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A Review of Kudzu's Use and Characteristics as Potential Feedstock

Joseph P. Gulizia * and Kevin M. Downs

School of Agriculture, Middle Tennessee State University, Murfreesboro, TN 37132, USA; kevin.downs@mtsu.edu
* Correspondence: jpg3y@mtmail.mtsu.edu; Tel.: +1-(615)-898-5217

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Abstract: This review assesses the potential use of kudzu (*Pueraria montana* var. *lobata*) as a feedstock for livestock. Kudzu in the United States is a recognized invasive plant species that has continued to cause problems for the environment and land owners. In kudzu's native countries, it has continued to have beneficial uses beyond being an adequate form of soil erosion control. Never the less, kudzu is a rampant weed that causes harm to many environments. In the United States, local farm owners have used ruminant species as a form of biological control to prevent the spread of kudzu and provide their animals with a high nutrition feed supplement. However, there are few reports that assess ruminal degradability in ruminants and kudzu quality. There is great potential for kudzu as a feed supplement for livestock species. Furthermore, using kudzu as a feed supplement for livestock species serves a dual-purpose of biologically controlling the spread of kudzu while providing those animals with a high-quality feedstuff.

Keywords: kudzu; feedstock; livestock; biological control; invasive species

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1. Introduction

During its active growing season, kudzu (*Pueraria montana* var. *lobata*) rapidly engulfs many woody and herbaceous areas in the Southeastern United States. It is an invasive plant species that has persistently evaded a definitive control method, and, as such, has created land management problems for many land owners. A major problem that land owners face is the destruction occurring from kudzu on their desired forages for agricultural production. Biological control using ruminants, specifically browsers, however, can be a beneficial control method for both the owner of the land and the animals. Kudzu is known to have a high nutritive content that can benefit animals. There is, however, limited data on kudzu's ruminal degradability in ruminants. This review will focus on kudzu's characteristics, uses, and qualities and assess its use as a potential feedstock for livestock species.

2. History of Kudzu

There are 17 species of kudzu in the genus *Pueraria* throughout the world (Table 1), all of which are native to China, Taiwan, Japan, and India [1–3].

Table 1. Species of *Pueraria* throughout the world [3].

P. tuberosa	*P. lacei*
P. sikkimensis	*P. bella*
P. candollei	*P. pulcherrima*
P. mirifica	*P. phaseoloides*
P. lobata	*P. peduncularis*
P. imbricata	*P. stricta*
P. edulis	*P. wallichii*
P. alopecuroides	*P. rigens*
P. calycina	

These cultures have implemented various uses of kudzu, including medicinal purposes or making it into cloth and paper [2]. Kudzu was first introduced into the United States from Japan in 1876 as a display at the first official World's Fair in Philadelphia, Pennsylvania in the Plant Exhibition section [2,4]. During the late 19th century, kudzu's broad leaves and dense growth was initially used as shade for porches and courtyards in the Southern United States. Kudzu quickly became popular and more common among Southern U.S. farmers for its advertised multi-purpose uses, including as soil erosion control, a cheap forage for livestock, and various practical uses around their homes [2]. In the 1930s, the U.S. Natural Resource Conservation Service (NRCS) oversaw combating soil erosion from improper agricultural practices [2]. They dispersed 85 million kudzu seedlings to Southern U.S. farmers to establish kudzu plots for soil erosion control and land revitalization [2]. Kudzu use in soil erosion control was optimal due to its rapid growth of vines that drop roots every few feet which grips and prevents excess soil movement [5]. Land revitalization came through kudzu's property of being a soil nitrogen fixer, which refilled overused, nitrogen deficit soils. In the 1930s, the U.S. government offered an $8 per acre incentive to plant kudzu seedlings. By 1946, there were approximately 1.21 million hectares of kudzu in the Southeastern United States [2].

Kudzu began gaining negative attention by the early 1950s, as it spread rampantly throughout the Southern U.S., causing problems for farmland owners [2]. It was destructive in killing trees, collapsing buildings, and destroying utility poles by aggressively traveling up these structures and forming a dense mass that would strain their integrity [6]. The climate of the Southeastern United States was ideal for kudzu to thrive, leading to it being placed on the United States Department of Agriculture (USDA) common weed list in 1970 [2]. Kudzu became an invasive plant species in the United States because it had no natural competitors in the environment to regulate its growth, as it would in its native Asian countries. In 1997, the U.S. Congress voted to place kudzu on the Federal Noxious Weed List. There is now an estimated 2.83 million hectares of land in the Southeastern United States that has been engulfed with this invasive plant species [2].

