,4-DHP to the less toxic 2,3-DHP by rumen bacteria, can be conjugated in the liver by the process of glucoronidation. It is concluded that by utilizing these 2 pathways of detoxification, goats are highly productive on sole diets of leucaena without the need for inoculation with *S. jonesii*; however adaptation to leucaena feeding is required in order to upregulate both pathways of detoxification (Halliday 2018). Unfortunately, most research concerned with feeding value and production responses of goats fed leucaena do not report on the animals' past history of leucaena consumption, inoculation status, current efficacy of detoxification, and in many cases, experimental diet adaptation protocols. All of these factors could interact with the intake and productivity of goats fed leucaena.

Feeding value of leucaena for goats

Leucaena can be fed to goats as an alternative source or cheaper substitute for conventional protein feed supplements (e.g. oilseed cake meals), which are often expensive or unavailable in more remote or extensive production systems (Clavero and Razz 2003; Leketa 2011). The presentation of leucaena and proportion of stem in the diet will significantly affect the results of leucaena-feeding experiments. Unfortunately, many experiments either feed stripped leaves only, which is unlikely to be representative of grazing or hand-feeding production systems, or do not specify the proportion of stem in the diet.

As part of a goat ration, leucaena provides both protein and roughage. Reports indicate a sole diet of leucaena fed to goats has digestibility coefficients for dry matter (DM) of 57–66% (form not specified), organic matter of 59–67%, crude protein (CP) of 62% (Mtenga and Shoo 1990) to 65% (Girdhar et al. 1991), and total digestible nutrient concentration of 59% (Girdhar et al. 1991). Chemical composition of leucaena is superior to that of other leguminous feeds, as leaf contains more CP (27.5%) and lower neutral detergent fiber (NDF, 24.4%) than lucerne (*Medicago sativa*), lablab (*Lablab purpureus*) and desmanthus (*Desmanthus bicornutus*) (20.3–21.5% CP and 23.6–36.9% NDF; Kanani et al. 2006). In vitro dry matter digestibility of leucaena (47%, including stem <2 mm diameter at a rate of 33% of feed on offer) was similar to that of pigeon pea (48%, including stem at a rate of 36% of feed on offer), but lower than that of the tree legume sesbania (62%, including stem at a rate of 43% of feed on offer), most likely as a result of sesbania's high acid detergent fiber (ADF) concentration (38%) (Karachi and Zengo 1997).

The high protein concentration and digestibility of leucaena increase the digestibility and CP concentration of the whole diet, which in many tropical goat production systems is likely to be quite low. Combining tropical, low-protein grass species or other forage resources with leucaena can increase DM intake. Including the leaves and soft stems of leucaena (stem proportion unspecified) in a basal diet of *Hymenachne pseudointerrupta* and concentrate (20% CP, 10.2 MJ ME/kg DM) resulted in partial substitution of the more digestible leucaena for the low-quality grass, increasing total DM intake (although without a recorded effect on digestibility of DM, organic matter or CP; Rahman et al. 2015). Mtenga and Shoo (1990) also reported that Tanzanian goats reduced their intake of *Chloris gayana* hay as amount of leucaena leaf on offer increased, but increased total intake on a liveweight basis. In that experiment, increasing leucaena on offer up to 100% of the diet had no effect on DM digestibility of the diet (Mtenga and Shoo 1990). However in some cases leucaena supplementation can increase DM intake without substitution. Supplementing a hay mixture of S*etaria palidefusca* and *Imperata cylindrica* with leucaena leaves resulted in only a low-level (non-significant) of substitution, but increased intakes of DM, CP and energy in goats (Tshibangu et al. 2015). When leaves and petioles of leucaena (29.6% CP) were fed to Barbari goats as a supplement to a rice straw diet, the resulting very high CP intake (6.8 g/kg $W^{0.75}$) caused an increase in the intake of the straw portion of the diet (Dutta et al. 1999).

In some cases responses to feeding leucaena can exceed responses to vegetable protein meals. Isocaloric and iso-nitrogenous total mixed rations (TMR), formulated with either leucaena or a mix of soybean, cottonseed and sunflower meals and fed to castrated male Saanen goats, had similar CP concentrations and digestibility of dry matter, organic matter, CP, NDF and ADF, but the leucaena TMR resulted in a DM intake 40% higher on a liveweight basis (Leketa 2011). In that experiment, the increased DM intake did not correspond with a difference in digestible organic matter or CP intake on a liveweight basis (Leketa 2011). However there are instances of leucaena supplementation decreasing DM intake in goats, which may be related to poor adaptation to leucaena toxicoses.

