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The United States Department of Agriculture (USDA) has one agency that is charged with providing technical assistance to private landowners. This agency is called the Natural Resources Conservation Service (NRCS) and has offices that serve every county in Texas. The NRCS assists people on a voluntary basis to apply engineering practices, agronomic practices, wildlife management and rangeland management to land.

This agency works one-on-one with private landowners in the development of conservation plans. Agency personnel help landowners make decisions concerning goals and objectives of their operation and choose the best practices to apply in a timely manner to meet the needs of the land, while obtaining the goals and objectives of the landowner. These decisions are recorded in a conservation plan, and practices are scheduled to achieve the goals and objectives. This conservation planning is done in partnership with local soil and water conservation districts, which are political subdivisions of the state of Texas. This process allows NRCS, as a federal agency, to work with private landowners.

The NRCS also works with private individuals and groups to implement conservation on the ground in concert with several Farm Bill programs that provide financial assistance for installing conservation practices. Programs address brush management, wildlife management, grazing management, range and pasture planting, cross fencing, water development for livestock, irrigation systems, erosion control, and programs that are specific for restoration of wetlands and rangelands. The 2018 Farm Bill offers America's agricultural producers and nonindustrial private forest landowners more assistance than ever before to voluntarily conserve natural resources on our Nation's privately owned farm and ranch lands.

Farm Bill financial assistance programs include the Environmental Quality Incentives Program (EQIP), the Conservation Stewardship Program (CSP), the Agricultural Conservation Easement Program (ACEP), and the Regional Conservation Partnership Program (RCPP).

For more information, contact a local NRCS office, USDA Service Center, local conservation district, or visit www.nrcs.usda.gov/texas.

Management Strategies for Sustainable Pastures and Beef Production

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For those of us who may ask, "I wonder what they meant when they said...?" we can always rely on the "authority" of Webster's Dictionary with definitions for current terminology in Agriculture and Corporate Business, including the following:

- **Management** - "Judicious use of means to accomplish an end; skillful treatment; to control and direct; executive skill."
- **Strategies** - "The large-scale planning and directing of operations in adjustment to combat area (climatic diversity)."
- **Sustainability** - "The ability to maintain or cause to continue in existence or a certain state, or in force or intensity."
- **Maintain** – "To continue or persevere in or with; to carry on; to hold or keep in any condition especially in a state of efficiency."

With respect to sustainability of forages and pastures for cattle production, management strategies provide guidance and set expectations and objectives for the overall property enterprises which focus on pastures and cattle production goals. From the perspective to "maintain," promote, or enhance sustainable pastures, managers should implement stocking strategies based on relevant, comparative data from Research and/or Extension publications. In addition, managers use on-site, visual assessments and mental integration of cause-and-effect impact on pasture-animal performance. Thus, management strategies include an array of input-output decisions with potential objectives to "match" forage-animal requirements for production and economic rewards (Rouquette, 2015).

Some of the input information that owners and managers may seek includes some of the following questions: 1) What forages are present on my property, and which forages are best adapted to my vegetation-climatic area? 2) What is the soil fertility status of my pastures, and how much, if any, fertilizer is required for my desired level of forage production? 3) What is the best stocking rate for my operation, and what visual or measured "indicator" shows an optimum stocking rate strategy for sustainable cattle production? 4) Should I produce or purchase hay, and how do I know if a supplemental protein or energy feed may be needed? 5) What breedtype of cattle are best adapted to my vegetation zone, and what season(s) should they calve? and 6) How can I plan a forage-cattle operation system that includes a sustainable ecosystem which encourages wildlife food and habitat? (Rouquette & Aiken, 2020).

Stocking strategies should be characterized within a specific vegetation zone and combined with the Art and Management of efficient forage utilization and sustainability for the desired or optimum pasture-animal production. Figure 1 is a schematic that shows Inputs, driven primarily by climate, soil, and forage, and Outputs, driven primarily by production per unit land area. In-between the Inputs and Outputs are the management Decisions, which include stocking strategies, of which stocking rate has the primary influence (Rouquette, 2015).

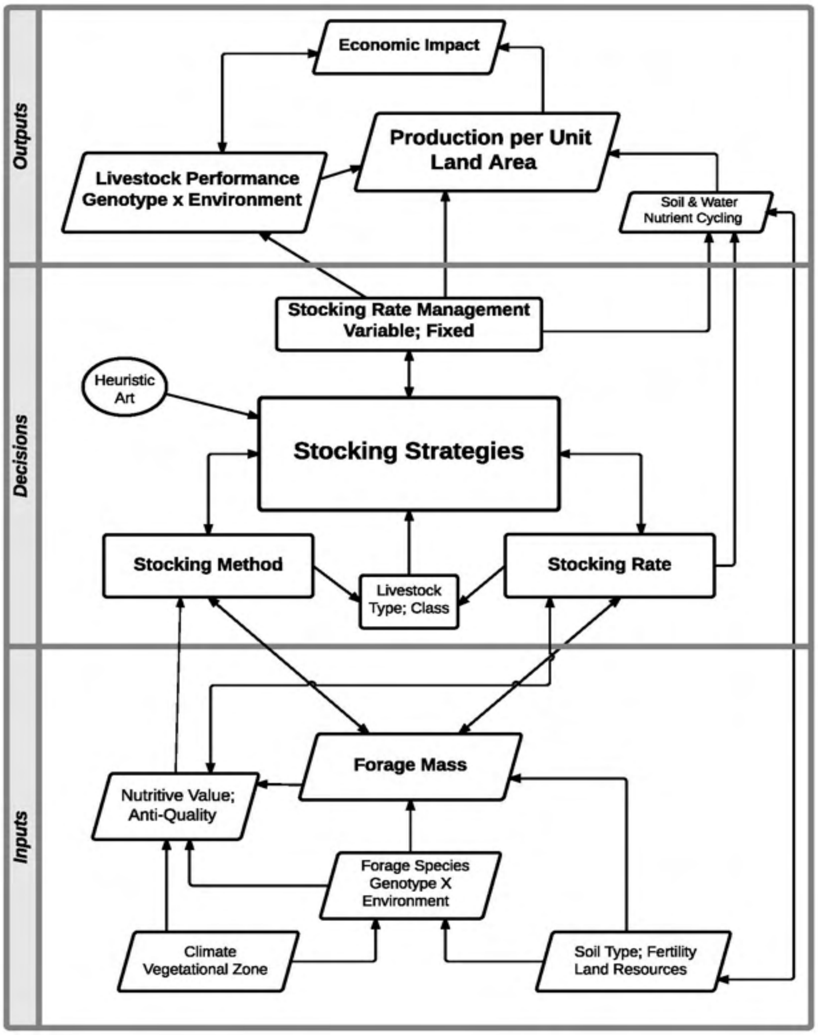


Figure 1. Inputs and outputs of pasture-animal systems as directed by stocking strategy decisions. (Adapted from F.M. Rouquette, Jr., 2015 Crop Sci. 55:2513-2530.)

Sustainability of pastures and cow-calf production in the US has received increased attention during the past few years. The increasing land values and ownership scenarios, redirected agricultural production objectives, and financial requirements for new (novice) ownership affect land use, livestock enterprises, and sustainability of the beef industry (Rouquette, 2017). Like many business enterprises, agriculture has similar concerns of sustainability with livestock products and production. The US Roundtable for Sustainable Beef (USRSB) is a multi-stakeholder initiative that was developed to support sustainability of the US beef value chain (USRSB, 2016). The USRSB has worked in collaboration with the Global Roundtable for Sustainable Beef (GRSB, 2016) to meet goals for beef value. Consequently, the GRSB has defined "sustainable beef" as a socially responsible, environmentally sound, and economical product. And, this product prioritizes natural resources, efficiency and innovation, people and the community, animal health and welfare, and food. Socially responsible is a synonym for

"Management." The primary definition of sustainable beef is dependent and controlled by management strategies and practices for environmental stability and economic returns. Some of the primary components of sustainable beef are illustrated in Figure 2. Site-specific vegetation zones, pasture ecosystems, management, and stocking strategies are the main components that influence sustainability of pastures and livestock production. The overall intensity of the operation is management specific. Thus, beef production and the beef value chain are controlled by biological-economic risks and stewardship-legacy objectives (Rouquette, 2017).

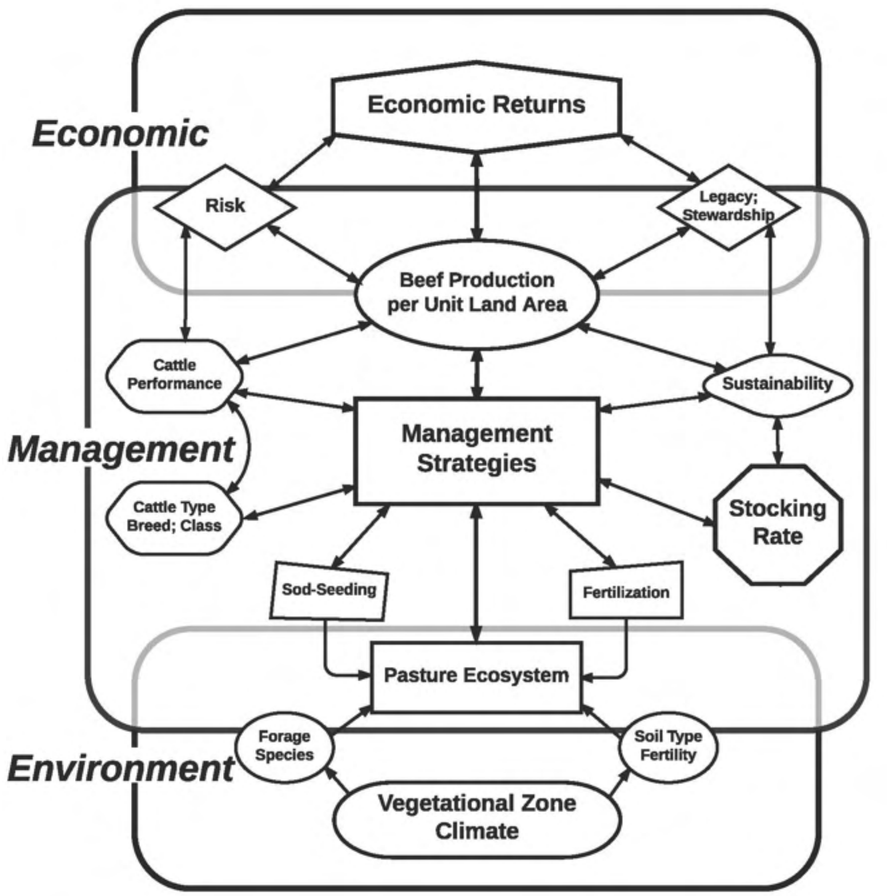


Figure 2. Sustainability of cow-calf production controlled by environment, management, and economic considerations. (Adapted from F.M. Rouquette, Jr., 2015 Crop Sci. 55:2513-2530.)

Production per animal and per unit land dictates the economic effect of the system, and is influenced primarily by stocking rate and secondarily by stocking method. Many stocking strategies have been proposed and incorporated to implement forage-animal production systems with outcomes that seek to optimize animal gains without the destruction of the forage resource. In other words, strategies that will "maintain" and "sustain" the plant-animal ecosystem are desired. In some of the early grazing research studies from the 1950s, management and stocking strategies for optimum forage utilization and animal performance introduced the concept of Flexible Grazing Management which was led by Dr. Roy E. Blaser (Blaser et al., 1962). Some of the management strategies evaluated from 1956 to 1982 by Blaser and coworkers included: a) fattening steers on pastures; b) first and last rotational grazers; c) top and bottom grazers; and d) creep or forward-creep grazing.

Stockers and Warm-Season Perennial Grasses

Numerous grazing experimentation using weaned, stocker calves on warm-season perennial grass pastures were targeted at forage utilization and animal performance to document sustainable management principles. Figure 3 illustrates the general forage production of warm-season grasses during the active growing period. Some stocking strategies used to enhance stocker gains from pastures included the following:

- **Animal Breedtype, Age, and Weight.** Young (< 6 mo), lightweight (< 450 lb), non-Brahman crossbred stockers grazing in the Gulf-Coast and southeastern US region have much lower ADG than older, heavier calves. Optimum to maximum ADG for steers stocked on bermudagrass, for example, may be achieved with long-yearlings weighing >650 lb, with a body condition score of ≤4, and having Brahman influence (Oliver, 1972, 1978; Rouquette et al., 2005).
- **Forage Variety or Cultivar.** The ADG of stockers is directly related to nutritive value (TDN, Crude Protein) and available forage mass. Among warm-season perennial grasses, 'Tifton 85' bermudagrass has produced greater stocker gains than other grasses (Hill et al., 1993). Tifton 85 bermudagrass has some of the highest digestibility and the best potential for optimum or maximum ADG from bermudagrass pastures.
- **Stocking Rate.** Adequate forage mass availability that allows stockers to selectively graze high percent leaf components results in optimum to maximum ADG. Results from grazing research have shown that optimum stocker gain is related to the amount of forage available for consumption. Expressing stocking rate as Forage Allowance (lb DM forage : lb Body Weight) shows that forage allowance > 1.0 : 1.5 is necessary for optimum ADG and gain per acre.
- **Stocking Method.** Continuous stocking and numerous "types" of rotational stocking approaches have been used to enhance stocker gains. The subject of continuous vs. rotational stocking has led to an active debate between scientists and among stakeholders. One of the primary strategies that results in reduced to no ADG from a rotational stocking venture is that of forcing stockers to have a high percent utilization of forage in the resident paddock. This "forced consumption" results in intake of low nutritive value stem portions before moving to another paddock. Regardless of any data that may provide an alternative or equal advantage for continuous vs. rotational stocking, the method of choice selected by a manager or stakeholder does not have to be scientifically assessed to be the "best method." Rather, the stocking method used must provide a "comfort zone" that has reduced risk and the perception of being the "best method" for the stakeholder's objectives (Bransby 1988, 1991).
  Alternative stocking strategies using a first-last rotational method (Blaser, et al., 1986), and which may incorporate a two-herd (Rouquette et al., 1992) or a three-herd system (Rouquette et al., 1994) on bermudagrass pastures significantly enhanced ADG of the first herd. In this scheme, the first grazers consumed only the top third of the forage available which had much higher nutritive value than the lower two-thirds remaining for the next herd.
- **Supplementation.** Numerous supplementation grazing experiments have been evaluated by scientists as a method of enhancing ADG compared to pasture-only stockers.

Depending upon the objectives, the foci of these experiments ranged from: 1) using levels and nutrient concentration of supplement to increase stocking rate and gain per acre; to 2) substituting supplements for reduced forage available in pasture; to 3) using supplements to increase ADG for a niche market; to 4) achieving the most cost-effective method of supplementation. In general, daily supplementation of 0.2% to 0.3% of animal Body Weight has shown the best biological efficiencies of supplement to extra gain ratio. The cost of the additional gain is most always the primary objective of a supplementation program for stockers.

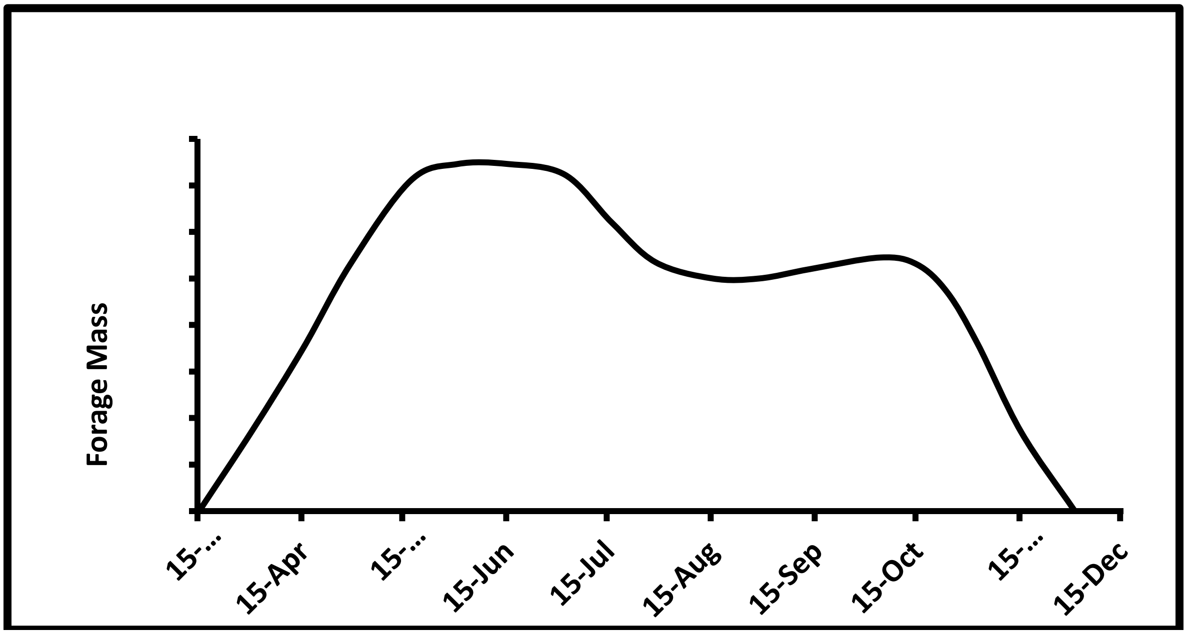


Figure 3. Illustration of forage dry matter mass variations of warm-season perennial grass during growth season.

Stockers and Cow-Calf on Winter Annual Forages

Active grazing can be extended into the fall, winter, and early spring using cool-season annual grasses or grass-clover management options (Mullenix & Rouquette, 2018). Small grains that are adapted to the Southern US include cereal rye, wheat, oats, and triticale. Rye has shown the best tolerance to low pH (acidic) soils. These small grains when combined with annual ryegrass have a bimodal forage DM accumulation trait (Figure 4). With a stocker operation, stocking strategies present challenges that are primarily related to fertilization with N and climatic diversity. With the major forage production occurring in the late-winter to early spring months, stocking rates have to be flexible to allow for proper utilization. Stocking strategies and stocking rates that are appropriate at initiation of grazing in November to December may be too high in December to January, and these initial stocking rates maybe too low in February to April (Rouquette, 2015). Thus, the stocking strategy for stocker cattle in which optimum to near-maximum gain per animal (ADG) and gain per acre are achieved must incorporate a flexiblstocking rate that may be two times greater in the spring than in the fall (Rouquette et al., 2013).