3. Characteristics of Kudzu

Kudzu (*P. montana*), the species that is predominately found in the Southern U.S., is a large, trifoliate-leaved, semi-woody, perennial vine that belongs to the legume family [2,5,6]. Plant species of the legume family are known for being soil nitrogen fixers. Kudzu vines can grow up to 0.3 m per day in early summer and as much as 18 m total during the growing season (May–October) [2,5,7]. It spreads from the root crown in any direction and will root at the vine nodes every few feet to establish new growths [2,5]. The spread rate of kudzu can be accelerated by small vines of other plants because kudzu can consistently twine around smaller vines more swiftly than large tree trunks [5,8]. Its tuberous roots (descended at the nodes) help maintain a heavy carbon reserve. Roots can reach a depth of 4 m and weigh as much as 91–136 kg in older kudzu patches [2,5,9]. The taproot is enlarged and beneficial in that it aids the plant in survival during drought periods [4,5].

Asexual regeneration is a frequent and common method by which kudzu multiplies. This occurs every few feet where nodes (the areas on the vine where leaves and roots branch) will send down roots establishing new root crowns [5]. There are few fruiting pods that develop viable seeds during the optimal growing season, but its vegetative reproduction continually takes place as the nodes establish roots [6]. During kudzu's third growing season after germination, seed production will initiate by producing a purple flower in late July to September in the U.S., if in full sun [5,6]. When seedpods are produced there are only 1–2 viable seeds, and these seed pods are only found on climbing vines [2,5]. A prolonged exposure to high summer temperatures and increased soil temperatures will accelerate seed germination by affecting seed coat permeability [5,10]. Attempts to eradicate kudzu by burning may also promote seed germination, where potential new growth would emerge after the burning attempt [5,10].

Kudzu is found in many places in the United States and can grow in a wide range of soil types, including sandy soils, acid soils, lime soils, lowlands with high water tables, in over-heavy subsoil, and in areas where winter soil temperatures do not drop below −32 °C [2,11]. Kudzu can be found in open fields, road sides, and near forest edges, but its spread is at its peak in open fields [5]. The widespread distribution of kudzu in the United States is shown in Figure 1.

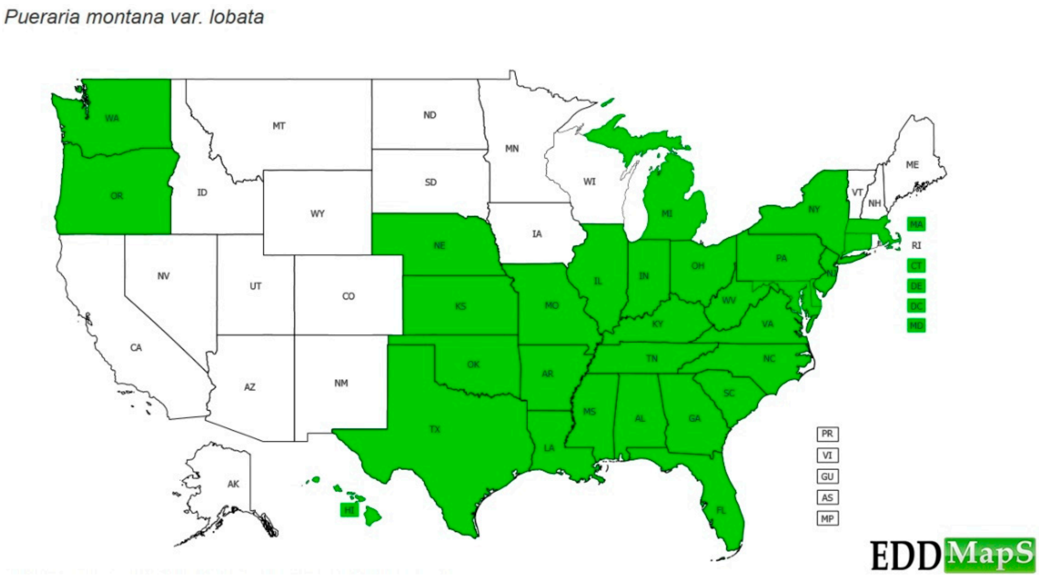

Figure 1. Distribution map of kudzu (*P. montana*) in the United States [12]. no data; species reported.

This map shows that kudzu has spread from the Southern U.S. and has acquired a level of hardiness to endure colder and dryer climates. Kudzu can endure drought and high temperatures, but will not thrive in wet soils and young vegetative growth will die in low temperatures [6]. When reaching temperatures between 30 °C and 35 °C, the efficiency of photosynthesis will be affected by increasing heat [5]. Kudzu will grow in many different soils, but the optimal soil type is a deep, loamy soil [2,4–6]. The most aggressive plots of kudzu are in the Southeastern U.S., with its optimal climates where winters are mild, summer temperatures rise above 27 °C, annual precipitation exceeds 102 cm, and sandy loam soils are widespread [4,5].