Production responses to leucaena-based diets

Integration of leucaena into rations has demonstrated positive production responses in dairy goats. Grazing dairy goats on leucaena has led to a significant increase in milk yields (Clavero and Razz 2003). For example, with an additional 2 h of browsing leucaena in addition to pasture feeding, crossbred Saanen-Anglo Nubian goats in Venezuela yielded 101.4 kg total milk compared with 66 kg for goats fed on pasture alone (Clavero and Razz 2003). When hammer-milled leucaena leaves and stems (proportions not reported) replaced full-fat soybean meal and partially replaced sunflower oil meal and cottonseed meal in an isonitrogenous total mixed ration, there was no reduction in milk yields or milk protein and fat concentrations, but liveweight gains during lactation increased, indicating that it could contribute to reducing ration cost for dairy goats (Leketa 2011).

When leucaena was fed as a cut-and-carry supplement to a grazing diet for goats, liveweight gains increased by up to 150% in the dry season and 50% in the wet season (Karachi and Zengo 1997) over the unsupplemented control. Goats adapted by upregulated rumen bacterial and hepatic detoxification pathways to consuming leucaena achieved growth rates of 41 g/d on 100% leucaena diets, outperforming 50% leucaena:50% natural grass diets (23 g/d), 50% *Gliricidia sepium*:50% grass (15 g/d) or a 100% gliricidia diet (22 g/d) (Halliday 2018). Adejumo and Ademosun (1991) provided a more complicated view of high leucaena rations for goats. Their research found consistent decreases in total DM intake as the proportion of leucaena leaf and stalk (removed from stems) in a *Panicum maximum*-leucaena diet increased up to 80%. After 10 weeks of feeding, goats fed the 80% leucaena diet began to show symptoms of leucaena toxicity, including hair loss and excessive salivation. In contrast, in 2 trials Halliday (2018) fed goats, adapted to leucaena, a sole leucaena diet for 7 weeks and 10 weeks, respectively, and observed no clinical signs of toxicity or any reduction in intake.

While leucaena has been successfully fed as a supplement for breeding does, results are somewhat equivocal. When leucaena leaves were fed with *Calliandra calothyrus* leaves as a supplement to does grazing natural pasture, there was a reduction in abortions and an increase in kid birth weights and weaning weights (Pamo et al. 2006). Although goats grazed on leucaena and natural pasture silvopastoral systems had lower conception rates than does grazed on natural pasture alone, the products of pregnancy (foetus and placenta) and foetal growth rates were increased (Akingbade et al. 2001). A subsequent experiment found mixed results in terms of multiple births for the silvopastoral system, but with a greater weight gain during pregnancy, and improved kidding rates, there was a benefit to the introduction of leucaena into the grazed breeding system (Akingbade et al. 2004).

Leucaena compares favorably with commercial protein concentrates and other legumes as a protein supplement for goats. When goats grazed a leucaena fodder bank (23.5% CP, 38.6% NDF) for 2 hours per day in addition to a *Cenchrus ciliaris* pasture (8.6% CP, 56.0% NDF), increases in average daily milk yields were the same as for goats supplemented with 300 g concentrate/hd/d (20.0% CP; Clavero and Razz 2003). When fed as a supplement to a sudangrass (*Sorghum bicolor*, 7.8% CP, 63.2% NDF, 36.7% ADF) diet, the leucaena (27.5% CP, 24.4% NDF, 13.4% ADF)-grass diet produced higher average daily gains, forage gain efficiency and intakes of legume than diets supplemented with lucerne (20.3% CP, 34.2% NDF, 26.5% ADF), lablab (21.5% CP, 36.9% NDF, 24.9% ADF) or desmanthus (21.5% CP, 23.6% NDF, 12.6% ADF) as a result of its higher CP and lower fiber concentrations (Kanani et al. 2006).

The positive production responses obtained from feeding leucaena to goats are not surprising, and correlate with similar documented benefits for cattle. However, there has been little research comparing nutritional responses of goats fed on leucaena with responses in sheep or cattle, and it would be interesting to know whether the smaller, but more digestively efficient rumen of the goat is able to gain more nutritional benefit from leucaena than cattle.