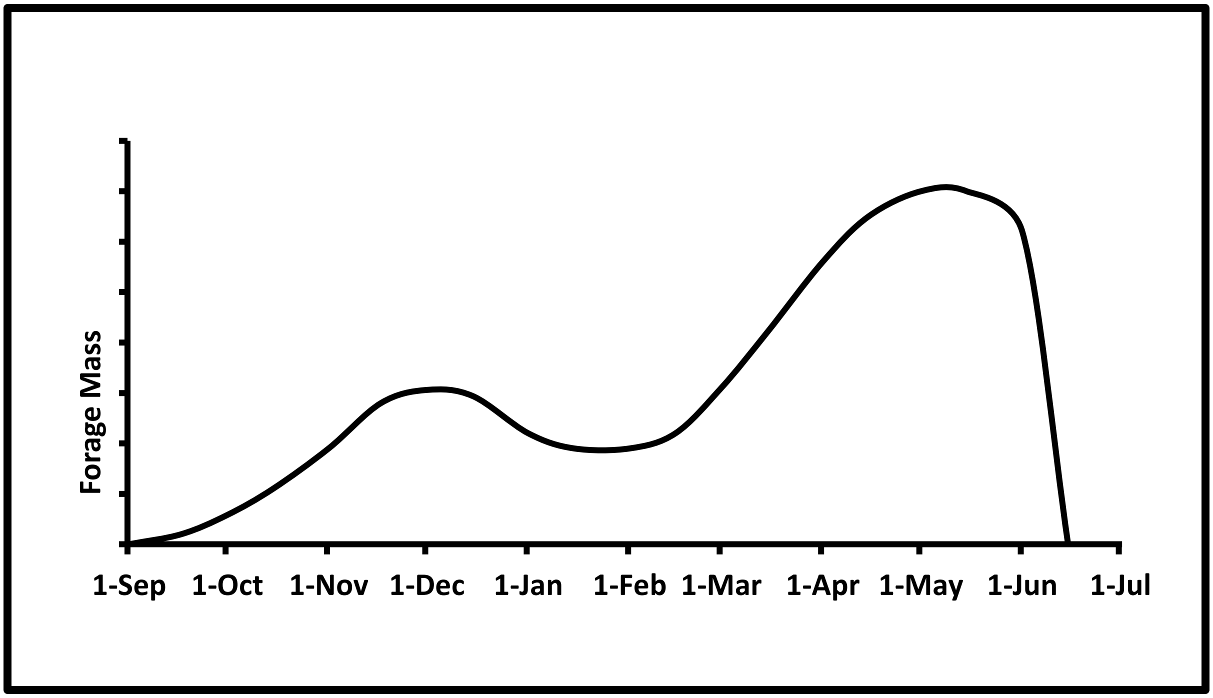


Figure 4. Bimodal forage mass and growth attributes of small grain and annual ryegrass pastures.

Perhaps one of the most recommended stocking strategies for small grain + ryegrass pastures is that of using cows and calves to assist with desired grazing pressure or forage availability. A commonly used stocking strategy to match forage production with utilization has been that of using limit-grazing of cows and calves or stockers (Altom, 1978). Some of these limit grazing strategies may involve grazing 2 to 3 days per week, 2 to 3 hours per day, or other combinations that allow managers to have a daily or weekly appraisal of forage produced and utilized.
For cows and calves, annual ryegrass and/or clovers have long been used to extend the grazing season on warm-season perennial grass pastures. The magnitude of stocking rate effects on cow-calf performance during a 29-year period has shown the relationship of forage mass and performance (Rouquette, 2017), and the impact on stand maintenance (Rouquette et al., 2011).

Cow-Calf

With respect to cows and calves, there are several management options that may be used for sustainable pasture and beef production. In the southeastern states from Interstate 20 to the Gulf of Mexico, warm-season perennial grasses are the basic forages for pastures. Figure 3 shows the general forage growth of these grasses during the year, from time of emergence from winter dormancy in the spring to time of active growth after the first killing frost in the fall. Cow-calf systems are therefore managed over a 365-day period with the basic pasture grass becoming dormant during the winter. Thus, to provide a constant source of forage for daily consumption, an array of strategies may be implemented that includes winter-annual forages and/or hay with stockpiled warm-season, perennial grasses with or without supplementation (Figure 5) (Rouquette, 2020).

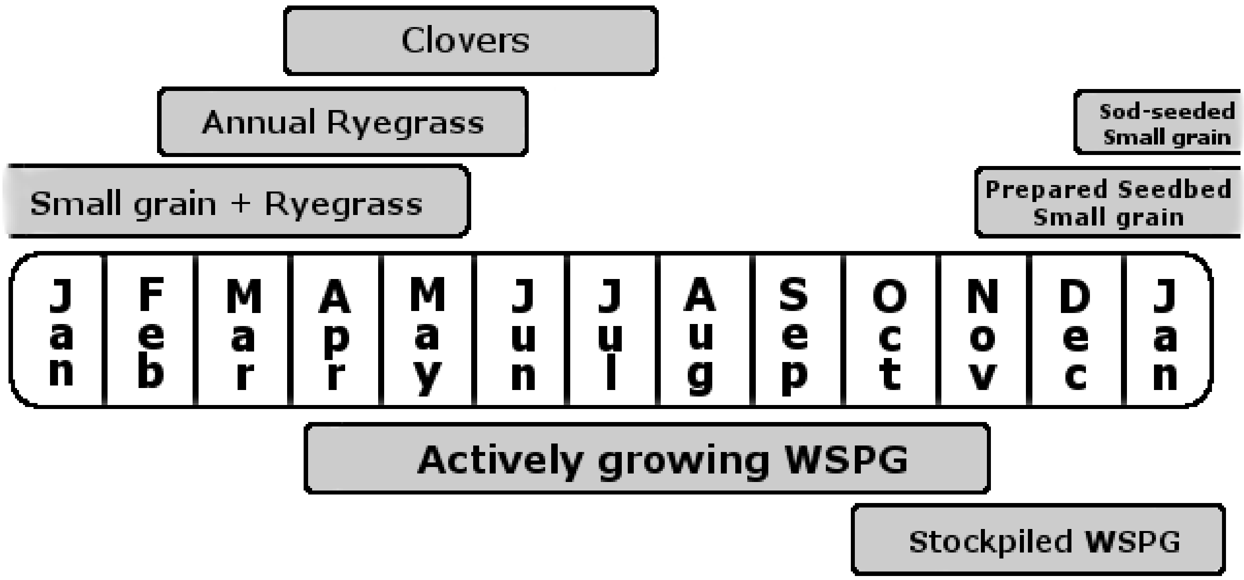
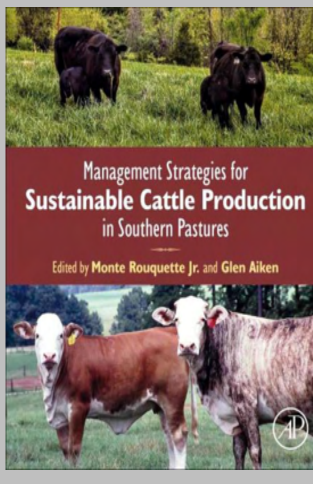


Figure 5. Forage combinations with warm-season perennial grasses (WSPG) for 365-day grazing in Hardiness Zone 8.

Time of calving is a management decision with considerations given for pastures within a specific vegetation zone. The choice and selection of a calving season offers challenges for management to match forage production traits and subsequent nutritive value of pastures with the opportunities for rebreeding the cow herd. Management objectives for calving season include desired weaning percent, weaning weight, and percent rebreeding. One of the most important considerations for rebreeding the cow herd is that of body condition score (BCS) of the cow at time of calving (Rouquette et al., 2018). Although there are always some differing circumstances, cows should have a BCS of 5 or greater at time of calving for successful rebreeding in the designated season. To decide on the best calving season for a specific property, some of the following objectives and decisions should be considered and explored by management (Figure 6). The most appropriate strategies to attain acceptable BCS and reliable, sustained 12-month calving intervals are related to the forage and pasture conditions during the dry cow period from time of weaning to the next calf. Thus, much if not all of the success of a 12-month calving system is due to the management of dry cows and pastures during the 3 to 4 months pre-calving.

- A warm-season perennial grass pasture that allows for overseeding with cool-season annual forages such as small grain, ryegrass, and clover.
- The calving season that offers the best opportunity to wean heavy-weight calves.
- The calving season that offers appropriate forage-pastures for dry cows to meet nutritional requirements for weight gain and with reduced costs for supplementation and labor.
- The calving season that offers the best opportunities for merchandizing/selling calves and cull cows.
- Pasture availability for retained ownership from time of weaning for an additional 100 to 200 days of grazing.



Management Strategies for Sustainable Cattle Production in Southern Pastures

Edited by: **Monte Rouquette, Jr.**, Regents Fellow and Professor of Forage Physiology, Texas A&M AgriLife Research Center – Overton, TX, and **Glen Aiken**, Center Director, UF-IFAS North Florida Research and Education Center – Quincy, FL

"Provides strategies to optimize cattle welfare and to help improve the sustainability of pastures and profitable cattle production."

KEY FEATURES

- **Documents the effects of cattle grazing on greenhouse gas emissions and carbon footprints.**
- **Discusses strategies to enhance soil fertility, soil health, and nutrient cycling in pastures.**
- **Provides information on the use of stocking rates, stocking strategies and grazing systems to optimize biological and economic implications of cow-calf production and weaned calves and stockers.**
- **Presents strategies for cattle supplementation and watering systems to minimize negative impacts on water and soil health.**
- **Describes pasture systems, production-harvesting, and consumer preferences for pasture-finished beef.**
- **Includes methods for weed control to maintain pasture condition and ecosystem stability.**
- **Describes management strategies to integrate cattle operations with wildlife sustainability.**
- **Chapters authored by 26 nationally and internationally recognized scientists from land grant universities and USDA/ARS centers in the southeastern US.**
- **A practical resource for scientists, students, and stakeholders on management strategies for pastures.**

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Figure 6. Management Strategies for Sustainable Cattle Production in Southern Pastures

Forage and pasture options for the more humid regions that include bermudagrass and cool-season annual forages, and which fit calving seasons for Fall (Table 1), Winter (Table 2), and Spring (Table 3), are provided as examples of management strategies (Rouquette et al., 2020). The long-term, 29-year relationship of lactating cow and suckling calf weight gain with stocking rate, expressed as Forage Allowance, on bermudagrass pastures overseeded with ryegrass or clover, is shown in Figure 7 (Rouquette, 2017).

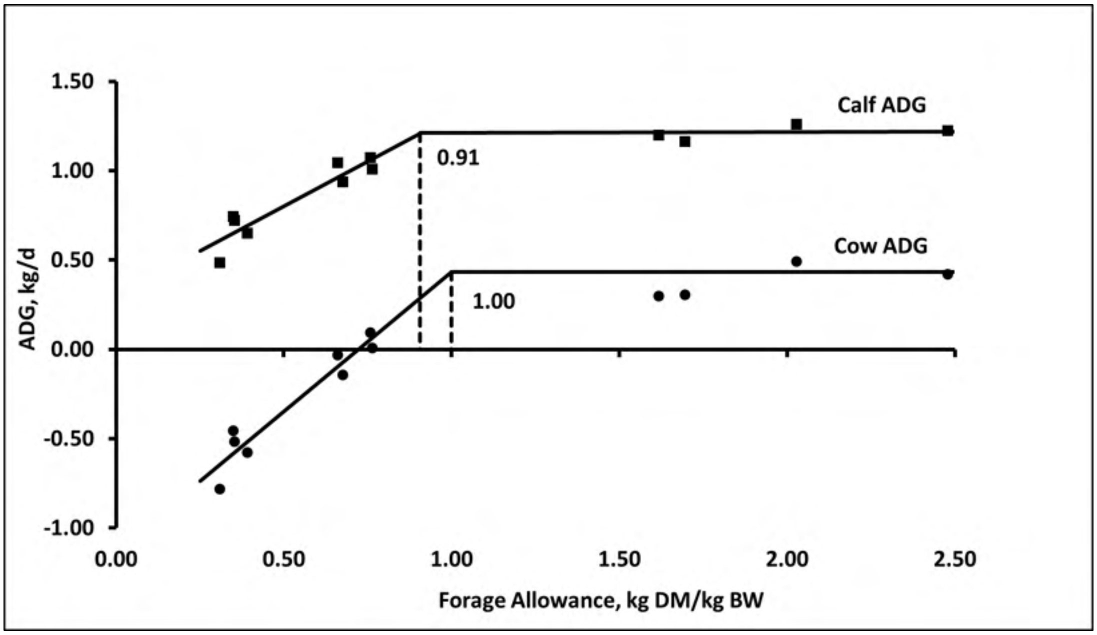

Figure 7. Relationship of cow and suckling calf ADG with forage allowance using a 29-yr stocking rate data set.

Table 1. Forage and pasture options for fall-calving cows.

MONTH	ANIMAL ACTIVITY	FORAGES AND PASTURES
AUG	Dry Cow	Warm season perennial grass (WSPG) pasture[1]
SEP	Calve	WSPG pasture
OCT	Calve; Suckling Calf	WSPG pasture
NOV	Calve; Suckling Calf	Stockpiled forage; WSPG pasture; Hay and/or supplement
DEC	Cow-calf; Suckling Calf **Dec1**: Initiate Breeding	Stockpiled forage; Hay and/or supplement; Limit-graze small grain[2] + annual ryegrass (option)
JAN	Cow-calf; Suckling Calf; Breeding Continues	Limit-graze small grain + annual ryegrass (option); Hay and/or supplement
FEB	Cow-calf; Suckling Calf **Feb15**: Terminate Breeding	Full-time graze small grain + annual ryegrass (option); Ryegrass and/or clover
MAR	Cow-calf; Suckling Calf	Full-time graze small grain + annual ryegrass (option); Ryegrass and/or clover
APR	Cow-calf; Suckling Calf	Ryegrass and/or clover; WSPG
MAY	Cow-calf; Suckling Calf	Ryegrass and/or clover; WSPG
JUN	**Jun15**: Initiate Weaning Cow-calf; Dry Cow	WSPG
JUL	**Jul 15**: Finalize Weaning Dry Cow	WSPG

[1]Bermudagrass, Bahiagrass; native grasses
[2]Rye, oats, wheat

Table 2. Forage and pasture options for winter-calving cows.

MONTH	ANIMAL ACTIVITY	FORAGES AND PASTURES
DEC	Dry cow	Warm season perennial grass (WSPG)[1]; Stockpiled forage; Hay and/or supplement;
JAN	Calve	Hay and/or supplement
FEB	Calve; Suckling Calf	Ryegrass and/or clover
MAR	Calve; Suckling Calf	Ryegrass and/or clover
APR	Cow-calf; Suckling Calf Apr15: Initiate Breeding	Ryegrass and/or clover
MAY	Cow-calf; Suckling Calf; Breeding Continues	Ryegrass and/or clover; WSPG
JUN	Cow-calf; Suckling Calf; Breeding Continues	WSPG
JUL	Cow-calf; Suckling Calf Jul1: Terminate Breeding	WSPG
AUG	Cow-calf; Suckling Calf	WSPG
SEP	Cow-calf; Suckling Calf Late-Sep: Initiate Weaning	WSPG
OCT	Late-Oct: Finalize Weaning Dry Cow	WSPG; Stockpiled forage
NOV	Dry Cow	WSPG; Stockpiled forage; Hay and/or supplement

[1]Bermudagrass, Bahiagrass; native grasses

Table 3. Forage and pasture options for spring-calving cows.

MONTH	ANIMAL ACTIVITY	FORAGES AND PASTURES
FEB	Dry Cow	Hay and/or supplement
MAR	Calve; Suckling Calf	Ryegrass and/or clover
APR	Calve; Suckling Calf	Ryegrass and/or clover
MAY	Calve; Cow-calf; Suckling Calf	Ryegrass and/or clover; Warm season perennial grass (WSPG)[1]
JUN	**Jun1**: Initiate breeding Cow-calf; Suckling Calf	WSPG
JUL	Cow-calf; Suckling Calf; Breeding Continues	WSPG
AUG	**Aug15**: Terminate breeding Cow-calf; Suckling Calf	WSPG
SEP	Cow-calf; Suckling Calf	WSPG
OCT	**Oct15**: Initiate weaning	WSPG
NOV	**Nov15**: Finalize weaning Dry Cow	WSPG; Stockpiled forage; Hay and/or supplement
DEC	Dry Cow	WSPG; Stockpiled forage; Hay and/or supplement
JAN	Dry Cow	Hay and/or supplement

[1]Bermudagrass, Bahiagrass; native grasses

Prolonged, high stocking rates and resultant low herbage mass (HM) under continuous stocking can cause substantial stand loss of both Coastal and common bermudagrass pastures. However, with the aggressive and persistent nature of invasive bermudagrass ecotypes, bermudagrass species continued to provide nearly complete ground cover under N-fertilization regimens. Tables 4-7 show the impact of long-term stocking rates and N fertilization on stand maintenance of bermudagrass. In the absence of N fertilization for 20 years, bahiagrass was a significant invasive species on low HM pastures. Under high HM, the originally planted Coastal and common bermudagrass made up 70 to 75% of the bermudagrass present after 38 years of grazing management. The genetic similarity dendograns and cluster analyses provided profound identification differences among bermudagrass ecotypes. Further genetic analysis would be needed to determine whether these differences were due to contamination from common bermudagrass types in adjacent areas of from intercrossing of Coastal bermudagrass with common bermudagrass pollen. Under grazing strategies for animal performance and production per unit land area, stocking rates of 1 cow-calf pair per ac (1250 to 1300 lb BW/ac) were sufficiently low enough to allow for adequate HM to promote bermudagrass stand maintenance. Low HM created by stocking rates of 2 to 3 cow-calf pair/ac (3150 to 4700 lb BW/ac) did not eradicate bermudagrass ecotypes and other sod-forming grasses; however, these stocking rates substantially eliminated the originally planted Coastal and common bermudagrass (Rouquette, et al., 2011).

Table 4. Long-term stocking and fertility regimen effects on percent stand of forages in Coastal bermudagrass pastures (Rouquette, et al., 2011).

	Bermudagrass	Bahiagrass	Other‡
	------------------------%------------------------		
Fertility Regimen			
N plus ryegrass	99.8 a†	0 b	0.24 a
No N plus clover	80.6 b	19.3 a	0.14 a

† Letters in a column grouping, followed by a different letter, differ at $p < 0.01$.
‡ Crabgrass and miscellaneous weeds.