Other factors that can affect growth of kudzu is light availability and the previous existing native plant life. As kudzu starts to encounter shade, growth will dwindle, whereas in direct sunlight the growth rate can increase 3-fold [5]. Kudzu contains a high leaf surface area, especially when climbing trees, which enhances the photosynthetic competition for light [5]. Kudzu is considered heavily shade intolerant in having the highest light requirement out of five native (*Rhus radicans*, *Clematis virginiana*, *Smilax rotundifolia*, *Vitis vulpina*, and *Parthenocissus quinque-folia*) and three exotic (*Pueraria lobata*, *Lonicera japonica*, and *Hedera helix*) vine species in the Southeast U.S. [5,13].

Kudzu differs among species around the world. American kudzu, compared to the Japanese counterpart, is distinctly different in how it overwinters. Kudzu is considered a semi-woody perennial because of its overwintering ability [5]. Overwintering is a process where vines develop thick bark, accumulate annual rings of vascular tissue, and attain a desirable stem diameter, usually around 2 cm [5,14]. American kudzu will produce these overwintering stems only on the vigorous, climbing plants, whereas the Japanese strain will produce the overwintering stems on the portions that lie just above the ground [5,14]. An additional difference with the North American cultivars of kudzu is that they have limited seed production and are less likely to thrive outside the Southeast U.S. [5].

4. Uses of Kudzu

In China and Japan, kudzu roots are dried and used for medicinal purposes to cure an array of common ailments [15]. Japan, during the 1700s, also attempted to utilize fiber from stems to make grass-like cloth and paper, and also grinding kudzu into flour for use in baking [2,15]. Asian grocery and health food stores still import kudzu flour to sell in the U.S. [9]. Other traditional uses of kudzu are as fiber to stuff cushions and chairs, as a mosquito repellent when burned, and to produce a palatable honey [15]. During the initial years that kudzu was introduced in the U.S., it was used as an ornamental vine (which was appreciated for its grape-like fragrance) to shade many southern U.S. homes [2].

As previously discussed, kudzu (*P. montana*) was first introduced to the United States as a means for erosion control, but was eventually considered a rampantly unstoppable vegetation that would start to take over the Southeastern United States. Kudzu continues to be an efficient method of soil erosion control on steep embankments, but there are more noninvasive species (e.g., tall fescue and bahiagrass) used now to address this issue [7,15]. Being a legume, kudzu has a dual-purpose of hosting nitrogen fixing bacteria that enrich the soil and is also a good source of nutrients when fed to herbivorous livestock [15].

5. Kudzu Nutrient Composition and Degradability

Kudzu (*P. montana*) is often compared to alfalfa. Kudzu leaves have a high nutritive value comparable to that of alfalfa (*Medicago sativa*), a common flowering plant used for grazing, hay, and silage for ruminants and other domestic herbivores [16–18] (Table 2).

Table 2. Nutrient composition of alfalfa hay and fresh kudzu (*P. montana*) leaves (dry matter (DM)) basis)

	Alfalfa, Hay, Sun-Cured, Midbloom [1]	Kudzu Leaves, Fresh [2]
Crude protein (CP), %	18.7	17.5
Neutral detergent fiber (NDF), %	46.0	48.1
Acid detergent fiber (ADF), %	36.9	38.2
Ca, %	1.37	0.7
K, %	1.56	1.0
Mg, %	0.35	0.3
Fe, mg/kg	224.60	162.3

[1] NRC [19], [2] Corley et al. [20].

As noted in Table 3, kudzu (*P. montana*) (kudzu aerial part (fresh), kudzu leaves (fresh), and kudzu hay) is a high quality legume feedstuff. Kudzu fed as an aerial part (fresh), leaves (fresh), or hay can satisfy most nutrient requirements for various ruminant species (Table 4). Kudzu silage has a high nutrient composition that would satisfy nutrient requirements for many ruminants (20.15% dry matter (DM), 92.01% organic matter (OM), 20.09% crude protein (CP), 8.14% Ash, 57.10% neutral detergent fiber (NDF), 38.32% acid detergent fiber (ADF), 8.25% Lignin) [21]. Kudzu leaves are higher quality than alternative kudzu feed sources, and satisfies nutrient requirements for most domestic ruminants [22]. Additionally, based on National Research Council's TDN criteria, kudzu leaves are considered a high quality legume forage [22]. Nutrient composition data indicates that kudzu has substantial potential as a feedstock for ruminant livestock species.

Table 3. Chemical and nutrient composition of kudzu (*P. montana*), aerial part, fresh, kudzu (*P. montana*) leaves, fresh, and kudzu (*P. montana*) hay (DM basis) [20,23–31].