Leucaena feeding systems for goats

While the benefits of feeding leucaena to goats have been well documented, there is a pressing need for information on the optimal method for including leucaena in goat production systems. Mohammadabadi and Jolazadeh (2017) suggest that extensively grazed, intensive and small-scale production systems limited by land availability can profit from fodder trees as a feed resource for goats. Much of the published literature on the use of leucaena for goat production necessarily entails animal house experimentation, using harvested leucaena, often stripped to leaves only, or processed into hay, meal or pellets, and as such is unlikely to be representative of commercial or smallholder goat production systems. While there are a range of options for inclusion of leucaena in goat production systems, there has been little documentation of the benefits and pitfalls, including economic implications, of various approaches to practical implementation.

Grazing and silvopastoral systems

Goats are noted browsers, exhibiting a preference for sourcing their feed from shrubs at head height and above, rather than from grazed grass at foot. They have physical characteristics, including a prehensile tongue, the ability to stand bipedally and a mobile upper lip, which allow them to forage easily from trees and shrubs, such as leucaena (Sumberg 1985). Goats therefore seem to be compatible with grazed leucaena systems. Grazed alleys of leucaena under-sown with grasses in silvopastoral systems are a common production system for cattle, and have potential to be extended to goats. Leucaena shrubs are planted in dense rows with pastures or crops in the inter-row spaces. A rotationally grazed fallow system has also been proposed, consisting of 3–5 years of alley cropping between stands of leucaena, during which there is no grazing, followed by 2–3 years of grazing leucaena during a cropping fallow (Sumberg 1985).

Management of leucaena silvopastoral systems for goats is dependent on the pasture composition and breed of goat; however, a range of stocking rates have been tested, with positive production results (Table 2).

Table 2. Goat productivity under a range of leucaena silvopastoral systems and stocking rates.

Pasture under leucaena	Stocking rate (head/ha)	Average daily gain (g/hd/d)	Gain (kg/ha)	Reference
Unspecified, but invaded by *Eragrostis* spp. and *Sporobolus* spp.	11.5	45–117	28–94	Morris and du Toit (1998)
	15	71–94	60–99	
	20	60–112	66–158	
Andropogon gayanus, Panicum maximum, *Cynodon* spp.	73	17	43	Carvalho et al. (2017)
Cenchrus ciliaris with fodder bank of leucaena	16	48 (+ milk production)	92 (+ milk production)	Clavero and Razz (2003)

The preference of goats for leucaena or grass in silvopastoral systems is likely to be dependent on the grass species planted in the silvopastoral system, availability of grass and leucaena, season, nutritional requirements of the goats and management of the leucaena. Unfortunately, most research papers do not report biomass availability of grass or leucaena, or management of the shrub stand. This had led to a wide range of reported preferences for leucaena in silvopastoral systems (Table 3).

In alley grazing systems, preference for, and time spent browsing leucaena, will be dependent on the availability and quality of both leucaena and the understorey grass. Time spent grazing leucaena is related to the available biomass of the understorey grass. Time spent browsing leucaena increased from 24 to 40% of total grazing time as pasture height was decreased by mowing (removing the effect of quality) and pasture biomass was reduced from 597 to 312 kg/ha (Orihuela and Solano 1999). The relatively high proportion of time spent browsing leucaena (55%) reported by Ketshabile (2008) is likely to be related to the relatively low quality of the grass (5.9% CP, 78.0% NDF, 52.1% ADF) compared with the leucaena (21.7% CP, 33.1% NDF, 22.6% ADF).

Goats tend to rely more on grass during the wet season (Sumberg 1985), when its quality and quantity would be greatest. Meanwhile, browse vegetation accumulates on the leucaena, which is available to be increasingly utilized by the goats as the dry season deepens, and the biomass available in the pasture becomes limited (Sumberg 1985). When availability of grass herbage was limited during the dry season in a mixed cropping and silvopastoral system, goats were far more willing to shift their grazing preferences to leucaena browse than were sheep, which instead increased their intake of low quality millet stubble (Dicko and Sikena 1992). When grazing a diverse pasture of 18 grass species and 18 herbaceous or shrubby legume species (including a stand of leucaena), sheep and goats showed a preference for legumes/leucaena over grass, whereas cattle spent more time grazing grass than legumes (which included leucaena, Singh et al. 1997). All tested animal species increased their preference for leucaena after the monsoon season ended (Singh et al. 1997). Goats displayed a preference for legumes longer into the dry season than sheep, but during spring (late dry season) leucaena was a less-preferred species for goats, which increased their grazing effort on grass, whereas sheep and cattle continued to prefer leucaena (Singh et al. 1997). This research did not report on relative quality or availability of any of the feeds.