Table 5. Long-term stocking and fertility regimen effects on percent stand of forages in common bermudagrass pastures (Rouquette, et al., 2011).

	Bermudagrass	Bahiagrass	Other‡
	------------------------%------------------------		
Herbage Mass			
Low	87 a†	0 b	13 a
Medium	68 b	30 a	3 c
High	64 b	30 a	6 b
Fertility Regimen			
N plus ryegrass	97 a†	1 b	2 b
No N plus clover	49 b	39 a	12 a

† Letters in a column grouping, followed by a different letter, differ at $p < 0.01$.
‡ Crabgrass and miscellaneous weeds.

Table 6. Invasive bermudagrass ecotypes and bahiagrass in Coastal bermudagrass pastures under long-term stocking intensities and fertility regimens (Rouquette, et al., 2011).

Fertility regimen†	Herbage mass	Coastal bermudagrass	Invasive bermudagrass ecotypes	Bahiagrass
		------------------------%------------------------		
N plus RYG	Low	14 b‡	86 a	0
N plus RYG	Medium	71 a	30 b	0
N + RYG	High	75 a	25 b	0
No N plus CLV	Low	21 b	73 a	7 b
No N plus CLV	Medium	24 b	45 b	31 a
No N plus CLV	High	78 a	22 c	0 b

†RYG, ryegrass; CLV, clover.
‡Means within a column and treatment not followed by the same letter differ at $p < 0.01$.

Table 7. Invasive bermudagrass ecotypes and bahiagrass in common bermudagrass pastures under long-term stocking intensities and fertility regimens (Rouquette, et al., 2011).

Fertility regimen[†]	Herbage mass	Common bermudagrass	Invasive bermudagrass ecotypes	Bahiagrass
		---------------------------	%	---------------------------
N plus RYG	Low	57 b‡	43 a	0 a
N plus RYG	Medium	60 a	41 a	0 a
N + RYG	High	66 a	34 a	0 a
No N plus CLV	Low	27 b	27 a	46 a
No N plus CLV	Medium	24 b	18 a	59 a
No N plus CLV	High	72 a	28 a	0 b

†RYG, ryegrass; CLV, clover.
‡Means within a column and treatment not followed by the same letter differ at $p < 0.01$.

Considerations for Management Strategies

The most reliable and predictable factor for indexing sustainability of cow-calf production is that of persistence and stand maintenance of forages in pastures of a vegetation zone. Stocking rate, intensity of defoliation regimens, and soil nutrient upkeep are the primary management strategies that control the desired level of pasture and cow-calf production. Management controls the degree of intensity of the cow-calf or stocker operations which are based on level of economic risk and desired environmental and stewardship options. These management strategies should be based on integrating relationships of pasture ecosystems and stand maintenance, environmental awareness, economic implications, and legacy-heritability objectives of property for strategic, sustainable forage-livestock production (Rouquette, 2017).

Management and stocking strategies are uniquely integrated with grazing pressure, stocking rates, deferment of pastures, and harvested forage. Stocking strategies should consider forage growth and nutritive value inputs and allow modifications on defoliation to match animal nutrient requirements in order to produce the desired level of production. The objectives of stocking strategies are targeted at matching stocking rates and stocking methods with climatic conditions for a specific ecoregion with the purpose of exploring optimum biological and economic impacts for a sustainable system (Rouquette, 2015). Stocking strategies should include economic goals and objectives in addition to risk awareness for sustainable pasture-animal production systems.

Successful managers should always have a multi-level “decision-indicator” that includes current, weekly, monthly, and seasonal expectations of forage growth and accumulation which are influenced by climatic conditions. Perhaps the “best strategy” is to “know” and “expect” the potential surplus or deficits in forage accumulation for the near future. Management should implement the “best approach” for optimum utilization via grazing, changes in stocking rate, altering the stocking method, and/or mechanical harvesting. Implementing management strategies requires a similar “mindset” as one preparing for a competitive event: The competitors for management are climatic diversities and appropriate timing to match soil-forage attributes with animal requirements for sustainable livestock production and an economically viable product (Rouquette & Aiken, 2019).

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Selection of Calving Season: Matching Forages, Pastures, and Stocking Strategies

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Much of the following discussion of calving season was taken from Rouquette et al., 2020. "Time of calving is a management decision. Certainly, given no boundaries for selection and management of warm-season perennial grass pastures with overseeded cool-season annual forages and/or hay and supplement, calving seasons will move toward the time for optimum forage availability and nutritive value. The selection of a calving season or seasons offers the challenges of matching forage production and nutritive value of pasture systems with rebreeding the cow herd. Opportunities for management also include a desired level of weaning percent, weaning weight, and percent rebreeding. Regardless of the calving season(s) selected by management, one of the most important considerations for calving and rebreeding for a consistent 12-month calving system is that of body condition score (BCS) of the cow at time of calving. Although there may be some "it depends" scenarios, cows should have a BCS of about 5 or greater at time of calving (Herd and Sprott, 1986). A body condition of 5, along with appropriate dry matter and forage nutritive value, will allow management strategies for use of stockpiled forage and/or energy-protein supplementation.

The most appropriate management strategies to attain BCS and reliable 12-month calving intervals are uniquely related to the forage-pasture conditions during the dry cow period from time of weaning to the next calving event. Too often, dry cows are pastured on reduced levels of forage mass and nutritive value that do not allow for increased body weight or condition. Thus, the success of a 12-month calving system is largely due to management strategies for cows and pastures during the approximate 3-month period when the cows are dry (approximately 90-days pre-calving).
In order to answer the question, "When is the best season of the year for calving on my property?" some of the following objectives and decisions should be explored by management:

- A warm-season perennial grass pasture that provides the most productive and reliable forage production, and which offers opportunities for hay and/or stockpiled forage for wintering.

- A warm-season perennial grass pasture that allows for overseeding with cool-season annual forages such as small grain, ryegrass, and/or clover.

- The calving season that offers the best opportunity to wean heavy weight calves.

- The calving season that offers forages/pastures that meet nutritional requirements for dry cow weight gain and with reduced costs for hay, supplementation, and labor.

- The calving season that offers the best timing or seasonal opportunities for merchandizing/selling calves and cull cows.

- Forage and pasture availability for potential retained ownership from time of weaning for an additional 100 to 200 days grazing. Retained ownership post-weaning could fit any calving season; however, fall-born calves would graze during the summer months, whereas winter- or spring-born calves would graze during the winter-spring period.

Fall-Calving Cows

Forage and pasture options for fall-calving animal activities are shown in Table 1. Fall-calving cows wean calves in June or early July depending upon management choice and climatic impact on bermudagrass or bahiagrass growing conditions. Two of the positive factors for fall-calving along the I-20 Corridor include the potential for heavy weight calves at weaning, and having dry cows during the hot, summer months. During the summer, the nutritive value of any moderately-managed warm season perennial grass meets or exceeds the nutritive requirements of a dry, pregnant, mature cow to maintain a BCS of $\geq$ 5 without the need for protein-energy supplementation. The initiation of breeding on 1 December will result in early September calves. With a suggested 75-day breeding season (1 December to 15 February), calving will be completed on actively growing bermudagrass by mid-November. Forage, hay, supplementation, and other pasture options for fall calvers are shown in Table 1. With advanced planning and preparation, small grain with or without annual ryegrass can be available for grazing by late November on prepared seedbed or mid- to late December if sod-seeded (Rouquette, 2020). Small grain plus ryegrass pasture costs may range from $150 to $250/ac depending upon the magnitude and extent of fertilization required. With average climatic conditions and forage growth during December - January along the I-20 Corridor, about 2 to 4 acres may be required for full-time stocking of one 1200-lb cow and 200-lb calf during the winter. One stocking strategy that may be used to reduce costs per cow is that of limit grazing (Altom, 1978). Limit grazing is a method of stocking 2 to 4 cows and calves per acre on small grain plus ryegrass and allowing active grazing for only 2 to 3 hours per day. During the first 2 to 3 hours on small grain plus ryegrass pastures, cows will fill and reduce or terminate active grazing. At this time, cows and calves are removed from these pastures and returned to an adjacent pasture with free choice, unrestricted access to hay or stockpiled forage. A limit grazing system can be used on a daily or every-other-day basis to match defoliation and regrowth of small grain pastures. This stocking strategy also provides a method to prevent overstocking of winter annual grasses. A creep-gate scenario will allow calves to graze winter pasture more often than the limited time that cows have access to small grain-ryegrass.

Table 1. Forage and pasture options for fall-calving cows

MONTH	ANIMAL ACTIVITY	FORAGES AND PASTURES
AUG	Dry Cow	Warm season perennial grass (WSPG) pasture[1]
SEP	Calve	WSPG pasture
OCT	Calve; Suckling Calf	WSPG pasture
NOV	Calve; Suckling Calf	Stockpiled forage; WSPG pasture; Hay and/or supplement
DEC	Cow-calf; Suckling Calf **Dec 1**: Initiate Breeding	Stockpiled forage; Hay and/or supplement; Limit-graze small grain[2] + annual ryegrass (option)
JAN	Cow-calf; Suckling Calf; Breeding Continues	Limit-graze small grain + annual ryegrass (option); Hay and/or supplement
FEB	Cow-calf; Suckling Calf **Feb 15**: Terminate Breeding	Full-time graze small grain + annual ryegrass (option); Ryegrass and/or clover
MAR	Cow-calf; Suckling Calf	Full-time graze small grain + annual ryegrass (option); Ryegrass and/or clover
APR	Cow-calf; Suckling Calf	Ryegrass and/or clover; WSPG
MAY	Cow-calf; Suckling Calf	Ryegrass and/or clover; WSPG
JUN	**Jun 15**: Initiate Weaning Cow-calf; Dry Cow	WSPG
JUL	**Jul 15**: Finalize Weaning Dry Cow	WSPG

[1]Bermudagrass, Bahiagrass; native grasses

[2]Rye, oats, wheat

By about mid-February, annual ryegrass should be available for full-time grazing, and this additional pasture area will also allow for full-time grazing on small grain plus ryegrass pastures. The initiation of stocking cool-season annual forages overseeded on bermudagrass is dependent upon planting conditions, date of planting, fertilization timings, climatic conditions, and whether stocking is to be limited or full-time. Establishment strategies and management for small grain plus ryegrass pastures and annual ryegrass or clover pastures provide a calendar of expected events and dates of implementation for pastures. It is important to remember that not all stocking activities occur on all the pastures at the same time. Therefore, multiple pastures are needed in the overall system of stockpiling forage, establishing cool-season annual forages, and supplying hay and supplementation. In addition, methods of flexible grazing are needed to incorporate graze:rest periods (deferment) for best management of utilization and sustainability of forage with desired animal performance. These strategies allow for stocking rates that provide for risk aversion during unfavorable climatic conditions of drought and/or cold temperatures.

Fall-calving cows and calves can be stocked at levels that match forage production in spring and early summer. Depending on stand of cool-season annual forages and fertilization regimens, stocking rates can vary from 2 to 3 acres per cow-calf to 1 acre per cow-calf. The abundance of spring-summer forage growth for small grain and ryegrass and for bermudagrass allow for flexible stocking and increased stocking rates for 30 to 60 days. This increase in stocking rate/grazing pressure on part of the property enhances forage accumulation and hay or baleage production from other pastures. Weaning weight expectations for fall-born calves weaned in early to late June may range from 650 lb to more than 900 lb. These weights are dependent upon stocking rate and stocking period on cool-season annual forages from February to mid-May, productive bermudagrass in spring and summer, breedtype of cow and lactation potential, and breed of sire with growth attributes. Often, a sire may be a different breed than the cows and/or a Continental breed, wherein all offspring are sold and not retained for replacements (terminal sire).

Winter-Calving Cows

Forages and pasture options for winter-calving cow activities are shown in Table 2. Winter-calving cows, if bull-exposed from 15 April to 1 July (75 days), will start calving in early January. From the time of weaning in mid- to late October, cows can have access to stockpiled bermudagrass until mid- to late December. In general, stockpiled bermudagrass has an optimum time for grazing and utilization in the fall until the onset of winter and accompanying cold, wet weather. Thus, an appropriate stocking strategy is to make near-complete utilization of stockpiled bermudagrass before Christmas. After that time, climatic conditions or grazing frequency causes the bermudagrass to lose its upright growth stature and become prostrate, which creates problems with grazing-intake. During the dry cow period before calving, a protein-energy supplement may be necessary to achieve the desired BCS of ≥ 5 at calving.

After calving in January to March, annual ryegrass and/or clovers provide an excellent, high quality forage for grazing. Annual ryegrass and clover produce their maximum DM from March to mid-May. These cool-season annual forages with or without hay can provide adequate nutrition to meet the nutritive requirements of winter calvers during the first half of the breeding season. Thereafter, fertilized bermudagrass or bahiagrass pastures can satisfy nutritive requirements for the lactating cow during the breeding season. A 75-day or shorter breeding season has been long-suggested as a management strategy to increase overall reproduction efficiency of the cow herd. A cow that requires more than 100 days to rebreed may be a result of previous stocking rates that reduced BCS to levels which prevented onset of estrus; or perhaps the cow is not an efficient reproductive animal for the herd or the economy of operation. Calves that are born within an approximate 75-day period provide for reduced labor inputs for castration and vaccinations, etc., and they can all be weaned on the same day. Weaning all calves at the same time enhances marketing-merchandizing of calves; improves efficiency of pasturing dry cows to meet nutritional requirements; and decreases labor and costs of "working cattle" to accomplish the weaning event. During the last 30 to 45 days of the breeding season, and throughout the lactation period for winter calvers, the primary forage will be warm-season perennial grass pastures. During the summer, there may be opportunities to incorporate summer annual grasses in certain soil types and climatic conditions. White clover may offer some restricted stocking. If a stand of white clover is available, but the acreage is too small for full-time grazing, an excellent opportunity is created for calves to creep graze white clover. In most areas in the I-20 Corridor, summer often includes periods of reduced rainfall events. Thus, to improve efficient forage utilization without engaging in stocking rates that would be detrimental to sustainability of pasture and/or animal performance, multiple pastures allow for grazing-haying options for the overall system. Once the breeding season has been completed, stocking rates could be increased for short periods of time (30 to 45 days), which could reduce cow BCS. This reduction in BCS of the pregnant, lactating cow can be reclaimed post-weaning for the dry cow, if necessary. Flexible stocking methods that include several (4 to 8 or more) pastures can provide for cattle residence and deferment (movement) without a strict rotational stocking scheme. However, there are numerous stocking methods that can achieve individual management objectives such that pasture sustainability and cow reproductive performance are not compromised.

Table 2. Forage and pasture options for winter-calving cows

MONTH	ANIMAL ACTIVITY	FORAGES AND PASTURES
DEC	Dry cow	Warm season perennial grass (WSPG)[1]; Stockpiled forage; Hay and/or supplement;
JAN	Calve	Hay and/or supplement
FEB	Calve; Suckling Calf	Ryegrass and/or clover
MAR	Calve; Suckling Calf	Ryegrass and/or clover
APR	Cow-calf; Suckling Calf **Apr 15**: Initiate Breeding	Ryegrass and/or clover
MAY	Cow-calf; Suckling Calf; Breeding Continues	Ryegrass and/or clover; WSPG
JUN	Cow-calf; Suckling Calf; Breeding Continues	WSPG
JUL	Cow-calf; Suckling Calf **Jul 1**: Terminate Breeding	WSPG
AUG	Cow-calf; Suckling Calf	WSPG
SEP	Cow-calf; Suckling Calf **Late Sep**: Initiate Weaning	WSPG
OCT	**Late Oct**: Finalize Weaning Dry Cow	WSPG; Stockpiled forage
NOV	Dry Cow	WSPG; Stockpiled forage; Hay and/or supplement

[1]Bermudagrass, Bahiagrass; native grasses

Spring-Calving Cows

Forages and pastures of spring-calving cow activities are summarized in Table 3. Spring calving has traditionally been defined as calves born from March through May. As a consequence of the warm-season perennial grass base for pastures and the occurrence of the first killing frost in the I-20 Corridor, calves are usually weaned from mid-October to mid-November at 5 to 8 months of age.

The highest nutritive value pastures for these cows and calves occurs from March to May with overseeded annual ryegrass and/or clovers. From June until time of weaning, bermudagrass or bahiagrass pastures, which have lower nutritive value, are available for grazing. These lower nutritive value pastures and decreased time spent as a suckling calf (age) on these pastures result in reduced weaning weights of spring-born calves, generally ranging from 400 to 650 pounds. This season of calving also mandates a breeding season from 1 June to mid-August for a 75-day period. Since forage nutritive value is at the lowest during this breeding season, cow body condition score must be watched closely for a successful rate of rebreeding. Cows that have BCS < 5 and/or with first calf will likely require energy-protein supplementation during breeding.
With spring-calving, cows are dry from late fall until late winter. Therefore, small grain pastures are usually not a part of the spring-calving pasture system due to status of the dry, pregnant cow. Since spring-calving cows may be dry for 6 months of the year, nutritive requirements for maintenance and/or gain may be met with stockpiled warm-season perennial grasses and/or hay with or without supplementation. Although pasture input costs may be lower compared to fall calvers, calf weaning weights are also significantly lower. Spring calving allows management to retain ownership of lightweight, fall-weaned calves as stockers on small grain plus ryegrass pastures."