Item	Kudzu, Aerial Part, Fresh					Kudzu Leaves, Fresh					Kudzu Hay
	Avg [A]	SD [B]	Min [C]	Max [D]	Nb [E]	Avg	SD	Min	Max	Nb	Avg
Dry matter, % as fed	26.5	5.5	17.4	35.0	8						
Crude protein, %	15.1	5.1	8.3	24.3	14	17.2	2.5	14.5	19.6	3	13.3
Crude fiber, %	33.1	5.2	22.6	40.6	10	29.6		21.5	37.6	2	40.3
NDF, %	53.9	2.9	50.6	55.8	3	48.1				1	
ADF, %	30.7	9.4	17.3	39.7	5	38.2				1	
Lignin, %	7.8	1.4	6.1	9.0	4						
Ether extract, %	2.4	0.6	1.5	3.3	10	3.3		2.6	3.9	2	2.5
Ash, %	9.3	2.6	5.6	13.6	11	8.1	0.3	7.8	8.3	3	9.3
Gross Energy, MJ/kg	18.5	6.3	6.2	26.4	*	18.7				*	18.7
Calcium, g/kg	12.3	0.6	1.9	4.1	11	10.9		7.0	14.8	2	18.3
Phosphorus, g/kg	2.4	7.4	1.9	27.7	12	1.1				1	1.0
Potassium, g/kg	13.2	0.6	2.6	4.2	8	14.7		10.0	19.3		
Sodium, g/kg	0.3				1	0.6					
Magnesium, g/kg	3.3				8	2.7		2.5	3.0		
Manganese, Mg/kg						438					
Zinc, Mg/kg						27					
Copper, Mg/kg						10					
Iron, Mg/kg						162					
Arginine, %	4.0				1						
Cystine, %	1.1				1						
Glycine, %	4.5				1						
Histidine, %	2.7				1						
Isoleucine, %	3.9				1						
Leucine, %	6.7				1						
Lysine, %	4.4				1						
Methionine, %	1.8				1						
Phenylalanine, %	4.2				1						
Threonine, %	4.2				1						
Tryptophan, %	2.4				1						
Tyrosine, %	3.3				1						
Valine, %	4.5				1						
OM digestibility, ruminants, %	62.0				*	65.6				*	55.1
Energy digestibility, ruminants, %	59.3				*	62.8				*	51.7
DE ruminants, MJ/kg	11.0				*	11.8				*	9.7
ME ruminants, MJ/kg	8.7				*	9.4				*	7.7
Nitrogen digestibility, ruminants, %	85.0				1						65.6

[A] Avg: average or predicted value, [B] SD: standard deviation, [C] Min: minimum value, [D] Max: maximum value, [E] Nb: number of values (samples) used, * Indicates that the average value was obtained using an equation.

Table 4. Kudzu's (*P. montana*) (kudzu aerial part (fresh), kudzu hay, and kudzu leaves (fresh)) nutrient composition compared with nutrient requirements of various domestic ruminant species (DM basis) [19,20,22–33].

Item	Composition [A]			Requirements [B]				
	Kudzu, Aerial Part, Fresh	Kudzu Leaves, Fresh	Kudzu Hay	Pregnant Replacement Heifers	Lactating Beef Cows	Lactating Dairy Cows	Lactating Ewes	Lactating Does
TDN, %	59.30	55.99	51.70	53.01	51.57	70.20	60.43	59.50
CP, %	15.10	17.20	13.30	7.82	7.56	15.60	11.20	14.50
ME, MJ/kg	8.70	9.40	7.70	4.61	7.93	11.20	9.15	
Ca, %	1.23	1.09	1.83	0.25	0.21	0.56	0.32	0.55
P, %	0.24	0.11	0.10	0.19	0.14	0.36	0.23	0.33

[A] Average or predicted values, [B] Average across a variety of months since conception, months since calving, milk yield, and stages of lactation.

In situ dry matter rumen degradation data provided by Corley et al. [20] separates kudzu into soluble, degradable, and indigestible fractions between leaf/stem and tuber (roots) (Table 5).

Table 5. In situ dry matter disappearance (DMD) and in vitro dry matter digestion (IVDMD) of kudzu (*P. montana*) plant parts [20].