As the higher quality feed in a silvopastoral system, when an energy concentrate supplement is fed, leucaena intake tends to be maintained while concentrate is substituted for grass. When goats managed in a leucaena silvopastoral system were supplemented with maize concentrate, they spent on average 6 hours grazing grass to 1 hour grazing leucaena (Carvalho et al. 2017). As the level of maize supplementation was increased, the goats substituted maize for the lower quality grass (14.1% CP, 66.1% NDF, 36.2% ADF) rather than the higher quality leucaena (33.0% CP, 40.1% NDF, 25.3% ADF), with time spent grazing leucaena unaffected by the level of maize supplementation (Carvalho et al. 2017). Apart from substitution targeting the lower quality diet component, intake of leucaena may have been maintained due to its role as the main source of protein in the diet. The proportion of time that goats spent grazing leucaena was not affected by regrowth time for the leucaena (45–75 days), most likely because leucaena height and quality did not vary over this period (Costa et al. 2015).

The susceptibility of goats to gastrointestinal nematodes means that they can benefit from a diet that encourages the use of browsed shrubs such as leucaena. Browsing allows goats to avoid infection with the larval population living in the grass sward (Hoste et al. 2010). There is also the potential for goats browsing leucaena to alleviate worm burdens by consuming anthelmintic secondary compounds in leucaena,

Table 3. Preferences of goats for leucaena and grass in unsupplemented alley-planted silvopastoral grazing systems.

Understorey grass species	Leucaena stand management	Time spent browsing leucaena (% total grazing time)	Time spent grazing grass (% total grazing time)	Reference
Panicum maximum	3 m inter-row spacing, grazed at flowering stage, ~1.5 m high	55 (goats) 12 (sheep)	45 (goats) 88 (sheep)	Ketshabile (2008)
Cenchrus ciliaris	1 m inter-row spacing, planted at 6,666 plants/ha, ~1.5 m high, continuously pruned	33	67	Orihuela and Solano (1999)[1]
Andropogon gayanus, *Panicum maximum* and *Cynodon* spp.	1.9 m inter-row spacing, planted at 1,999 plants/ha	15	85	Costa et al. (2015); Carvalho et al. (2017)

[1]Mean time. Time spent browsing increased with decreasing grass availability.

although evidence of the ability of goats to self-medicate with leucaena has not been established (Hoste et al. 2010; Ventura-Cordero et al. 2018). The high condensed tannin (CT) concentration in leucaena can indirectly improve resistance and resilience of goats to worm infection by increasing protein flow to the duodenum and upregulating specific immune responses to infection (Thi Mui Nguyen et al. 2005). It has also been proposed that there is a direct effect of secondary compounds, including CT, on hatch rate and larval development in goats (Thi Mui Nguyen et al. 2005). Protein extracts from leucaena seeds have a demonstrated ovicidal effect on *Haemonchus contortus* eggs collected from goats (Soares et al. 2015). Goats fed a basal diet of rice straw supplemented with harvested leucaena foliage in an animal house experiment had worm egg counts 15–35%, and coccidian oocyst counts 25–85%, of those in goats supplemented with grasses (Nguyen Kim Lin et al. 2003).

There are several practical concerns in grazing leucaena systems with goats. Bark stripping or ring-barking is frequently raised as a risk in grazing goats on leucaena (Sumberg 1985); however, documentation of the extent and implications of this problem is scarce. Morris and du Toit (1998) noted some stripping of bark by goats during the late summer in South Africa, as did Goetsch et al. (2014), although this did not kill any of the trees. Bark stripping has been reported even when leaves were plentiful (Muir et al. 1991). When bark is stripped around the entire circumference of a stem or trunk, die-off occurs above the point of the damage, but the plant survives and new growth continues below the point of damage. In the study of Muir et al. (1991), on average 72% of the circumference of damaged branches was stripped. Plants with only part of the stem circumference stripped re-grew bark over the stripped area, in some cases completely. As damage increased, the number of branches below 30 cm height increased, and the number of branches above this height decreased and leaf biomass distribution followed the same pattern. The suitability of leucaena for coppicing indicates that leucaena may be resilient to ring-barking damage. However the comparative productivity of the plants under cutting or grazing by goats has not been tested.