Table 3. Forage and pasture options for spring-calving cows

MONTH	ANIMAL ACTIVITY	FORAGES AND PASTURES
FEB	Dry Cow	Hay and/or supplement
MAR	Calve; Suckling Calf	Ryegrass and/or clover
APR	Calve; Suckling Calf	Ryegrass and/or clover
MAY	Calve; Cow-calf; Suckling Calf	Ryegrass and/or clover; Warm season perennial grass (WSPG)[1]
JUN	**Jun 1**: Initiate breeding Cow-calf; Suckling Calf	WSPG
JUL	Cow-calf; Suckling Calf; Breeding Continues	WSPG
AUG	**Aug 15**: Terminate breeding Cow-calf; Suckling Calf	WSPG
SEP	Cow-calf; Suckling Calf	WSPG
OCT	**Oct 15**: Initiate weaning	WSPG
NOV	**Nov 15**: Finalize weaning Dry Cow	WSPG; Stockpiled forage; Hay and/or supplement
DEC	Dry Cow	WSPG; Stockpiled forage; Hay and/or supplement
JAN	Dry Cow	Hay and/or supplement

[1]Bermudagrass, Bahiagrass; native grasses

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Weaning Weights from Fall and Winter Calving Seasons: Influence of Stocking Rates on Pasture

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Forage and pasture research has been a major emphasis at the Texas A&M AgriLife Research and Extension Center at Overton since 1968. During this time, various warm-season perennial grasses have been evaluated for seasonal and total dry matter production and nutritive value. Numerous forages and pasture systems have been grazed with cow-calf and stocker cattle from 1969 to date. During this time, F-1 Hereford x Brahman (HXB) or Angus x Brahman (AXB) cows and their calves have been used in stocking rate and stocking method studies. Stocking rates were used to create different levels of forage mass. Forage allowance calculations have been made for each pasture using the relationship of forage dry matter to animal body weight. Using the comparison of forage allowance to cow and calf ADG, the relationship of stocking rate on animal performance can be documented for use in stocking strategies and management of pastures (Rouquette, 2017). For the past several years at Overton, bermudagrass pastures overseeded with annual ryegrass and/or clover, such as crimson or arrowleaf, have been evaluated using cows and calves (Rouquette et al., 2018). Thus, with overseeded pastures, active grazing is available from about mid-February to early October. In order to evaluate the forage x animal relationships for this entire active forage growing period, bred cows and calves from fall and winter calving seasons were used and stocked at three rates. Additional details on forage x animal performance have been summarized in several publications (Rouquette 2017; Rouquette et al 2018; Rouquette et al 2020).

A major outcome of this grazing research has been the archival of pasture x animal performance data from time of birth to harvest via BeefSys (Rouquette et al 2003). Weaning data on the fall-born (Sept – Nov) and winter-born (Jan – Mar) calves from this research, including weight, age, and weight per day of age are shown in Tables 1, 2, and 3. During this 44 year period, there were 5114 weaned calves used to summarize the effect of stocking rates (low, medium, and high) on weaning weight x birth month. These calves were from HXB or AXB cows with sires that included Angus, Hereford, and Simmental.

Table 1 shows the overall average weaning weights for steers and heifers grouped by birth month. The heaviest weaning weights were for fall-born calves born in September followed by October-born and November-born at 703, 657, and 619 lb, respectively. For winter calves, January-born had the heaviest weaning weight of 625 lb followed by February-born at 600 lb and March-born at 529 lb. Weaning weights were similar for calves born in November or January.

Table 2 shows weaning weights x birth month according to the assigned stocking rate for cows and calves. As expected, steers and heifers on low stocked pastures weaned at heavier weights than calves on high stocked pastures. Considering all 6 birth months and all stocking rates, weaning weights ranged from 755 lb for September-born and low stocking rates to 479 lb for March-born and high stocking rates. Table 3 shows a closer examination of birth month and calf performance at weaning. These data show the weight per day of age, or approximate ADG, and age of calves by birth month and stocking rate. The highest weight per day of age from these 5114 calves ranged from about 2.77 to 2.92 lb/da and occurred at low stocking rates for calves born in February, March, September, October, and November, and at medium stocking rates for calves born in November.

To set priorities for matching forages with calving season, or to match calving season with forages, management strategies must consider the 365-day pasture-animal costs and the calf weight at the time of sale. Fall-born calves (Sept - Nov) are normally weaned in mid- to late June due to the increasing forage dry matter and acceptable nutritive value from bermudagrass. Thus, fall-born calves are usually older and heavier at weaning than winter- or spring-born calves because of forage and pasture conditions for stocking rate. Winter-born and spring-born calves must be weaned in the fall before pasture conditions mandate the use of hay and supplement to over-winter dry, pregnant cows.

Both the fall-born and winter-born calves in these Tables had access to some limited and/or full-time grazing on winter annual forages. Thus, the summary weights are indicative of the inclusion of these high nutritive value forages. Important considerations for calving season and age at weaning are related to matching the genotype x environment for cattle and for forages. Pasture management strategies of calving season and stocking rate can be designed for sustainable forages and optimum animal performance and economic rewards.

Table 1. Average weaning weights for fall and winter born steer and heifer calves.

Birth Month	Weaning Weight[1]
Winter	(lb)
January	625 c[2]
February	598 d
March	526 e
Fall	
September	703 a
October	656 b
November	618 c

[1] 5114 calves during 44 years.
[2] Weaning weights followed by a different letter differ at P < .05.

Table 2. Weaning weights for fall and winter born calves from three stocking rates during lactation.

	Weaning Weight[1]		
	Stocking Rate		
Birth Month	Low	Medium	High
Winter	---------------------- (lb) ----------------------		
January	666 c[2]	635 d	573 f
February	656 c	599 e	537 h
March	564 fg	535 h	479 i
Fall			
September	755 a	698 b	655 c
October	714 b	660 c	594 e
November	691 bc	621 d	543 gh

[1] 5114 calves during 44 years
[2] Weaning weights followed by a different letter differ at P < .05

Table 3. Weight per day of age (DOA) and age at weaning for fall and winter born calves from three stocking rates during lactation

	Stocking Rate[1]					
	Low		Medium		High	
	Age	Wt/DOA	Age	Wt/DOA	Age	Wt/DOA
Birth Month	(d)	(lb/d)	(d)	(lb/d)	(d)	(lb/d)
Winter						
January	251 d[2]	2.68 cd[3]	249 d	2.57 e	250 d	2.30 g
February	234 e	2.82 a	230 e	2.63 d	233 e	2.32 g
March	195 h	2.91 a	201 g	2.72 bc	200 gh	2.40 f
Fall						
September	273 a	2.77 ab	270 b	2.59 e	271 ab	2.42 f
October	258 c	2.78 ab	250 d	2.65 d	255 c	2.34 fg
November	236 e	2.92 a	221 f	2.82 a	234 f	2.44 f

[1] 5114 calves during 44 years

[2] Weaning ages followed by a different letter differ at P < .05.

[3] Weights per day of age followed by a different letter differ at P < .05.

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Long-Term Cow-Calf Performance on Overseeded Bermudagrass Pastures at Different Stocking Rates and Fertility Regimens: 2022 Fertilizer Prices and Costs of Gain

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The "energy crisis" we thought we had encountered a few years ago was just an appetizer compared to the "servings" we're now experiencing in forage-animal production in 2022. Regardless of current domestic oil and gas production policies, captive supplies, import quotas, future inventories, fuel substitutes, or greed, the costs of living and doing business in the US has experienced dramatic price increases. With increased and seemingly ever-increasing energy prices, the costs of "doing business" have caused many to re-think their operating strategies. For the agricultural producer, not only have they experienced increased prices in fuel, fertilizers, and feed ingredients, but they also have had to deal with appraisal districts and increased taxes for all land uses. Management strategies and implementation options for pastures and beef production were drastically altered by the more than doubling of nitrogen fertilizer prices from 2003 to 2008. However, the 2008 prices for fuel and fertilizers were just the introduction to the policy decisions made in 2020 that caused some drastic increases in prices of fuel and fertilizers for 2021 and into 2022. With the current world-wide energy demands, escalating prices of feed grains, and uncertain supplies of oil and gas, beef producers have been forced into major reassessments of management input and cash-flow alternatives. The economic dilemma for producers is that there is no transition period to adapt to the new pasture-beef production cost paradigm. With no likely price reductions in fuel, fertilizer, and feed grains in either the short-term or long-term future, every cash input must be evaluated and scrutinized for potential returns.

Although there are no archived pasture-animal databases to answer all management concerns, there are some specific, long-term, fertilizer regimen x stocking rate experimental data for both common and Coastal bermudagrass from Texas A&M AgriLife Research at Overton (BeefSys, Rouquette et al, 2003). The text that follows will provide forage-animal experimentation information with discussions on general fertilizer x stocking rate management options and projected pasture production and forage persistence for cow-calf operations.

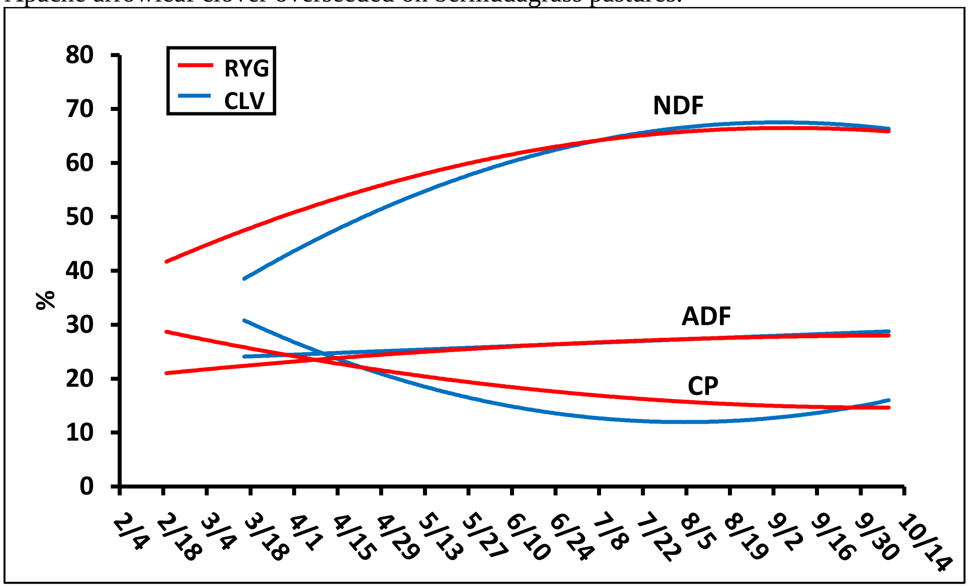
Recycled Nutrients and Cow-Calf Stocking Rates

Background. During the spring of 1968, common and Coastal bermudagrass pastures were established at the Texas A&M AgriLife Research and Extension Center at Overton. Initial pH ranged from 5.7 to 6.4 on these upland, sandy loam Coastal Plain soils. During the year of establishment, all pastures received 2 ton/ac lime (ECCE 65) and split-applications of fertilizer at a rate of 120-65-65 lb/ac N-P_2O_5-K_2O. Grazing was first initiated during the spring of 1969 with three stocking rates based on forage availability. Beginning in 1969, all pastures received a total fertilization rate during the growing period of 200-100-100 lb/ac N-P_2O_5-K_2O. Nitrogen was split applied at 50-65 lb/ac at each time of fertilization, whereas, P_2O_5 and K_2O were applied once at the initial spring fertilization. During the 1969 and 1970 grazing season (April to October) of 180-days, pastures consisted of bermudagrass only and were not overseeded. Common bermudagrass pastures were overseeded in the fall of 1970 with a mixture of 'Gulf' ryegrass and 'Dixie' crimson clover. Coastal bermudagrass pastures were evaluated as pure stands until overseeding with Gulf ryegrass and 'Yuchi' arrowleaf clover in the fall of 1974. From the initiation of grazing overseeded common bermudagrass in 1971 and overseeded Coastal bermudagrass pastures in 1975, all pastures have been overseeded with ryegrass and/or clover through 2022. The original fertilization strategy was to apply N-P_2O_5-K_2O at an approximate ratio of 2:1:1. The average annual fertilizer applications were 200-100-100 lb/ac N-P_2O_5-K_2 from 1969 through 1984.

In the fall of 1984, a nutrient cycling experiment was initiated and all stocking rate pastures for both common and Coastal bermudagrass were sub-divided equally into two fertility x winter annual forage treatments: 1) N + ryegrass, and 2) no N + K_2O + clover (Silveira et al. 2016). Phosphorus fertilizer was not included as a component of either N vs no N-fertility treatments because soil P concentrations were assessed to be adequate for grass or clover production. In addition, we wanted to eliminate long-term residual soil P buildup under stocking conditions. Fertilizer applications of either N-0-0 vs. 0-0-K_2O were used from 1985 through 1997. The N rates varied from an average of 408 lb/ac for four years from 1985-1989, 238 lb/ac from 1990-1994, 290 lb/ac for 1995-1996, 221 lb/ac for 1997, and an average of 250 lb/ac from 1998 through 2022. The annual K_2O rates averaged about 112 lb/ac through 2004, and then averaged about 60 lb/ac until 2022. From 1985-1997, no fertilizer P was applied. Beginning with the 1998 grazing season and continuing through 2022, all pastures received phosphorus, potassium, sulfur, magnesium, and boron. Phosphorus was applied at about 100 lb/ac P_2O_5 from 1998 through 2004, and then 60 lb/ac through 2022. However, only the N + ryegrass pastures received nitrogen fertilizer with 2022 rates of 250-60-60.

Stocking rates have varied by bermudagrass and fertility regimens according to forage mass available for meeting experimental protocol. Samples for forage mass (availability) were taken from each pasture by hand-clipping quadrats to ground level at initiation of stocking and at approximate 28-d intervals. Three stocking rates were achieved using a variable stocking rate (put-and-take) to create three levels of forage mass. The targeted forage mass ranged from 500 to 1000 lb/ac for High stocking rates, 1250 to 2000 lb/ac for Medium stocking rates, and > 2500 lb/ac for Low stocking rates. At approximate 14-d intervals, forage samples from each pasture were collected to assess nutritive value. At several locations in each pasture, hand-plucked forage samples that visually represented animal selectivity were collected. The selected plant parts collected represented >80% leaf and <20% stems. After drying, samples were ground to pass a 1mm screen and a sequential analysis of neutral detergent fiber (NDF) and acid detergent fiber (ADF) was made (Goering and Van Soest, 1970). Forage nitrogen was determined using a block digester colorimetric method via Technicon Auto Analyzer. Figure 1 illustrates changes in nutritive value components during the seasons from cool-season annuals to exclusive bermudagrass (Rouquette et al. 2018).

Figure 1. Neutral detergent fiber (NDF), acid detergent fiber (ADF) and crude protein (CP) of annual ryegrass and Apache arrowleaf clover overseeded on bermudagrass pastures.



Long term, 30-yr, averages for stocking rates from mid-February to late September have approximated 0.95, 1.5, and 2.2 cow-calf pair/ac (1500 lb BW= 1 cow and calf) for common bermudagrass, and about 1.1, 1.7, and 2.8 cow-calf pair/ac for Coastal bermudagrass (Rouquette 2017). To accommodate overall length of cool-season and warm-season stocking seasons, rebreeding and calving season, and pasture size, fall-calving pairs were stocked on overseeded bermudagrass pastures from February to mid-June; whereas, winter-calving pairs were stocked on exclusive bermudagrass pastures from late June to late September or early October. Cattle from both calving seasons were exposed to bulls for 75 days. Animal performance for both calving seasons has been used to provide forage-animal relationships from February to October without disruptions for calving or breeding on test pastures (Rouquette et al. 2018).

Cow-calf Performance and Stocking Rates

The Average daily gain (ADG) responses to stocking rate for both fall-and winter-calving pairs shows season-long effects of stocking rate on both lactating cow and suckling calf for both Coastal (Fig. 2) and common bermudagrass (Fig. 3) overseeded with ryegrass + N or clover without N fertilizer. Both cow and calf ADG decreased with increasing stocking rates as anticipated. However, the impact of lactation showed a buffering effect on stocking rate impact on calf ADG. At low stocking rates with opportunities for selective grazing, calf ADG was more than 2.5 lb/day from either clover or ryegrass. With increased stocking rates, bermudagrass overseeded with ryegrass + N had greater calf ADG than clover without N. Cow ADG was positive at the low and medium stocked Coastal and low stocked common bermudagrass. At high stocking rates, cows lost 1 to 1.5 lb/day and had reduced body condition score (BCS). Additional data analyses showed that bred, lactating Brahman-influenced F-1 cows may be grazed at stocking rates that reduce BCS to 4 or less at weaning and recover BCS on bermudagrass pastures with ad libitum forage mass for 90% rebreeding (Rouquette et al., 2020).

Figure2. 29-yr average relationship of cow and calf ADG to stocking rate on Coastal bermudagrass overseeded with ryegrass (RYG) or clover (CLV)

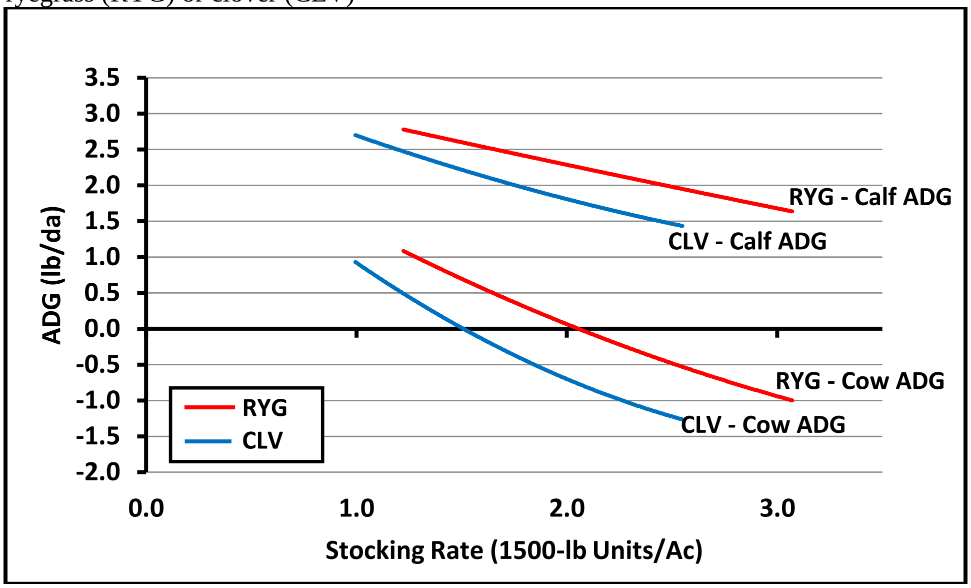


Figure3. 29-yr average relationship of cow and calf ADG to stocking rate on common bermudagrass overseeded with ryegrass (RYG) or clover (CLV)