	In Situ DMD, %			IVDMD, %
	Soluble Fraction	**Degradable Fraction**	**Indigestible Fraction**	
Leaf and Stem	29.1	48.6	22.4	64.8 (Leaf) 73.7 (Stem)
Tuber	38.1	31.2	30.7	59.9

Legumes, such as kudzu and alfalfa, have a high rate of degradability due to a low concentration of water-soluble carbohydrates [34]. Corley et al. [20] provided data that kudzu contains 17.5% CP in leaves, similar to alfalfa at 18.7% CP (Table 2). Kudzu leaves contain a high concentration of CP, making it a potential feed for growing ruminants [20]. The stem and tuber portions of kudzu do not have the same potential in regard to providing optimal nutrients to the ruminant. Moreover, kudzu leaves contain a significantly higher CP level than stems; however, kudzu leaves contain significantly lower ADF (a common predictor of energy level in forages) [22]. Corley et al. [20] found a 5–7% lower CP level in stems than leaves (Table 6). In addition, Corley et al. [20] observed that kudzu tuber contained 8.6% CP (Table 6). Zhao et al. [35] reported that kudzu roots contain a range of CP from 3.18–4.58%. As growth time of kudzu root increases, CP tends to decrease to levels below 4.58%. In contrast, lipid content of kudzu root increases with an extended growth period to levels above 32.2 g/kg [35].

Table 6. Nutritive values of kudzu (*P. montana*) plant parts [20].

Parameters	Leaf	Stem	Tuber
Crude protein, (CP), %	17.5	10.3	8.6
Neutral detergent fiber, (NDF), %	48.1	73.7	39.8
Acid detergent fiber, (ADF), %	38.2	44.0	53.3
Ca, %	0.7	0.1	0.4
K, %	1.0	1.0	0.3
Mg, %	0.3	<0.1	0.1
Fe, mg/kg	162.3	156.6	3600.0

Additionally, Gulizia et al. [36] observed that kudzu from two different growing seasons contained a higher concentration of nutrients than in previous reports (Table 7). This study also observed that early season kudzu dry matter degradability was 84%, and late season kudzu degradability was 79% over a 72 h incubation period. Gulizia et al. [36] concluded that kudzu (regardless of growing season) was highly degradable over a 72 h incubation period in ruminants, and has potential as a feedstock.

In comparison, alfalfa is a high-quality forage characterized by high digestibility and swift ruminal degradation [37]. Alfalfa and kudzu leaf and stem have similar in situ rumen degradation, with alfalfa having an average rate of 73.35% and kudzu having 78% maximum degradability [20,38]. Alfalfa leaf and stem have an average soluble fraction of 34.8% and an average degradable fraction of 38.6%, whereas kudzu leaf and stem are 29.1% and 48.6%, respectively (Table). This data can potentially predict that alfalfa leaf and stem contain more starch, sugars, and protein than kudzu leaf and stem, but less concentrations of cellulose and hemicellulose. Coblentz et al. [38] allowed alfalfa to ferment in the rumen for 96 hours, whereas Corley et al. [20] only allowed 24 hours of fermentation for kudzu. In situ dry matter disappearance for whole plant alfalfa was found to be 76.6, 79.6, 79.2, and 81.91% in four studies [38–41]. It is common for alfalfa to have high nitrogen levels that are highly degradable. High degradability of nitrogen in alfalfa can lead to poor utilization of available nitrogen in lactating dairy cows [38].

Table 7. Near infrared reflectance spectroscopy (NIR) chemical composition of early (ES) and late season (LS) kudzu (*P. montana*) leaves incubated in experimental fistulated bovine during in situ rumen degradation study periods (DM basis) [36].

Analysis	ES	LS
DM, %	88.2	88.5
CP, %	30.5	26.7
Available protein, %	28.9	24.9
ADF, %	18.4	26.2
NDF, %	27.3	45.7
Lignin, %	4.40	6.3
Net Energy (maintenance), Mcal/kg	1.80	1.23
Net Energy (growth), Mcal/kg	1.19	0.68
Ca, %	1.54	1.74
P, %	0.43	0.28
Mg, %	0.35	0.39
K, %	2.05	2.05
S, %	0.34	0.39
Cl, %	0.45	0.55
Lysine, %	1.55	1.25
Methionine, %	0.48	0.40

6. Anti-Quality and Anti-Nutritional Factors of Kudzu

Kudzu contains a variety of secondary metabolites. Table 8 summarizes a qualitative analysis of some common secondary metabolites found in tropical kudzu. Data is limited on quantitative analysis of many secondary metabolites in kudzu leaf and vine. These secondary metabolites can act as anti-nutritional or anti-qualitative factors [42,43]. Legumes, such as kudzu, are beneficial in nitrogen fixation and improvement of animal diets. Secondary metabolites in kudzu, however, can interfere with nutrient intake, absorption, and utilization [42,43].

Table 8. Summary of qualitative tests from phytochemical screening and analysis of kudzu (*Pueraria phaseoloides*) [43].

Secondary Metabolites	Tropical Kudzu
Organic acids	+++
Reducing Sugars	+++
Saponins	+++
Tannins	+++
Steroids and triterpenoids	++
Saccharides	++
Alkaloids	+
Depsides and depsidones	+
Coumarin in by-products	+
Flavonoids	+
Cardiac glycosides	+
Catechins	-
Lactones	-
Purines	-
Quinones	-

(+++) large presence; (++) medium presence; (+) small presence; (-) absence or inconclusive result of secondary metabolites.