Up-rooting of browsed shrubs can be a problem with other grazed tree legumes established with stake techniques, such as gliricidia (Sumberg 1985), but establishing leucaena from seed has prevented this problem in research in Nigeria. Seed-establishment may also prevent branch damage to browsed trees, as branches naturally grow lower along leader stems, rather than from the top of stakes (Sumberg 1985). Coppicing also promotes low branching, and can improve access to foliage, as well as preventing branch damage. Tree height can become a restriction for grazing goats to access leucaena browse. Wild bush buck (*Tragelaphus scriptus*) and Nguni and Boer goats (*Capra hircus*) have preferred grazing heights of less than 0.5 m (Haschick and Kerley 1996; du Plessis et al. 2004) and maximum grazing heights of 122 (Boer goats) and 166 (bush buck) cm, respectively (Haschick and Kerley 1996). This constraint can be addressed by coppicing, bending down stems of narrow trunks (Sumberg 1985), cutting branches above 1.2 m when necessary (Muir et al. 1991) and choice of leucaena variety.

The economic benefits and costs of fallow leucaena-goat alley-grazing systems compare favorably with alley-cropping systems, such as maize-cassava, in West Africa (Sumberg 1985). Grazing fallow regrowth reduces capital investment and management issues associated with planted pastures (Sumberg 1985). A comparison of the use of alley-grown leucaena as goat feed with its use as a green mulch for a maize crop in Western Tanzania predicted a 50% benefit of feeding the leucaena to goats (Karachi and Zengo 1997). In general, there are limited system or whole-farm gross margin analyses of these systems, and there are many key issues which need research.

Cut-and-carry feeding systems

Leucaena is fed to goats mainly as fresh material in cut-and-carry feeding systems, which are flexible, and labor- and resource-efficient (Sumberg 1985; Palmer et al. 2010). In many cases, the leucaena inputs to these systems are derived from alley-cropping systems, similar to the silvopastoral systems described above. One hectare of alley-cropped land can yield 4 tonnes of leucaena foliage, of which 25% can be removed without reducing crop yields, sustaining 3 does and their offspring on a sole leucaena diet (Upton 1985). In other cases leucaena is obtained from planted fodder banks, or harvested from wild-grown shrubs.

In cut-and-carry feeding systems leucaena can act as a protein supplement or form the whole of the diet. Farmers feed it chopped or directly offer branches to goats which are intensively housed, tethered or free-grazed. Leucaena can also be fed (sun)dried (Mtenga and Shoo 1990) and processed into leaf meal (Mohammadabadi and Jolazadeh 2017) or as leaf protein concentrate (Farinu et al. 1992), although these systems are less often practiced by farmers. Leaves, stems and bark can all be fed to goats. Bark has been shown to be palatable to goats although the total amount of bark needs to be limited to avoid a reduction in nutritive value of the total ration (Palmer et al. 2010). When fed cut-and-wilted material, goats have displayed a strong preference for leucaena over other tree forages *Albizzia lebbek*, *Gliricidia sepium* and *Tamarindus indica* (Mtenga et al. 1994). When fed to housed goats, leucaena can be presented as whole or chopped branches. Feeding in troughs is common, but hanging branches in bunches or laying them on racks above the goats' heads caters to their natural browsing instinct, while reducing the potential for nematode larval infection from feces which can fall into ground-level troughs.

Conclusions

Goats have a natural inclination to browse woody shrubs, are frequently raised in tropical and low-nutrition production systems and are well suited to integration with leucaena. They can adapt to leucaena toxicosis through bacterial and hepatic detoxification pathways, which permits productivity gains by the addition of leucaena, up to 100% of the diet. Despite a large body of research demonstrating the benefits of leucaena in various goat diets and production systems, there is a lack of information identifying the differences between goats and other ruminant species in the use and utilization of leucaena. Concerns that goats are unsuited to silvopastoral systems owing to the risks from ring-barking persist, although the ability of leucaena to survive and re-sprout from low on the stem, as well as documentation of successful grazed leucaena systems, suggests that these fears may be overstated. However, there is little documentation regarding the practicalities or economics of successful extensive or intensive goat production systems that include leucaena. A priority for future work is farming systems research examining the integration of goats and leucaena, including in crop-livestock systems.

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(Note of the editors: All hyperlinks were verified 24 April 2019.)

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