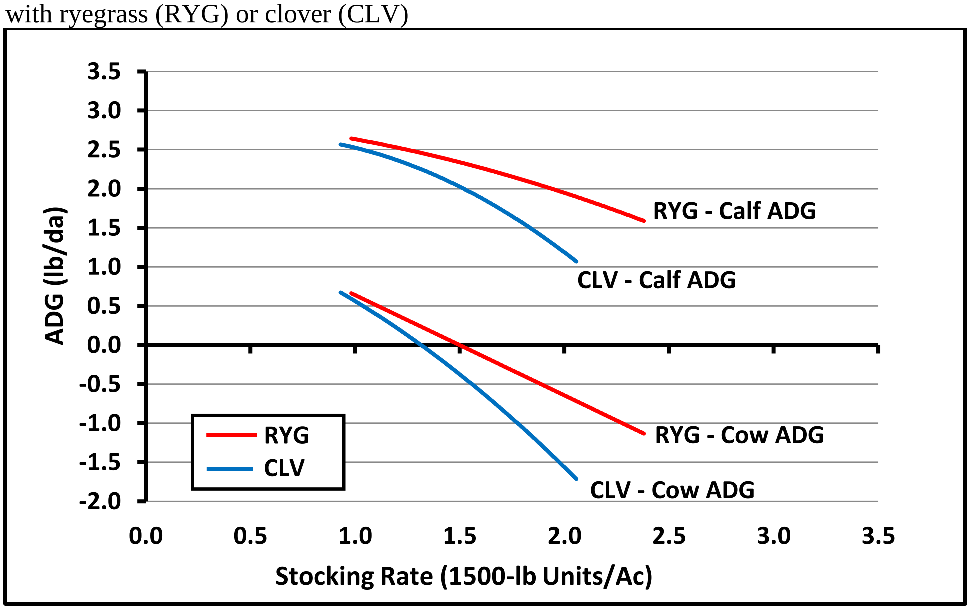
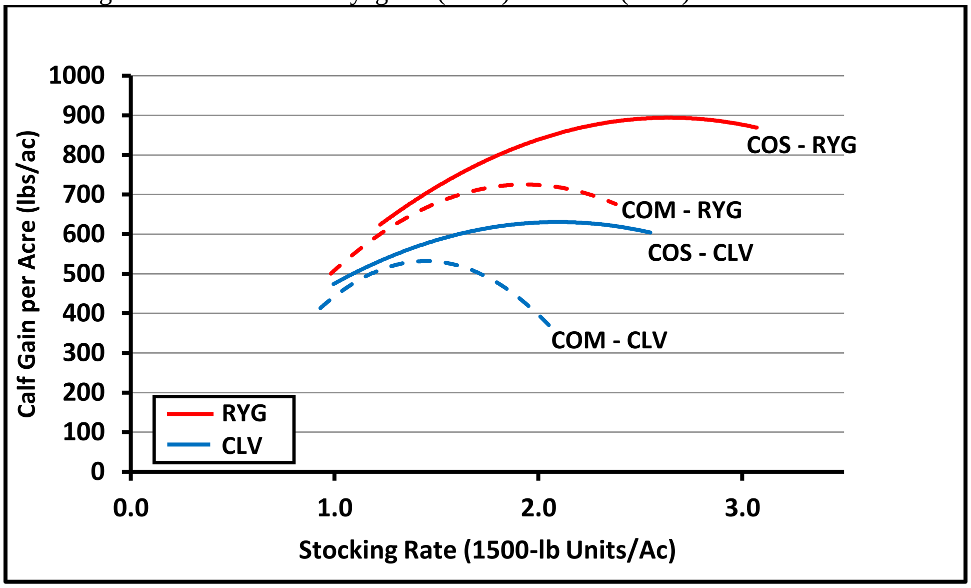


Figure 4 shows the 29-yr average suckling calf gain/ac was greater for Coastal overseeded with ryegrass due to more forage production from N-fertilized pastures. Common bermudagrass overseeded with clover and without N fertilization had the lowest calf gain per ac, and was most negatively affected by high stocking rate due to reduced forage mass.

Figure4. 29-yr average relationship of cow gain to stocking rate on common (COM) and Coastal (COS) bermudagrass overseeded with ryegrass (RYG) or clover (CLV)



The relationship of cow and calf ADG with level of forage mass is shown in Figure 5. Lactating cows required approximately 1800 lb/ac forage mass to maintain body weight. For optimum calf ADG, about 2500 lb/ac bermudagrass mass was required. Figure 6 shows the relationship of ADG with cow and calf forage allowance. Forage allowance is the relationship of forage dry matter (DM) with animal body weight (BW). Thus, the optimum forage allowance for cow ADG showed to be about 1.0 (DM:BW) (Fig 6). The optimum forage allowance for the suckling calf was about 0.90 (DM:BW) with lactation providing a buffer to stocking rate.

Figure5. 29-yr average relationship of cow and calf ADG to forage mass on common and Coastal bermudagrass overseeded with ryegrass or clover

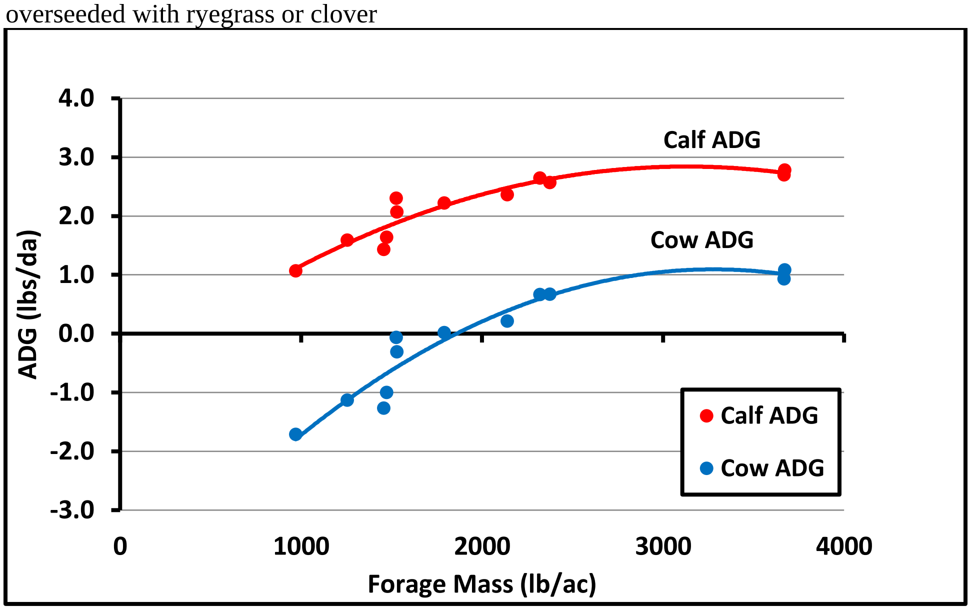
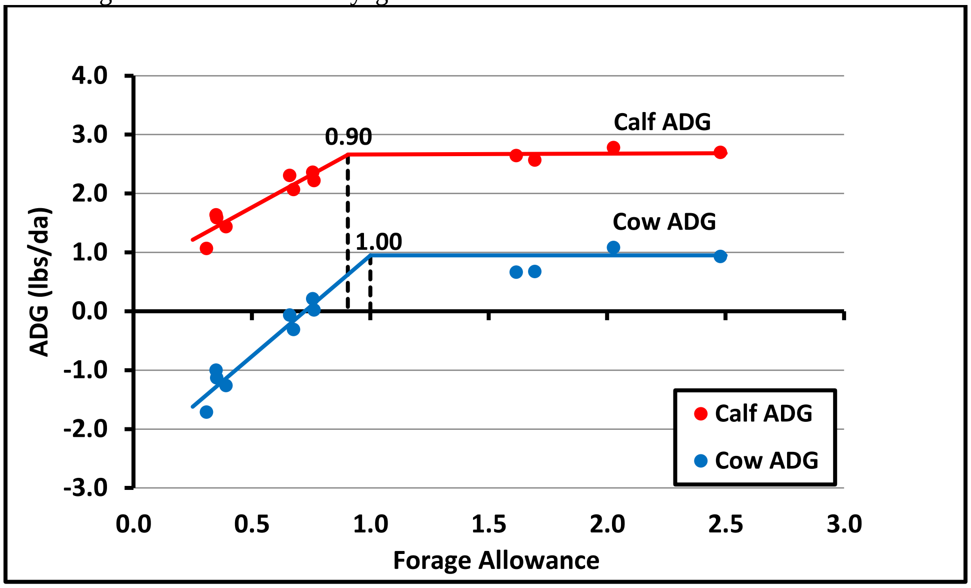


Figure6. 29-yr average relationship of cow and calf ADG to forage allowance on common and Coastal bermudagrass overseeded with ryegrass or clover



Fertilizer Costs

The 29-year average stocking rates and resulting suckling calf gain per acre are shown in Table 1. Calf gain per acre ranged from a low of about 450 to 470 lb/ac for clover without N overseeded on Coastal bermudagrass at a low stocking rate and common bermudagrass at both a low and high stocking rate (Fig 4 and Table 1). Using ryegrass and nitrogen on Coastal bermudagrass, calf gains were about 900 lb/ac at high stocking rates. There are numerous expenditures that may be used for estimating a year-long cow budget. Although seed and fertilizer expenditures represent the major pasture costs for overseeded bermudagrass pastures, only fertilizer prices will be included to provide an estimate of fertilizer costs/lb calf gain. Other costs associated with wintering, land costs, labor, interest, etc. must be included for accurate year-long expenses. Evaluating only fertilizer costs, it becomes readily apparent that the clover overseeded pastures have the least fertilizer costs per lb gain (Table 1). Bermudagrass overseeded with annual ryegrass and fertilized with 250-60-60 had fertilizer costs of $365/ac, with N costs at $1.10/lb. Thus, fertilizer costs/lb gain ranged from $0.40 /lb gain to $0.68 /lb gain. With N fertilizer cost at $0.75/lb, the fertilizer costs for overseeded ryegrass on bermudagrass was $268.50/ac. This reduced cost of N resulted in fertilizer costs/lb calf gain from $0.30 to $0.51/lb (Table 1). With increased costs of N fertilizer, Coastal bermudagrass would be the preferred pasture to fertilize with nitrogen and with a medium to high stocking rate depending upon management strategies for calf sales and body condition of cows at weaning. From the perspective of reducing risk plus the opportunity to harvest hay off the pastures, a lower stocking rate of about 1 to 1.5 acres per cow-calf unit during the February to October period may be a best management strategy.

Table 1. 29-year average stocking rate, suckling calf gain per acre, and fertilizer costs per pound of gain on Coastal (COS) and common (COM) bermudagrass pastures using 2022 fertilizer prices.

	Clover			Ryegrass			
						Cost of N	
						$0.75/lb	$1.10/lb
Bermudagrass	Stocking rate, pair/ac[1]	Calf gain, lb/ac	Fertilizer costs, $/lb gain[2,4]	Stocking rate, pair/ac[1]	Calf gain, lb/ac	Fertilizer costs, $/lb gain[3,4]	Fertilizer costs, $/lb gain[3,4]
COS – Low	0.99	470	$0.17	1.22	612	$0.44	$0.58
COS – Med	1.50	560	$0.14	1.88	796	$0.34	$0.45
COS – High	2.55	610	$0.13	3.07	894	$0.30	$0.40
COM – Low	0.93	446	$0.18	0.98	522	$0.51	$0.68
COM – Med	1.47	537	$0.15	1.55	727	$0.37	$0.49
COM – High	2.06	454	$0.18	2.38	779	$0.35	$0.46

[1]One cow-calf pair = 1500 lb body weight

[2]Clover fertilizer: 0-60-60 = $81/ac

[3]Ryegrass fertilizer: 250-60-60; with N @ $1.10/lb = $356/ac; with N @ $0.75/lb = $269/ac

[4]Fertilizer component costs: P_2O_5 = $0.65/lb; K_2O = $0.70/lb; N varies between $0.75/lb to $1.10/lb

Pasture-Beef Cattle Fertilizer Management Options

The basic fact for all pasture-livestock producers to remember is that grass production is nitrogen dependent. The basic forages for pastures in Texas, as well as in most of the Southwest and Southeastern US, are warm-season perennial grasses. This category of forages includes bermudagrass, bahiagrass, dallisgrass, and numerous other introduced and native species. In many areas of Texas, nitrogen-containing fertilizers have been a regular part of hay and pasture production for livestock. The immediate and perhaps long-term extended changes in fertilization use on forages for pasture and/or hay will be dependent upon numerous factors including: 1) price of fertilizer; 2) price of cattle; 3) forage requirements for soil N-P-K and lime to meet pasture and/or hay needs; 4) economic stocking rate that is sustainable with moderate, minimum, or no fertilization; and 5) alternative land-use, leasing, and with or without livestock. Thus, some of the management questions may include…"How many cattle can my pastures accommodate with reduced or eliminated fertilizer input?" "How sustainable are my perennial grass pastures without nitrogen fertilizer?" "How long can I "mine" these pastures?" "Should I produce or purchase hay?" "Can I afford to use winter annual forages?" "If I make only one application of nitrogen, what is the best rate and when is the best time of the year to fertilize?" "Should I consider stocker cattle in my operation?" "Should I substitute supplementation for fertilizer?" "Should I lease more land…or lease my own land to someone else?" The primary management concerns remain focused on how to offset cow costs associated with fertilizer, hay, supplemental feed, fuel, etc. with projected percent calf crop weaned, sale weight of calves, retained ownership, and culling of cattle.

Cow-calf and/or stocker operations from pastures require on-going management decisions to adjust for seasonal and total forage production-availability, animal performance expectations, wintering costs, and other operating expenses. In general, rainfall and temperature fluctuations and soil nutrient status control forage production. Thus, stocking rate adjustments dictate requirements for fertilizer, hay, and/or supplemental feed to meet animal performance expectations. For cow-calf producers, wintering costs associated with hay and supplement to maintain cow condition for calving and rebreeding are responsible for a substantial part of the 12-month cow costs. Thus, fertilizer management during the summer months, hay production or purchase, and inclusion of winter annual pastures requires primary consideration during escalating input prices. In response to increased fertilizer prices, management may choose an array of options; however, these strategies will likely include one of the following: 1) eliminate all fertilizer; 2) reduce fertilizer to minimum applications; or 3) continue with moderate fertilization applications. With any strategy, there is an action followed by reaction or adjustment due to those decisions. Some of the action-reaction scenarios for fertilizer management may include some of the checklist items that follow:

Eliminate All Fertilizer

1. Obtain a soil test analysis. If soil status of pH, P, etc are acceptable, then clovers may be overseeded for late winter-early spring grazing. These grazed clovers provide a source of nitrogen fixation via excreta and these nutrients are available for use by bermudagrass or other warm-season forage. This recycling of nutrients stimulates forage production and reduces the "soil mining" effects.
2. Reduce stocking rate and/or lease additional pastureland to account for reduced forage production.
3. Hay requirements may be met by purchasing hay based on nutritive value and weight. However, if clovers are components of the pasture system, then allowing them to set seed with hay harvest after seed maturation will provide some of the hay requirements. In addition, these clover seed-abundant hay bales can act as a method of reseeding pasture areas, and this process is enhanced by "unrolling" the round bales onto new seeding areas during the autumn.
4. Supplementation may be required during the wintering period depending upon nutritive value of hay and/or deferred pasture for "standing hay."
5. Time of calving may have to be adjusted to fit the seasonal availability of forage nutrients and dry matter from pasture and/or hay. In general, if winter annual forages are not components of this system, then a late spring calving may best fit pasture conditions without prolonged supplementation of the cow herd.
6. Herbicide applications and/or mowing of pastures will be required to control annual weeds and perennial woody species that will invade pastures.
7. Bahiagrass and common bermudagrass will initially dominate these pastures with an extended absence of N-fertilizer. Subsequent invasion by other annual and perennial grasses may become more predominant with time.

Reduce Fertilizer to a Minimum Amount

1. Obtain a soil test analysis.

2. Fertilizer strategies based on soil analysis may include non-Nitrogen fertilizer plus overseeded clovers with required lime and/or Phosphorus fertilizer.
3. Other fertilizer strategies may include overseeding with annual ryegrass with one or two winter N applications (50 lb/ac) to stimulate ryegrass and/or one or two spring-summer N applications (50 lb/ac) to stimulate bermudagrass, bahiagrass, etc.
4. Strategic, timely application of N is imperative to match climatic conditions and best utilize the optimum effectiveness of N rate and forage production.
5. Hay requirements may be met with harvest of clover and/or ryegrass at seed maturation, or by purchasing hay based on nutritive value and weight.
6. Evaluate forage conditions for proper stocking rate and incorporate a regimented cow culling procedure based on performance.
7. Herbicide applications and/or mowing may be required to control annual weeds and perennial woody species.
8. Some forage species composition changes will likely occur on non N-fertilized pastures with increases in bahiagrass and assorted ecotypes of common bermudagrass.

Continue With Moderate Fertilization

1. Obtain a soil test analysis for use with overseeded winter annual clovers, ryegrass, and/or small grains.
2. Apply lime (ECCE-100) as appropriate primarily for cool-season annual forages.
3. Consider rates of 50 to 60 lb N/ac for each application with the potential of 3± applications on small grain + ryegrass, 2± applications on ryegrass, and/or 2 to 3 applications during the exclusive bermudagrass phase.
4. Increase forage production-utilization efficiencies by harvesting hay and/or utilization of stocker calves (retained and/or purchased).
5. Consider selling excess hay.
6. Adjust calving and weaning dates for increased weaning percent and weaning weight.
7. Apply herbicides to eliminate competition for nutrients, water, and space.

Stocking Strategies and Nutrient Cycling

Stocking strategies and nutrient cycling have inseparable relationships, and in the course of stable or diminishing cattle prices and unstable and increasing costs of fertilizer, fuel, and feed grains, there is an increased dependency on recycled nutrients for forage production. Management strategies are personal and “zip code specific.” Using the long-term fertility regimen x stocking rate nutrient cycling database from Texas A&M AgriLife Research-Overton as a model for management strategies, the following options should be considered for production and costs for specific sites:

- Pastures in the Pineywoods Vegetational region at Overton had a 15-year history of N-P-K applications from 1969 through 1984. Once fertilization strategies were changed and implemented, soil P was deemed to be at moderate to high levels. However, from 1998 to 2022, P_2O_5 had been applied. The soil nutrient "base" determines the fate of reduced fertilization of pastures. A soil test analysis provides this information on suggested rates of fertilizer and limestone.

- By eliminating all N fertilizer and overseeding bermudagrass with an adapted clover, pastures continued to be stocked from about March 1 through September. And, at low stocking rates of 1.5 to 2.0 acres per cow-calf pair, forage will likely be sufficiently abundant to minimize risks due to climate. However, at high stocking rates, bahiagrass and various bermudagrass ecotypes are likely to invade the pastures. Perhaps more important is that the absence of N fertilization on bermudagrass pastures allows for increased opportunities for weed invasion, which in turn, requires herbicide applications or mowing.