There are both toxic (i.e., alkaloids, saponins, isoflavones, etc.) and nontoxic (i.e., tannins, cutin, biogenic silica, etc.) secondary metabolites in plant materials [43,44]. Alkaloids, cyanogenic glycosides, toxic amino acids, saponins, and isoflavones are toxic compounds present in low concentrations [43,44]. These compounds at concentrations less than 20 g/kg can have negative effects when absorbed by an animal, including neurological problems, reproductive failure, gangrene, and potential fatalities [43,44]. Lignin, tannin, cutin, biogenic silica, and volatile terpenoids make up the non-toxic compounds present in high concentrations. These compounds at concentrations greater than 20 g/kg can result in decreased digestibility and palatability [43,44].

Saponins are in high concentrations in tropical kudzu (*Pueraria phaseoloides*), causing tympanism (accumulation of gas), reduced rumen microbial fermentation, and hepatic photosensitivity [43]. Saponins also create stable foam in water and impart a bitter flavor to forages, thus decreasing the likelihood of intake by the animal [43]. Saponins are major anti-nutritional and anti-qualitative factors, but tannins are the primary negative factor in legumes [43]. There are two types of tannins, hydrolysable and condensed varieties, with the latter being found in legumes, sorghum grains, and tree leaves. Tannins contain a large amount of phenolic hydroxyl groups, allowing them to create links with proteins and other molecules [45]. A main concern with tannins in feedstuffs is their negative effects on the ruminant digestive system through protein interactions [45]. Tannins will affect the nutritive value of plant dry matter, reducing the palatability by precipitating salivary proteins and nutrient digestibility by diminishing the permeability of the rumen wall through interactions with the outer cellular layer of the digestive tract. Tannins consumed at >50 g/kg of dry matter concentration will cause ruminants to reject feedstuffs, while consumption <50 g/kg seems to not affect voluntary feed intake [46–49]. Digestive enzyme activity may also decrease from tannins' ability as a potent inhibitor. Tannins have the potential to cause negative effects to an animal, including impaired ruminal digestion; low milk yield; toxic degenerative changes in the intestine, liver, spleen, and kidney; and constipation [45]. Both saponins and tannins cause negative effects, but the positive effects these secondary metabolites can have, including diminished ruminal methane production, is still being explored [43,50].

Organic acids and reducing sugars are the remaining secondary metabolites that have large concentrations in kudzu. Organic acids can bring about precipitation of calcium ions in the blood, leading to muscle weakness, nephritis, kidney stones, gastrointestinal irritation, and hypocalcemia syndrome in grazing ruminants and horses [43]. In large concentrations, reducing sugars can be problematic for equines [43,51]. Equines fed a high concentrate diet will produce excess lactic acid, resulting in water retention and decreased pH values in the lumen of the digestive tract [43,51]. This risks the possibility of digestive disorders, including osmotic diarrhea and colic [43,51]. Additional secondary metabolites, such as coumarin by-products, depsides and depsidones, alkaloids, steroids, triterpenoids, flavonoids, and cardiac glycosides can also cause negative effects [43]. Lastly, kudzu contains phenolic compounds that can have allelopathic advantages [52,53]. Kudzu leaves and roots contain 2–3% (DM) phenolic compounds [52,53]. Kudzu growing soils contain approximately 50 times more phenolics than soils devoid of kudzu [52,53].

7. Biological Control of Kudzu Using Animals

Plant populations are controlled naturally by their environment and by natural enemies. Invasive species are unique in disrupting an ecosystem to which it does not belong due to a lack of natural control [54]. Invasive species are the second largest cause of biodiversity (total variability within and among species of all plant organisms and their habitats) loss, behind habitat destruction [55]. The degree of invasiveness may increase with a lack of natural competitors [55,56]. Plant species that are established in an environment outside of its natural habitat may be less regulated by the native herbivores in the area, thus resulting in the rapid growth of an invasive plant species [55,56]. This leads to unwanted imbalances in an ecosystem that have potential to harm native species. These invasive plant species can be controlled by chemical or biological methods. Biological control is a method by which one organism is used to control another and can be used to restore ecosystem balance [56]. Biological control of problematic species using animals was recorded as early as 9,500 years ago when cats were domesticated to control rodents [56]. Animals used in biological control of invasive plant species can range from insects to ruminants. Therefore, land owners can manage livestock to use invasive plant species as diet supplements and not only enhance animal production, but also slowly diminish the infestation of the invasive species.

Kudzu (*P. montana*) must undergo constant application of some control method to yield results in lowering its occurrence. Efforts to successfully control this plant is heavily influenced by timed treatments within its life cycle [6]. Biological control using grazers and browsers can be an effective and cost-efficient method, but it is a slow process [6]. Elimination of kudzu is possible by frequent defoliation by animals over several years. By over defoliating and reducing photosynthetic carbon, hydrogen, and oxygen (CHO), kudzu will halt its metabolic processes and regrowth will be prevented [2]. Defoliation during the fall will reduce the amount of resources roots receive for survival through the winter, thus accelerating the progression of eradication [5].

Kudzu (*P. montana*) can be eliminated using cattle to over graze it at 80% consumption of the vegetative growth for 3–4 years [2,6]. In contrast, tropical kudzu (*Pueraria phaseoloides*) could be efficiently controlled using cattle on a rotational grazing system in less than 2 years [57]. However, for tropical kudzu to be eradicated in 2 years, the soil should be compact and drain poorly [57]. Vines which these animals cannot reach may be cut and fed to ensure that defoliation is effective. Remaining plant material after those 3–4 years can be spot treated with recommended herbicides [6]. Furthermore, continuous grazing and browsing of infested areas for approximately 2 months during kudzu's growing season (May-October in the U.S.) can be effective in its eradication. Older infestations become increasingly hard to eradicate. Kudzu over 10 years old will be minimally affected by over grazing and over browsing, so herbicide application may be necessary [6–8]. However, kudzu's hardy nature tends to make application of herbicides difficult due to the stockpile of starch in its tap root [58].

8. Use of Kudzu as a Feedstock

Grazers (e.g., cattle and sheep) and browsers (e.g., goats and deer) will consume kudzu (*P. montana*) when available, but it is easily overbrowsed or overgrazed [4]. Kudzu is known to produce a forage of high quality that contains a crude protein (CP) concentration of 15% or higher and a total digestible nutrient (TDN) value of over 60%, but the use of this plant as a feedstuff has limitations. Kudzu grows rapidly, but it produces a low forage yield of 2–4 tons of dry matter per acre per year [2]. Pairing low forage yield with a vine-like growth habit makes harvesting problematic. During dry periods, producers can harvest kudzu annually or biennially, as it retains moisture for growth deep within the roots [2]. Grazers and browsers can be enclosed on a plot of kudzu to control its growth, while also receiving a high quality source of nutrients that potentially results in increased animal performance. Lynd and Ansman [59], Miller and Edwards [60], and Rhoden et al. [61] reported that heavy grazing kudzu for 3–4 growing seasons with cattle, swine, horses, sheep, or goats in August and September could prove to be effective at starving and preventing growth of kudzu. Though data is limited, there are examples of kudzu's use as a feedstock.

Tropical kudzu contains a high nutrient composition as shown in Table 9. Overall, *P. montana* and *Pueraria phaseoloides* tend to be similar in nutritive value. Previous research utilizing tropical kudzu determined that it is palatable and contains an adequate amount of CP for ruminants. Monteiro et al. [62] observed that dairy cows fed a diet that consisted of tropical kudzu supplemented with sorghum grain could support a milk yield of 8.1 kg milk/day.

Table 9. Chemical composition and nutritional value of tropical kudzu (*Pueraria phaseoloides*), aerial part, fresh (DM basis) [26,63–71].

Item	Avg [A]	SD [B]	Min [C]	Max [D]	Nb [E]
Dry matter, % as fed	19.0	4.0	14.0	32.7	33
Crude protein, %	19.3	3.3	13.1	25.8	48
Crude fiber, %	33.0	3.9	26.7	40.2	42
NDF, %	49.4		46.3	51.9	2 *
ADF, %	38.2	5.1	28.4	38.5	3 *
Lignin, %	7.1	1.6	5.4	8.5	3
Ether extract, %	2.2	0.7	1.0	3.9	38
Ash, %	8.7	1.7	5.3	11.3	46
Gross Energy, MJ/kg	18.9				*
Calcium, g/kg	9.6	2.2	5.4	14.5	42
Phosphorus, g/kg	2.7	0.7	1.5	4.0	41
Potassium, g/kg	23.6	7.2	10.2	36.5	39
Sodium, g/kg	0.1	0.1	0.1	0.2	3
Magnesium, g/kg	3.0	0.5	2.1	4.1	38
Manganese, mg/kg	98		43	153	2
Zinc, mg/kg	40		39	42	2
Copper, mg/kg	12		12	13	2
Iron, mg/kg	206				1
Arginine, %	4.1		4.0	4.3	2
Cystine, %	1.1				1
Histidine, %	1.8		1.7	1.9	2
Isoleucine, %	3.9		3.5	4.4	2
Leucine, %	6.4		5.8	7.0	2
Lysine, %	3.3		3.2	3.3	2
Methionine, %	1.8				1
Phenylalanine, %	4.5		4.4	4.6	2
Threonine, %	4.4		4.3	4.4	2
Tryptophan, %	1.2				1
Tyrosine, %	3.4				1
Valine, %	4.6		4.3	4.9	2
OM digestibility, ruminants, %	62.2				*
Energy digestibility, ruminants, %	59.4				*
OF ruminants, MJ/kg	11.2				*
ME ruminants, MJ/kg	8.8				*
Nitrogen digestibility, ruminants, %	80.0				1