- When applying only N fertilizer and eliminating P_2O_5 and K_2O, overseeded ryegrass on bermudagrass has provided a more reliable winter-spring forage supply to initiate grazing by mid- to late February. Ryegrass is more tolerant of dry conditions and frequent defoliation compared to clovers. With the N + ryegrass strategy, nutrient cycling is active and suggested N fertilization may include one to two applications of 50 lb/ac N for ryegrass period and one to two applications of 50 lb/ac N for the bermudagrass growing phase. Annual ryegrass, however, is not tolerant to low soil pH of less than 5.0 to 5.5; thus, soil tests and limestone recommendations are required management strategies.

As forage-cattlemen move into the next paradigm of input costs, the "secrets for success" are closely tied to "using forages that produce and animals that perform." This mandates that every aspect for the forage-cattle operation must be critically evaluated. For many operators who choose to eliminate most if not all fertilizers, the long-term experimentation at Texas A&M AgriLife Research-Overton suggests nutrient cycling is a valuable asset for forage production. And, some species composition changes will occur once N fertilizer is removed for prolonged durations. Some of the checklist management strategies that may be implemented to counter increased fertilizer, fuel, and feed prices include the following:

1. Create a pasture management plan of action that is firm but flexible.
2. Implement a fertilization strategy via soils test and reason(s) for need.
3. In many situations, the most cost-effective fertilizer strategy is to apply one or two applications of only Nitrogen at 50 to 60 lb/ac per application.
4. Hybrid bermudagrasses such as Coastal or Tifton 85, for example, produce more forage per unit of N fertilizer compared to common bermudagrass.
5. Add legumes to the pasture system after assessing soil analysis and pH.

6. Use broiler litter as a nutrient source.
7. Increase efficiency of forage utilization for specific classes of cattle.
8. Make hay from pastures and eliminate exclusive hay meadows.
9. Purchase hay based on nutrient analysis and weight of package.
10. Make strategic, timely herbicide applications as warranted.
11. Maintain accurate, up-to-date cattle records for culling options.
12. Reduce stocking rate.
13. Enhance weaning percent, weaning weight, and/or weight at time of sales.
14. Alter weaning schedule and consider retained ownership options for stockers with or without supplementation.
15. Critically assess supplementation strategies, product cost, and supplement to extra gain conversion.
16. Market cattle proactively through special sales, etc.

The “rules” for management have changed with increasing fertilizer and fuel costs for operating pastures-livestock systems. Although the “game” does not “look like” the more familiar one of a few years ago, the “game plan” remains the same. And, that is to set production targets, manage to manipulate forage utilization systems to enhance economic returns, and sustain the soil – plant resources.

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Grazing Management and Stocking Strategies for Pasture-Beef Systems: Experimental Confirmation vs Testimonials & Perceptions

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One of the most universal similarities of grazing systems is that "everyone has one!" And, whether the grazing management and stocking strategies are based on experimental evidence, experience, or perceptions-philosophy, grazing systems may be difficult to change, alter, or amend. What is the target? Rouquette and Aiken (2020) stated that "forage-based livestock production is challenged to enhance sustainability of pastures and cattle production, and to maintain economic stability in the presence of changes in market prices of cattle, fertilizer, feed, and other requirements. Management strategies that meet production goals while maintaining soil and ecosystem health and with minimal impact on the environment require a basic understanding of how: 1) the intensity, rate, and duration of stocking will impact cattle performance and production; 2) grazing systems can be used to maintain sustainable, productive pastures; 3) innovations in feeding and watering systems can be used to minimize negative impacts on water and soil health; 4) management of soil nutrients, which are components of nutrient cycling, can be effective in minimizing environmental impacts and controlling input costs; 5) control of noxious weeds is needed to maintain forage composition, pasture condition, and ecosystem stability; and 6) forage systems can accommodate wildlife habitat and diet requirements." The Global Roundtable for Sustainable Beef (2016) defined "sustainable beef" as a socially responsible, environmentally sound, and economically viable product that prioritizes natural resources, efficiency and innovation, people and community, animal health and welfare, and food.

Vegetational Hardiness Zones and Forages

Grazing management strategies and implementations vary among introduced forages on pastures and native grasses on rangelands. Although management and mindsets may be targeted toward sustainable beef cattle systems, the Vegetational-Hardiness Zones of semi-arid vs humid conditions dictate and control adapted and persistent forages in each region. In the more humid regions, warm-season perennial sod-forming grasses such as bermudagrass and bahiagrass are forages that are best adapted and tolerant to increased grazing pressures. These forages may also be harvested for hay, baleage, or silage. In semi-arid regions, native perennial warm-season bunch grasses and other forbs and browse are the best-adapted forages for rangelands. Tolerance to frequency and severity of defoliation regimens differs for sod-forming rhizomatous grasses in humid vs bunch grasses in semi-arid regions. Thus, stocking strategies and expected economic returns may be substantially different between introduced and native grass pastures. Figure 1 shows the annual precipitation in the Southern US. Stocking strategies vary within climatic and vegetational zones based on growing conditions for adapted forages.

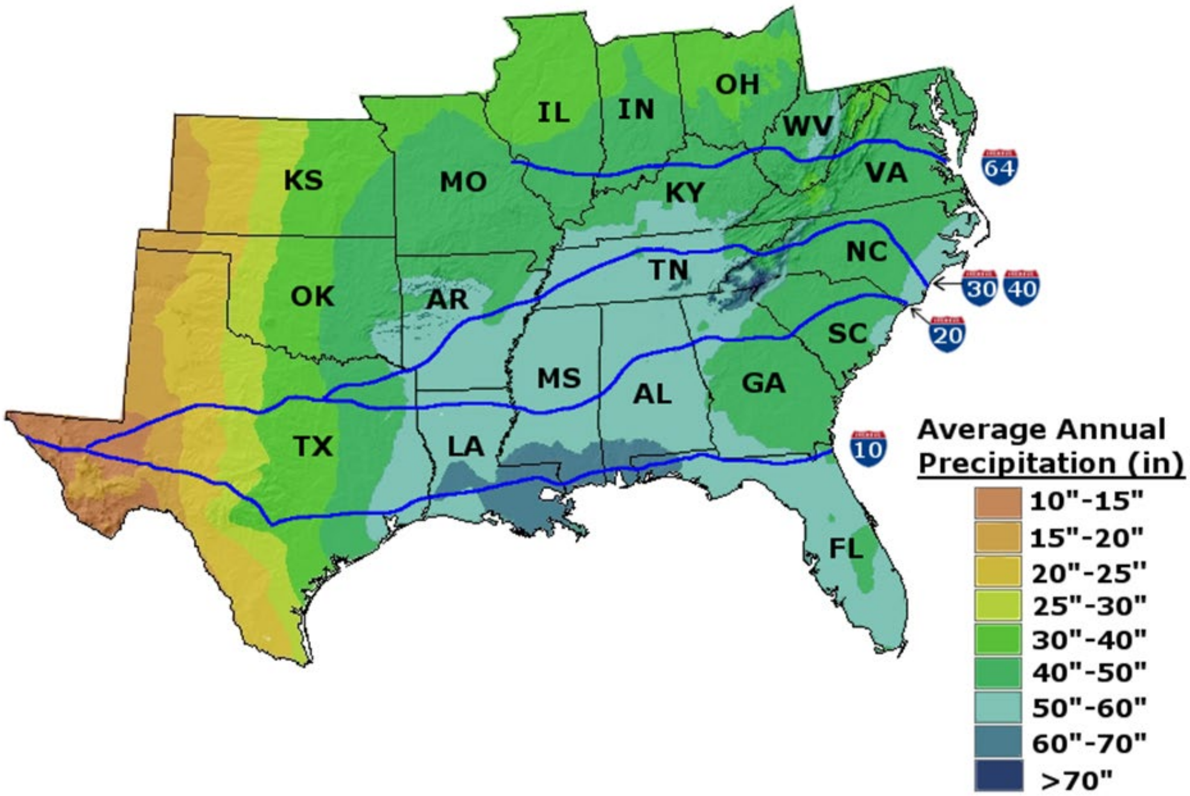

Figure 1. Thirty-year average annual precipitation in the Southern Region, 1981-2010.

Grazing Management

Grazing management has been defined as the manipulation of grazing in pursuit of a specific objective or set of objectives (Allen et al., 2011). Those strategies that can be manipulated include grazing intensity, grazing frequency and timing of grazing (Sollenberger et al., 2020). Sollenberger et al. (2020) further described that grazing intensity is related to severity of grazing and may be animal-based such as stocking rate, or pasture-based such as forage mass or plant height. However, these descriptions refer to only one component of the grazing system i.e., animal or forage; it does not integrate both components for purposes of management. Thus, grazing intensity would be best described as forage allowance (amount of forage dry matter per unit animal liveweight; Forage DM:Animal BW), or as grazing pressure (relationship between animal body weight and amount of forage); thus, both factors of pasture-based and animal-based components are combined (Allen et al., 2011; Sollenberger et al., 2005). Figures 2 and 3 show long-term relationships of forage mass and forage allowance with cow and calf ADG.

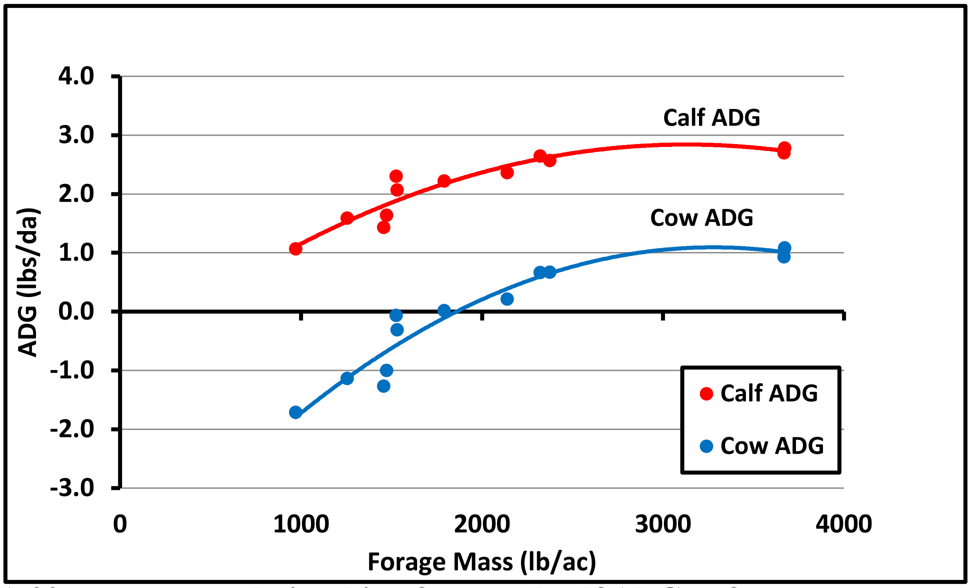

Figure 2. A 29-yr average relationship of cow and calf ADG to forage mass on common and Coastal bermudagrass overseeded with ryegrass or clover. Rouquette, 2017.

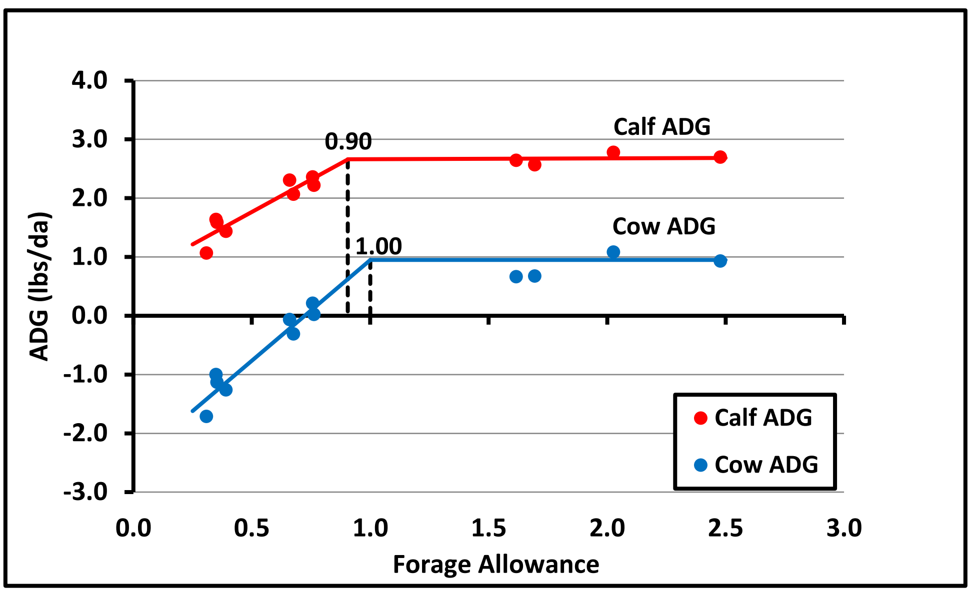

Figure 3. A 29-yr average relationship of cow and calf ADG to forage allowance on common and Coastal bermudagrass overseeded with ryegrass or clover. Rouquette, 2017.

Grazing frequency is related to stocking method in that one of more than 20 stocking methods (Allen et al., 2011) affects grazing frequency. Timing of grazing relates to the physiological stage of forage growth and maturity when grazed, or to the chronological time in the season when grazing occurs.

Stocking Methods

Stocking method has been defined as a "procedure or technique to manipulate animals in space and time to achieve a specific objective" by Allen et al., 2011. They suggested that the objectives of a specific stocking method could vary from: a) allocate forage nutritive value among livestock classes; b) enhance efficiency of forage utilization; c) diminish the detrimental or negative effects on soils and/or plants; to d) extend the stocking season. Stocking methods can be considered as variations of continuous or rotational stocking. Some examples of stocking methods presented are:

Alternative Stocking
Continuous Stocking
Creep Stocking
Deferred Stocking
First-Last Stocking
Forward Creep Stocking
Frontal Stocking
Intensive Early Stocking
Intermittent Stocking
Mixed Stocking
Mob Stocking
Non-Selective Stocking
Put-and-Take Stocking
Ration Stocking
Rotational Stocking
Seasonal Stocking
Sequence Stocking
Set Stocking
Strip Stocking
Variable Stocking

Pastures: Continuous vs Rotational Stocking

With respect to published experimentation on pastures, Sollenberger et al. (2012) compiled the results of continuous vs rotational stocking in a review of 19 refereed journal papers. These publications included 29 separate experiments on the comparison of gain per animal, ADG responses, and 26 separate comparisons for gain per acre on continuous vs rotationally stocked pastures. These nearly 60 experiments were conducted in different states over a period of more than 20 years. Data collected included forage mass, nutritive value, gain per animal, stocking rate, and gain per acre.

More than 70% of these experiments showed no effect of stocking method on nutritive value components. However, nearly 85% of these studies showed an advantage for rotationally stocked pastures in forage quantity or carrying capacity. The average increase in forage mass was about 30% for rotationally stocked vs continuously stocked pastures.

With no effect of stocking method on nutritive value, but with an increase in forage quantity, how does this translate to gain per animal and gain per acre for stocking method?

With respect to ADG:

- 66% of the studies showed no difference in stocking methods.
- 20% showed continuous to be better than rotational.
- 14% of the studies showed on advantage for rotationally stocked pastures.

The primary explanation for a reduced to non-effect of rotational stocking on ADG was that cattle are "forced" to graze the pasture to achieve a high percent forage utilization in the resident paddock (Rouquette, 2015). Forced consumption of forage into the lower part of the standing crop (sward) results in intake of low nutritive value stem portions. Cattle on continuous stocked pastures have opportunities for selective grazing. When given a choice of forage availability, cattle select more than 80% of their diet as leaves (Roth et al., 1990). Thus, higher nutritive value of diet usually favors continuous stocking.

Forage mass and forage allowance (DM:BM) set the boundaries for potential ADG. However, forage nutritive value is responsible for setting the upper limits on ADG. Therefore, both forage mass and nutritive value are collectively responsible for attaining maximum ADG from pastures (Rouquette, 2015).

What about gain per acre and stocking methods? In the Sollenberger et al. (2012) review of 26 grazing experiments that reported results for Gain per Acre:

- 73% of the studies showed no difference between continuous vs rotational stocking.
- 23% showed an advantage for rotational stocking (all cool-season forages).
- 4% showed an advantage for continuous stocking (Coastal bermudagrass).

What's Best for Pastures: Continuous or Rotational?

"Few topics in agriculture have been addressed with such charismatic language with such abandonment of scientific evidence and logic" as discussions of continuous vs rotational stocking (Bransby, 1988, 1991). In many stocking method discussions, the debates are often focused on experimental confirmation data vs testimonials and perceptions. The stocking method of choice eventually becomes a personal decision for management and does not have to be assessed as the "Best Method." Selecting management and stocking strategies to make optimum use of forage production, individual animal performance, and overall gain per acre led to the concept of Flexible Grazing Systems (Blaser et al., 1962). These grazing systems may not be "hardcore rotationally, time-scheduled stocked," but they do involve multiple pastures with strategies to incorporate flexible movement of cattle based on forage needs for grazing, and stored forages in concert with desired ADG for economic returns per unit area of land. Some examples of these flexible stocking strategies include:

- Two-Herd System of First and Last Grazers (Rouquette et al., 1992);
- Three-Herd System using different classes of cattle (Rouquette et al.,1994);
- Creep or Forward-Creep Grazing (Blaser et al.,1986);
- Systems for Fattening Steers on pasture (Blaser et al.,1956).

Rangeland: Continuous vs Rotational Stocking

Briske et al. (2008) reviewed experiments related to stocking rangelands with strategies comparing continuous vs rotational stocking. Although rotational stocking was a viable stocking strategy for rangelands, the perception that rotational was superior to continuous grazing was not supported by the majority of experimental investigations. They further concluded that the continued advocacy for rotational stocking as a superior system was based on perception and anecdotal interpretations rather than on experimental results. Briske et al. (2014) conducted an assessment of holistic management and concluded that, "the vast majority of experimental evidence does not support claims of enhanced ecological benefits in Intensive Rotational Grazing compared to other stocking strategies and including the capacity to increase storage of soil organic carbon". Thus, of all the practices one may adopt for grazing, the primary factor that controls the resultant sustainability of forage pasture rangeland is that of **stocking rate.**

Mob Stocking

Allen et al. (2011) defined mob stocking as "a method of stocking at a high grazing pressure for a short time to remove forage rapidly as a management strategy." What is a mob? How are livestock mobs controlled? One of the first uses of "mob stocking" has been attributed to G.O. Mott who used this term after visiting with Australian researchers (Gurda et al., 2018). The terminology and application were first used in evaluation of warm-season perennial grass cultivars and germplasm (Mislevy et al., 1983; Rouquette and Florence, 1983; Gildersleeve et al., 1987). Although there were no prescribed stocking standards, the defoliation technique simulated high-intensity, rotational grazing using a high stocking density. From these initial defoliation techniques for forage cultivar evaluation, mob stocking has been promoted as a viable, economic, and biological enhancement strategy; thus, a philosophical approach without experimental evidence. Thus, non-replicated demonstrations on semi-arid and humid environments have not been well-defined but have been implemented and promoted without comparative data on stocking rates and effects on soil health attributes.