[A] Avg: average or predicted value, [B] SD: standard deviation, [C] Min: minimum value, [D] Max: maximum value, [E] Nb: number of values (samples) used, * Indicates that the average value was obtained using an equation.

In 1945, tropical kudzu (*Pueraria phaseoloides*) was introduced to a herd of Guernsey cows. Initially, few cows ate kudzu, but within days cows consumed it regularly [63]. This experiment was conducted when common pasture crops did not produce a sufficient forage. For one continuously grazing cow during the dry season, an estimated one acre of tropical kudzu was needed. Telford and Childers [63] determined that tropical kudzu should only be grazed once during the dry season. To use kudzu for grazing, it should not be grazed to the ground to preserve quality and regrowth ability. Tropical kudzu had an estimated 11,000–18,150 kg of forage production per year during these experiments. Successful grazing was also established using oxen and goats, and an adapted use for other livestock and poultry.

Kudzu has been used as a source of feed for a variety of research animals. Bhatt and Sharma [23] fed fresh kudzu-vine (*Puereria thunbergiana*) ad libitum to experimental Angora rabbits. In the Malagasy Republic, both *Puereria thunbergiana* and *Pueraria phaseoloides* were successfully grown as a high protein feedstuff [26,58]. Using kudzu as an alternative feed source has been successful due to its palatability and positive results have been shown when fed to beef and dairy cattle [22]. Cows utilizing kudzu as a feedstock produced milk with no color or flavor differences [22]. Piper [72] and Shurtleff and Aoyagi [73] observed that when given a choice, cattle, hogs, chickens, goats, sheep, horses, and rabbits preferred kudzu over grasses or commercial hay. Research conducted in Alabama on Angora goats observed that kudzu populations were effectively controlled with 27 animals/hm^2 [52,74]. Additionally, kudzu is ideal as an emergency feed source when common sources are low [22]. Polk and Gieger [75] demonstrated that when alfalfa became limited, kudzu meal at 9% of their diet could be substituted in chick rations. Kudzu and various grasses (e.g., pará grass) can form a desirable combination (when grazing) to increase protein content and reduce the need for commercial feeds [63]. Poultry have been observed to graze kudzu and consume kudzu seeds; however, there have been no reports on potentially using poultry as a way to biologically control kudzu [52,59]. Nworgu and Egbunike [76] researched potential growth performance effects of feeding tropical kudzu (*Pueraria phaseoloides*) leaf meal to broilers. They concluded that, although the tropical kudzu leaf meal was rich in nutrients, tropical kudzu leaf meal should not be included in broiler diets as it led to poor growth rates. However, there are a growing number of researchers that are assessing leaf meals as an alternative protein supplement in modern poultry diets [77,78]. Thus, further research should assess the potential viability of kudzu's use as a protein supplement in countries that have limited access to modern protein supplements (e.g., soybean meal). This would indicate that kudzu can be of real relevance for non-herbivore species such as poultry.

9. Summary and Applications

Kudzu's high quality nutrient composition, degradability, and palatability suggest that it can be a valuable potential feedstock for livestock species. Its widespread distribution and rapid growth rate make it ideally suited as an economical feedstock, particularly in regions of scarce feedstuff availability. Producers must recognize, however, the challenges of managing kudzu for grazing and browsing species. With kudzu's unique growth habits as a climbing vine, containing livestock species in areas of high kudzu mass can be challenging and may require considerable ingenuity. Furthermore, efforts to prevent overgrazing/overbrowsing should be highlighted. Kudzu leaf volume can be quickly depleted, effectively limiting kudzu's use as a feedstock. Overgrazing/overbrowsing would be a preferred approach if the producer was attempting to control kudzu with livestock, but not if using as a sustainable source of nutrients.

This review has attempted to coalesce an array of information on kudzu into a comprehensive overview of its characteristics and potential significance as a feedstuff for a variety of domestic animal species. Much information, however, remains to be elicited on kudzu. Kudzu is often viewed in a negative light as an invasive weed species. Kudzu is, however, much more than that and holds significant potential as a feedstock in the United States and other countries where nutrient availability for production animals is limited.

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