A multi-year and replicated mob stocking experiment was conducted in the Nebraska sandhills (Redden, 2014; Lindsey, 2016; Andrade et al., 2022). During an approximate 75-day period in each of 8 years, a 120-paddock rotational system with 1 grazing event was compared to a 4-paddock rotational stocking system with either 1 or 2 grazing events. The ADG of yearling steers at the same stocking rate was different for each method at about 0.4 lb/day for the 120-paddock, 1.25 lb/day for 4-paddock with 1 grazing event, and about 2.2 lb/day for 4-paddock with 2 grazing events. The overall summary from this experiment was that there was no grazing treatment effects on plant species composition, forage mass, or root growth dynamics. They concluded that the additional infrastructure, labor, and management costs could not be justified using this mob stocking system in this vegetational area.

Mob, rotational, and continuous stocking were evaluated in a temperate grassland area with endophyte-infected Tall Fescue, Orchardgrass, Kentucky bluegrass, white clover and red clover during three years (Tracy and Bauer, 2019). Forage mass and nutritive values were similar across all grazing methods. Cow-calf performance was reduced under mob stocking. They concluded that mob stocking may be a beneficial strategy for short-term vegetation management rather than for season-long stocking. In addition, authors suggested that mob stocking appeared to be an unwise investment due to the limited benefits for forage and livestock in the Virginia environment.

Mob stocking may offer a management strategy in environments and conditions with a diverse, multi-species forage and browse vegetation. Management should be reminded that mature dry cows may be the “best” cattle for use with this stocking method due to nutrient requirements, which are primarily for maintenance and not for growth, lactation, and/or estrus. And the “least desirable” cattle to use in mob stocking are young, lightweight (450-700 lb) stocker-yearlings due to the reduced nutritive value of the more mature forage available for selection.

Is Regenerative Grazing a Mob Stocking Method? Regenerative grazing has been self-defined as practices or methods of stocking that enhance ecosystem services, soil health, etc. And it often includes Intensive Rotational Grazing that may range from one to a few days’ residence on a pasture with 30 to 60 days or more rest, which is a form of mob stocking. Regenerative agriculture has been generally described/defined as methods or approaches for soil conservation and enhancing ecosystem services. Thus, regenerative agriculture is not a specific practice but rather is based on philosophies of a variety of management practices or strategies that promote soil health and sustainability. Giller et al. (2021) reviewed the origins of regenerative agriculture and the various philosophies and definitions for its implementation. They found that many producer testimonials on the internet suggested their adoption of Regenerative Agriculture was “underpinned by the philosophy that seeks to protect and enhance the environment.” They also reported that many “regenerative practices” such as crop residue retention, cover cropping, and reduced tillage were central to the “canon of good agricultural practices”; whereas other practices were contested and at best were “niche” such as permaculture and holistic grazing.

Regenerative or Sustainable Agriculture. Giller et al. (2021) investigated the recent terminology of "Regenerative Agriculture" from an agronomic perspective. Although this terminology has been in use from the early 1980's, only since 2016 has regenerative agriculture been adopted and incorporated into a "buzz word" used by multi-national companies, charitable foundations, USDA, etc. Regenerative agriculture has shown to be no different than sustainable agriculture, sustainable intensification, climate-smart agriculture, organic farming, agroecology, etc. Giller et al. (2021) further suggested that academic and research agronomists need to engage constructively with individuals, organizations, and corporations that champion regenerative agriculture and address the scientific method. They provided areas and questions to be addressed that would assess the agronomic aspects of the mechanism and dynamics of regeneration. In summation, they suggested that such investigations "will also help to separate the philosophical baggage and some of the extraordinary claims that are linked to Regenerative Agriculture, from the areas and problems where agronomic research might make a significant contribution."

Stocking Strategies and Sustainability of Pasture-Beef Systems

Some of the positive attributes of various rotational stocking strategies are:

- A more uniform level of forage utilization and perhaps an "improvement in efficiency" of grazing.
- Vegetation cover may be enhanced with "proper stocking rate;" however, vegetation may be destroyed at high stocking rates.
- Potential for more uniformity of excreta distribution.
- Mandates regular inspection of livestock and pastures.
- Grazing can be combined with mechanical harvesting.
- Management perception that the system is a "best management practice" for the soil/plant-animal ecosystem.

Grazing intensity measured as stocking rate or pasture height is the most important factor in grazing management and stocking strategies. Stocking rate has overriding effects on forage production, pasture persistence, animal performance, and environmental impact of pasture-based livestock systems. Rouquette (2015) suggested that managers must consider some of the following factors to optimize output from the system: a) understanding forage growth and regrowth; b) experience with animals and animal husbandry; c) intuitive application of decisions for input and outputs; d) knowledge of current and forecasted weather conditions in an ecoregion; e) ability to assume the risks associated with stocking outcomes; f) constant awareness of vegetation and land resources; and g) an alternative or "escape plan" for animals in the event of extreme climate conditions.

Stocking strategies should be characterized or designed within a specific Vegetation or Hardiness Zone and combined with the art and science of management for efficient-strategic forage utilization and sustainability for the desired optimum pasture-animal production. Thus, management strategies are site-specific for multiple input-output decisions with objectives to 'match' forage-animal requirements to production and economic rewards (Rouquette, 2015). Grazing management strategies control the degree of intensity of beef cattle production based on level of economic risk and desired-expected environmental stewardship goals These management strategies should be focused on integrating relationships of pasture ecosystems and stand maintenance, environmental awareness, economic implications, and legacy-heritability objectives of property for sustainable forage-livestock production (Figure 4; Rouquette, 2017).

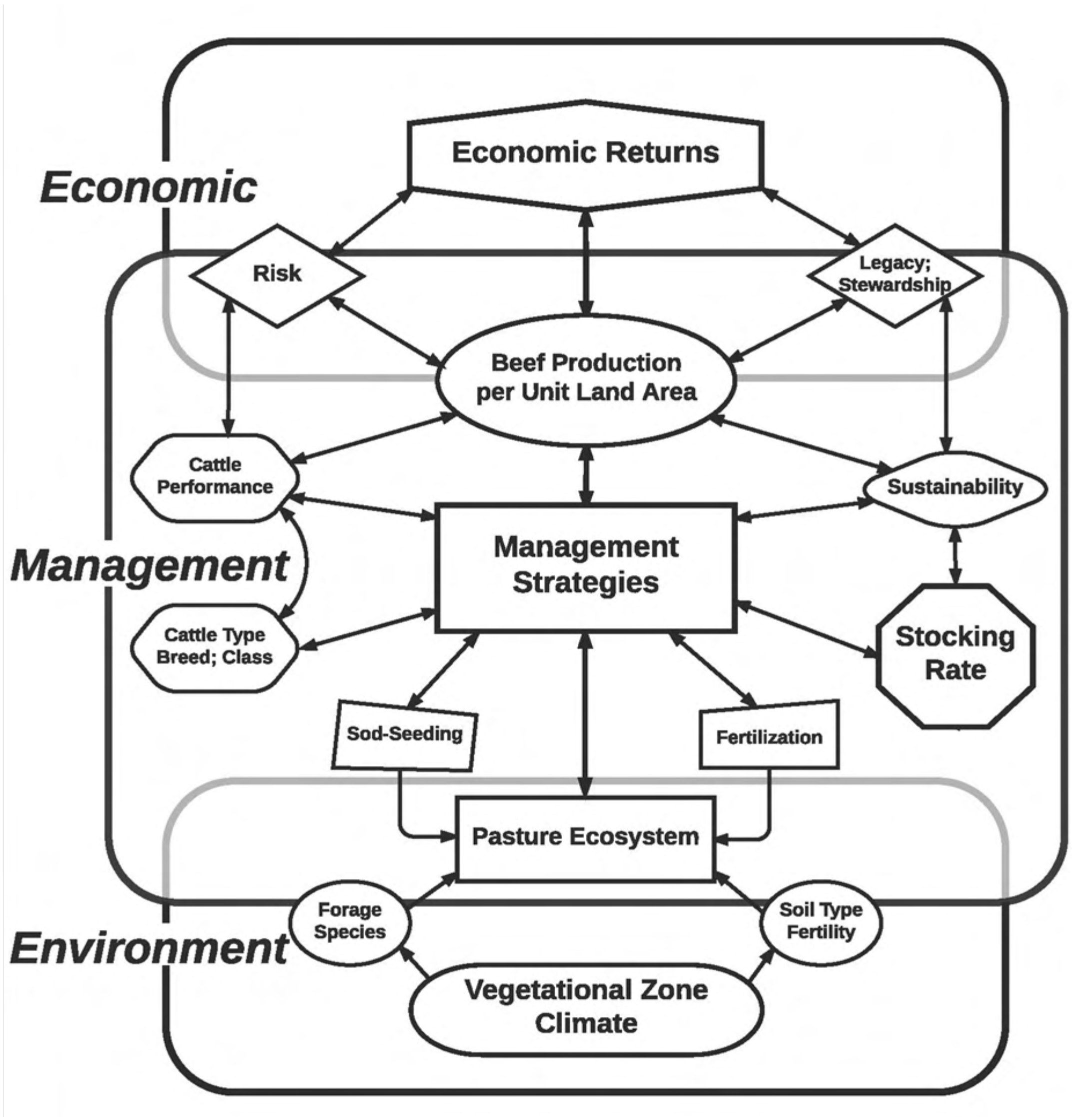

Figure 4. Sustainability of pasture-cattle production systems guided by environment, management, and economic considerations. Rouquette, 2017.

Experimental Data or Testimonials

Implementing revised or new management strategies requires attention to detail and the use of results from comparative experiments. Some of these strategies may include fertilizer ratio and fertilization rate for hay or pasture; supplementation ingredients and amount to deliver to specific classes of livestock; breed type for cow-calf and/or stocker operations; forage cultivars for perennial and/or annual pastures; stocking method for sustainable beef system and economic returns; and seasonal and/or year-long stocking rate or carrying capacity of property. Sollenberger et al. (2020) summarized that "Within the community of grazing management practitioners, proponents of one approach or another may rely too heavily on anecdotes and too lightly on data." They also suggested that "before adopting a new grazing management approach, there is value in requesting DATA that support the recommendations being made. It is equally important that the source of the data be an independent organization without conflict of interest, and that the experiments be conducted on a time and size scale that provides relevant results to producers." The Land Grant System was designed to disseminate these types of data results through State Agricultural Experiment Stations and Extension Service publications and short courses. And their recommendations-suggestions are routinely based on multi-year and/or multi-locational comparative research and experimental data. Grazing systems should be viewed as "work in progress" as management fine-tunes input strategies for sustainable pasture-livestock systems and positive economic returns.

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Forage and Pasture Options for Wintering Cattle

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If it wasn't for the wintering period and the need to feed hay…the cattle business would be fun…and more profitable!! The primary forage base for pastures and rangeland in Texas is warm-season perennial grasses. With the drastic changes in climatic-vegetational zones in Texas, there is considerable variation in species diversity and production from these grasses that range from bermudagrasses to native bunchgrasses. However, these grasses are uniquely similar in that they have restricted to non-existent growth after the first killing-frost and during the winter months. Thus, for the cattleman, management strategies for wintering the cow herd must include an array of options for dry matter (DM) and associated costs of the forage and/or pasture.

Class of Cattle and Performance Expectations

All cattle have daily requirements for energy and protein with roughage being the primary source for cattle on pasture and/or rangeland. In order to make biologically productive and economically sound decisions for wintering cattle, the performance expectations must be considered for the specific class of cattle. The daily nutrient requirement for classes of cattle varies with body weight, age, sex, stage of production, and performance expectations. These nutrient requirements are available in tabular format from several printed sources as well as from on-line, web-sites. Although the specifics of meeting an animal's nutrient requirements may require some study and/or evaluation, the "short-cut" answer is that grazing cattle prefer to consume ad libitum quantities of forage. And, the daily DM intake for cattle may vary from less than 2% to nearly 3% of body weight. The extent of intake as a percent of body weight is bounded by availability of forage AND the quality (nutritive value) of the forage. Thus, with knowledge of the nutritive value of the forage, strategies may be developed for a supplement source that can provide energy and/or protein to meet animal requirements and performance expectations.

Forage and Pasture Options

The winter process, duration, and costs are directly related to climatic conditions, primarily rainfall that occurs during the spring-summer months. Although the temperature extremes during the winter are factors for consideration of DM requirements, forages produce DM during summer months that is available for active and deferred grazing in fall-winter. And, hay production is a critically important factor that dictates the flexibility, aversion to risk, and cost of wintering cattle. In the absence of spring-summer rainfall, and to the extent that drought conditions prevail, the costs of "wintering" can also include the "summering" of cattle.

Stockpiled Forage

One of the oldest pasture-rangeland management strategies has been that of stockpiling forage or deferment of grazing during late summer-early fall for subsequent use by cattle after frost occurs. Thus, after frost, cattle may graze these non-active growing forages during late-fall and winter. Although it is obvious, these warm-season perennial grasses do not have active DM production…AND…the quality of the stockpiled grass DOES NOT improve with time. A forage sample for quality analyses is one of the best investments to confirm whether or not supplementation is required. And, if supplementation is required, decisions can be made on whether it be energy-based and/or protein-based.

By estimating available DM per acre by visual, height of forage, or actual measurements using quadrats, management strategies can be developed concerning the expected duration of stocking. Forage utilization and stocking strategies may range from a continuous, non-restrictive access to an entire pasture, or to some rotational, restrictive access to a designated portion of the deferred area. With a limited supply of stockpiled forage, management often wants to control access, grazing duration, and time spent in the "hay-replacement" area. As a primary management strategy to reduce costs associated with hay, the "controlled stocking" approach could have negative aspects on animal performance. This "control" strategy can be detrimental to maintenance of weight in the event that management seeks to increase forage utilization efficiency. For any deferred, stockpiled grass, the bottom third of the plant is always lower in nutritive value than the top third of the plant, Thus, in many instances of controlled, rotational stocking, animals that are forced to consume the bottom third of the plant may not maintain weight due to lowered nutritive value as well as restricted DM for intake. Thus, depending on the lactation or pregnancy stage of cows, management decisions for rotational stocking may be best for animal performance if "maximum utilization efficiency" is not the primary objective of stocking.

Hay

One of the oldest methods of conserving forage is that of hay making. Although the technology and mechanization of making, storing, and shipping hay has made some major improvements, the costs associated with hay remains largely that of a supply-demand scenario. In prolonged, drought conditions and especially those that have occurred in Texas in 2010 and 2011, excess forage for hay production becomes a limited commodity. And, during periods of below-average forage production, managers are forced to cull cattle and/or initiate hay feeding prior to the onset of the normal wintering period. Perhaps most concerning and distressing for managers is the general lack of availability of hay in addition to the increased costs. Table 1 provides estimated hay costs for cows that consume 25 lbs/day during a haying period of 60 to 180 days and with cost of hay ranging from $80 to 300/ton. The obvious, spreadsheet information shows that expensive hay and prolonged haying periods cannot be tolerated except under specific circumstances. And, in worst-case scenarios, the best option may be to disburse the cow herd.

There are several reports on methods and strategies of feeding hay on an ad libitum and restricted basis. In general, large round bales fed with free access can result in loss of hay that exceeds 25%. With current hay costs, all round bales should be offered with hay rings, etc. The question of "what is the least amount of hay that can be fed to mature, pregnant cows?" may have some site-specific answers; however, in general, the cow likely needs at least 1% BW of forage, or about 10 to 12 lbs/day. But, additional energy and protein supplement is also required for performance, and this is most-often provided via range calves, etc. Before implementing a drastic reduction in daily DM, expectations for animal gain, reproduction, etc needs to be considered.

Table 1. Estimated hay costs for cows with variable costs per ton and duration of feeding.

	Hay Costs ($)					
Cost/ton	$80	100	150	200	250	300
Cost/lb	$0.04	0.05	0.075	0.10	0.125	0.15
Cost/day*	$1.00	1.25	1.875	2.50	3.125	3.75

Duration of Haying (days)	Hay Costs per Cow ($)					
60	$60	75	113	150	188	225
90	$90	113	169	225	281	338
120	$120	150	225	300	375	450
150	$150	188	281	375	469	563
180	$180	225	338	450	563	675

* Assumes hay fed at 25 lbs/da per cow which approximates ad libitum quantity for a mature cow.

Winter Pasture Options

In the absence of moisture and anticipated rainfall, winter annual grasses such as small grains and ryegrass or clovers may not be a viable, productive option. However, in various vegetational zones in Texas, the use of winter pastures has long-been used primarily for stocker cattle and secondarily for cows and calves. From the stand point of reliability and establishment, in most areas, we would rank these forages as small grain > ryegrass > clovers. With the increased cost of hay and reduced availability of forage for grazing, the use of winter pastures may offer an excellent option for wintering cattle under normal rainfall events.

Management and utilization of cool-season annual forages such as small grains, ryegrass, and clovers for optimum economic returns involve an integration of basic forage-animal production knowledge with the decision-ability to implement various events in a timely manner. The art and science of an economically successful grazing venture with winter annual pastures is not an especially easy task. Managers are required to make projections on forage DM growth and production as well as forage removal by grazing in order to establish an initial stocking rate. Then, successful managers are forced to revise these original estimates and project stocking rates once again during another part of the season. This does not necessarily imply that managers must buy-and-sell to adjust stocking rates; however, the dynamic nature of growth rate of cool-season annual forages requires some management flexibility in stocking density used to optimize animal gains. Thus, the primary management decisions involved with successful winter pasture grazing ventures are those of setting and manipulating stocking rates.

Forage Production and Timing of Events for Small Grains

The timing of events is generically important for the success of any endeavor. With cool-season annual forages, timing of planting, fertilization, grazing initiation, grazing duration, defoliation severity, selection of weight-class of livestock, and purchase-sell decisions control economic returns. A management calendar for small grain and ryegrass for stockers production in East Texas, for example, is shown in Table 2. The timing of events and fertilization schedules will vary with vegetational zone and soil fertility.

Table 2. Small Grain + Ryegrass Management Calendar for Cattle in the I-20 Corridor.

Month	Prepared Seedbed	Sod-Seeded
August	1st - Disk site and Roller-Pack to conserve soil moisture	1st-15th Initiate Defoliation Practices for bermudagrass (graze or hay) Do Not Fertilize
September	Plant from 5th to 15th ; Drill or Broadcast & Roller-Pack; Plant Small Grain @ 2" deep; Plant Ryegrass @ 0-1/2" deep; Fertilize at planting to soil test with N-P_2O_5-K_2O (i.e. 250 lbs/ac 21-8-17)	Graze, Harvest Hay and/or Shred. 15th to 25th Disk Lightly (2” to 3” depth, don’t “turn sod”; Initiate Planting on 25th- Drill or Broadcast; Plant Small grain @ 2" deep; Plant Ryegrass broad-cast; Use Pasture-Drag/Chain-link to insure seed contact with soil; DO NOT FERTILIZE (Nitrogen will stimulate bermudagrass growth)
October	Check for Army Worms and be prepared to treat. Read label for rates and restrictions for grazing.	Planting date acceptable until late Oct Fertilize to soil test with N-P_2O_5-K_2O (i.e. 250 lbs/ac 21-8-17) when forage reaches 4" height ± usually late October to early Nov±; Climate dependent
November	Fertilize on 1st ± at 50 to 65 lbs N/ac; Initiate grazing by Nov 15th to Dec 1st with approx. 1 to 1.5-500-lb stockers/ac or limit-graze with fall calvers; Check for Army Worms until frost	Fertilize late-planted areas as above

December	Graze with 1 to 1.5-500 lb stockers/ac or limit graze with fall calvers; Fertilize on 15th ± at 50 to 65 lbs N/ac	Fertilize on Dec. 1st - 15th at 50 to 65 lbs N/ac; Initiate grazing from 15th to Jan. 15 with approx. 1 to 2-500-lb stockers/ac or limit graze with fall-calvers

Table 2 Small Grain + Ryegrass Management Calendar for Cattle in the I-20 Corridor

Month	Prepared Seedbed	Sod-Seeded
January	Graze with 1 to 1.5-500 lb stockers/ac or limit graze with fall calvers; Be prepared to offer hay and/or extra pasture area depending on stocking rate, forage availability, and climatic conditions.	Graze as in Dec. Be prepared to offer hay and/or extra pasture area due to climatic conditions
February	Graze Fertilize on 1st to 15th at 50 to 65 lbs N/ac	Graze as in Jan. Fertilize on 1st - 15th at 50 to 65 lbs N/ac
March	**NOTE:** Pasture and forage productivity will increase dramatically which will allow for increased stocking rate of 50 to 100%. Additional stockers or cows and calves will be required by March 1 to March 15 to the first of April to optimize forage utilization and animal performance per acre.	
April	Graze with 2 to 3-650-lb stockers or with cows & calves; Fertilize on 1st at 50 to 65 lbs N/ac..IF... Forage is Needed!! **NOTE:** Fertilization on this date will be dependent upon ryegrass conditions and stocking rate.	Graze with 2 to 3-650-lb stockers, or with 1 to 1.5 cows & calf/ac; If forage production is needed, fertilize on 1st at 50-65 lbs N/ac or to soil test
May	Graze Ryegrass will mature mid-to late May. Plan to terminate stocking by mid-to late May	Graze. Stockers may be removed in mid-May. If cow-calf, stock at 1 to 1.5/ac Fertilize Option ± 15th to 30th with 50-65 lbs N/ac...IF....ryegrass pasture and bermudagrass grazing is needed. **NOTE:** Fertilization on this date will be dependent upon forage conditions and stocking rate desired during the summer.

June	If available, graze summer annual "forage" such as crabgrass, bermudagrass, etc with cows and calves at w to 3 ac/cow-calf	Graze bermudagrass with cows and calves at 1 cow-calf/ac to 2 ac/cow-calf.
July	15th; Disk & prepare for planting ±	Graze bermudagrass with cows and calves as in June.

Forage DM Production of Small Grains

Small grains have a bimodal function of dry matter (DM) production during the fall-winter-spring period (Fig 1). And, when annual ryegrass is included in the forage mixture for pasture, then the late-winter-spring DM production skews the forage response heavily toward February through May. For example, small grains with or without annual ryegrass may provide initial grazing in November-December, but the magnitude of DM is based on date of establishment and fertilization schedules. Forage DM from these pastures accelerates in the fall until climatic conditions (temperature and/or rainfall) cause a dramatic reduction in growth rate usually in late December to early February. Thus, in the case of small grain-ryegrass pastures, there may actually be three distinct "seasons" in which a different stocking rate would be deemed as "optimum" (Fig. 1). The opportunity for management decisions, therefore, to capitalize on this predictable bimodal DM growth curve is to be prepared for the occurrence of erratic DM production. This does not imply that managers become meteorologists; however, within specific regions of the state, long-term weather data are available that will assist with predicting periods of climatic-risk for forage production.

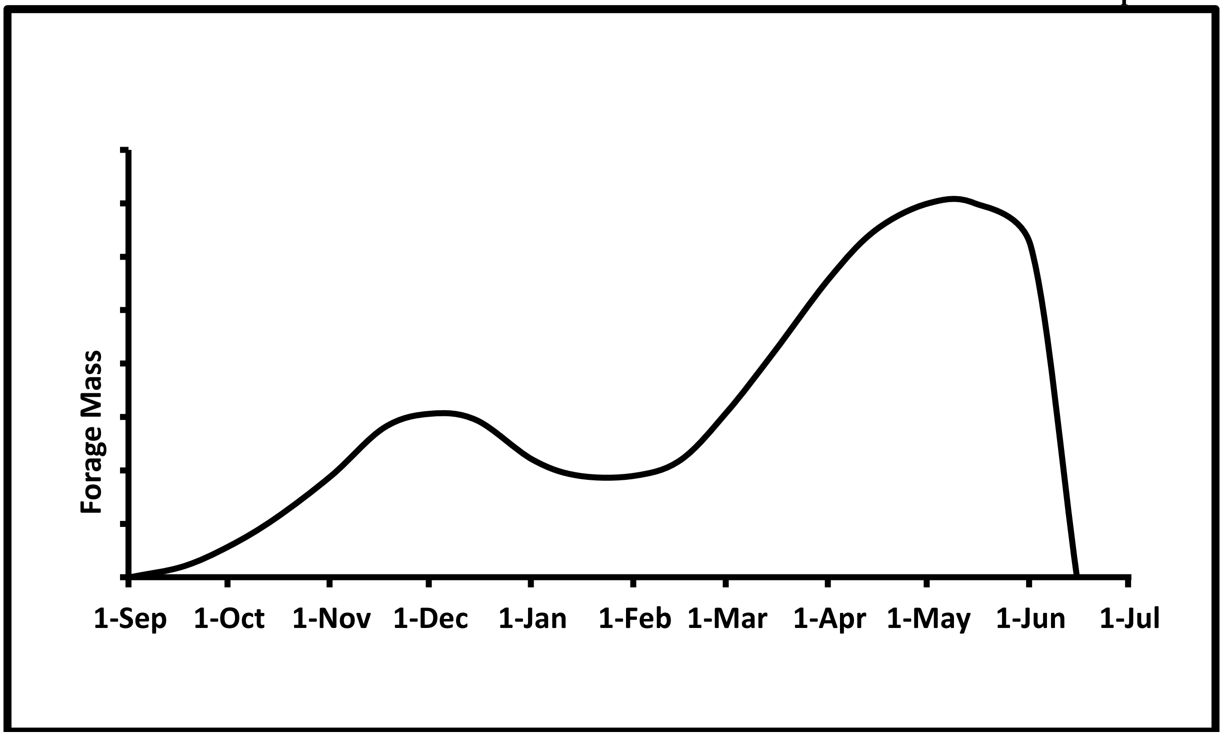

Figure 1. A generalized schematic of bimodal forage growth for rye-ryegrass in the southeastern US

Perhaps one of the best grazing management scenarios is that of having stocking rates which allow the opportunity for excess forage DM through the winter, and then expose the pasture(s) to sufficient stocking rate and severity of defoliation in the spring to maintain the forage in a vegetative stage of growth while allowing stocker calves to make near maximum daily gains (2.5 to 3.5 lbs/day). Forage production is accelerated by proper timing of establishment and fertilization. During more than 25 years of small grain ryegrass grazing at the Texas A&M AgriLife Research and Extension Center at Overton, the timing of these events has generally been as follows for over-seeded (sod-seeded) bermudagrass pastures:

1. Plant in late September to mid-October; this is rainfall-dependent.

2. Discourage fall bermudagrass growth via delayed fertilization during late summer and/or forage removal via grazing, haying or shredding. Also, one may lightly disk (2-3" depth) the sod without intent to permanently destroy the bermudagrass. In this case, the disks should not be set to "turn" sod and soil, but rather to create slight scarification of the sod. If a grain drill is used, then the drill openers will "fit" into the disk grooves. If a grain drill is not used, then seed can be broadcast-applied with a low to no N fertilizer source. The use of N fertilizer at this time will encourage bermudagrass growth.

3. After small grain-ryegrass has initiated growth to 3" to 5" and stand survival is relatively certain (barring inclimate drought or armyworm infestation), then fertilize by applying all of the P_2O_5 and K_2O requirements, and about 40 to 50 lbs/ac of N (according to soil test recommendations; usually this may range from late October to early November).

4. In late November to early December (after first killing frost) refertilize with N. (For sandy soils in East Texas, this will be about 50 to 65 lbs/ac N.)

5. Apply N fertilizer (50-65 lbs/ac N) in early February and once again in late March to early April. (At the Texas A&M AgriLife Research and Extension Center at Overton, total N rates have ranged from 200 to 250 lbs/ac, but N rate should be based on soil tests and objectives and/or requirements for DM production). Another N–fertilization (50-65 lbs/ac N) may be applied in mid-May to complete the ryegrass growth period and to initiate a "flush" of bermudagrass. The mid-May fertilization could be the last fertilizer applied during the summer months; however, stocking rate and forage DM requirements dictate this decision. Fertilization of winter annual forages and moderate stocking rates enhances nutrient cycling and creates a 12-month management program wherein the bermudagrass root system continues to use and re-use fertilizer nutrients deposited as excreta.

For other, specific soil-climate regions, fertilizer timing and rates will vary. And, for prepared seedbed plantings, timing of events does not have to contend with bermudagrass; thus, earlier planting-fertilization schedules are in order. Most importantly, grazing can be initiated earlier on prepared seedbed vs sod-seeding. Using the above-mentioned outline timing of events, small grain-ryegrass sod-seeded into bermudagrass pastures may be available for full-time grazing by late November to early December.

Stocking Method and Stocking Rate on Small Grains

The utilization of small grain-ryegrass pastures varies with management objectives and risk associated with the grazing venture. Small grain-ryegrass pastures are not inexpensive, but this should not necessarily imply that they are too costly to justify for use in an overall grazing plan. With pasture costs of $150 to $250/ac depending on N rate, utilization of forage DM and animal performance parameters (stocking rate) control the profit potential from these pastures. Although the following stocking strategies were not intended to be an all-inclusive listing, some decisions for method of use and stocking rates for small grain-ryegrass pastures areas may include the following options to optimize forage utilization considering a bimodal DM production mold:

Option 1: Stock pastures initially so that the low winter growth rate does not necessitate animal removal. In this scenario, additional cattle must be incorporated into the grazing scheme in mid-February to early March, and/or excess spring growth must be harvested as silage or hay (hay is usually not a good alternative in March and April due to inclement weather conditions for curing). The "additional" cattle may be part of the resident cows and calves and/or may involve winter-spring purchased cattle.

Option 2: Stock pastures during the fall with a moderate to heavy stocking rate, vacate pastures during the winter, if necessary, supplement with hay and/or protein, and resume grazing in the spring. This necessitates an adjacent sacrifice area for cattle to reside during this potential 30 to 45-day winter period. This approach assumes cold, inclimate weather during December-January, and thus is site-climate specific.

Option 3: Stock pastures initially at the "optimum" spring stocking rate (1650-2000 lb BW/ac) in the vegetation zone of the Texas A&M AgriLife Research Center at Overton, and exercise a limit-graze scenario during the fall-winter period until the rapid spring forage growth rate occurs (usually late February to early March). This management strategy is a good choice for full-calving cows and involves supplemental hay and protein in addition to an adjacent "sacrificed" area for animals to reside. Normally, these limit-graze systems would entail a 2- to 3-hr grazing per day with a 20- to 22-hour deferment, or some alternate-day grazing plan. The primary objective is to have some optimum number of cattle on hand and available for grazing during the spring flush-growth period which in the Pineywoods region is March through mid-May.

Option 4: Delay stocking winter pastures until mid-to-late winter (mid-January to early February) or until the rapid spring forage growth rate occurs. A component of a stocker grazing scenario is that cattle may be purchased at a time when prices are generally higher than during the previous fall season. However, there are limited hay and supplemental requirements for this approach. Or, if cattle are purchased during the fall, backgrounding on hay or standing forage, and supplemental protein is required. This option may also be used for cows and calves.

Stocking rate, as alluded to earlier, becomes the single most important factor controlling forage regrowth, animal performance, and potential economic returns. Although stocking rate appears to be a "moving target", management can use some established "rules-of-thumb" for site specific areas.

For small grain-ryegrass pastures, any set stocking rate is likely not to be the "proper" stocking rate because of fluctuations in DM production. However, long-term grazing experiments with stocker cattle in East Texas at the Overton Center have shown that initial December stocking rates of 650 to 800 lbs body weight (BW) usually do not necessitate a reduced or de-stocking decision due to winter climatic conditions. However, at this initial stocking density, an abundance of forage usually accumulates from mid-March to late May which requires additional cattle (increase stocking rate) or mechanical harvesting. An integral part of the stocking rate decision for small grain-ryegrass pastures is the method of stocking used. For example, a multi-pasture (n = 8±) rotational stocking system that employs a 2 to 3-day residence grazing of each pasture usually enhances forage DM production compared to similarly stocked continuously grazed pasture. Further, this magnitude of forage DM production is most dramatic during mid-winter when climatic conditions cause slow forage growth rates. If one chooses a rotationally stocked system, then cattle would likely have shorter residence time (n = 1 to 2 days) on any particular pasture in the fall and spring compared to a longer residence time (n = 2 to 4 days) during the mid-winter period. In general, as forage growth rate slows, then the movement of cattle among paddocks slows (i.e., longer resident time on each paddock). And, with fast forage growth rate, the movement of cattle is increased (faster) from paddock to paddock (i.e., shorter resident time on each paddock).

Initial stocking rates of 1000 to 1250 lbs/ac BW in the fall are subject to increased risk or likelihood of providing supplemental hay during mid-winter. And, with these higher initial stocking rates, some system of graze-rest would be preferred over continuous stocking. One reason for choosing these higher initial stocking rates is to create some "optimum" stocking rate for the 60- to 75-day period during the spring which should approach 1650 to 2000 lbs/ac BW at the Overton Center.

Management must choose the desired level of performance for stocker cattle. The age-old question for management of what do you want..... "more gain per animal or more gain per acre?", the answer is usually, "Yes". If the overall average daily gain (ADG) is to exceed 2.5 lbs/hd/day, then stockers require an abundance of forage DM from which to select their daily ration. However, if ADG of 1.8 to 2.0 lbs/day is acceptable, then less forage refusal areas (spot grazing) should be apparent, and utilization of the small grain-ryegrass pasture may range from 3" to 5" in height.
As evidenced by the above discussions, the best stocking rate plan by management exists when flexible alternatives exist and when management controls cattle numbers to fit the current situation. Some of the "best fit" stocking scenarios may exist when multiple (n = 2 or more) sets of cattle may be used to graze excess forage growth. Although many situations exist, most notable are: (a) use of additional stocker cattle in the spring which were either purchased late or backgrounded during the winter; and/or (b) use of resident fall or winter calving cows and their calves to graze excess forage on a full-time or limit-graze scenario.

Forage Production and Timing of Events for Ryegrass and Clover

Annual ryegrass has become the most widely used cool-season annual forage in Texas and in the southeastern U.S. Ryegrass may be planted alone or in combination with small grains and/or clovers. A management calendar for ryegrass of clover for East Texas is shown in Table 3.

Table 3. Clover or Ryegrass Overseeded in Bermudagrass Management Calendar for Cattle in I-20 Corridor.

Month	Clover	Ryegrass
August	Bermudagrass is primary forage; about 15th initiate defoliation plans	Bermudagrass is primary forage; about 15th initiate defoliation plans
September	Initiate close defoliation of bermudagrass via hay harvest or stocking	Initiate close defoliation of bermudagrass via hay harvest or stocking
October	15th, with closely-defoliated bermudagrass pastures, lightly disk pastures (≈2-3" deep), plant via drill or broadcast. Seed must contact soil.	1st to 15th, with closely-defoliated bermudagrass pastures, lightly disk pastures (≈2-3" deep), plant via drill or broadcast. Seed must contact soil.
November	15th - 30th, after 1st killing frost, fertilize via Soil Test with P, K, etc.	15th - 30th, after 1st killing frost, fertilize with complete fertilizer of N-P_2O_5-K_2O (i.e. 200 lbs/ac 21-8-17) via Soil Test)
December	IF...Pastures not fertilized to date, fertilize with P, K, etc by 10th	IF...Pastures not fertilized to date, fertilize by 10th. Fertilization at 50 ± lbs N/ac is needed before Dec. 10th ±
January	No Grazing	Grazing at low SR may be possible (2 to 3 acres/cow-calf) ± - Climate-dependent
February	15th, Potential to initiate grazing @ low SR (3 to 4 ac/cow-calf)	1st - 15th, Fertilize with 50 to 65 lbs N/ac; 15th initiate grazing (2 ac/cow-calf)
March	1st - Initiate full-time grazing @ 1 to 2 ac/cow-calf.	Graze (1 cow-calf/ac)
April	Graze; 15th Crimson in full flower; Arrowleaf is vegetative 1 ac/cow-calf	1st, Fertilize with 50-65 lbs N/ac (1 to 1.5 cow-calf/ac)
May	1st - Crimson clover matures; 1st - Continue grazing with cow-calf. 1 ac/cow-calf 15th Arrowleaf initiates flowering; 1-15 Harvest Hay ±	1st, Continue grazing (1 to 1.5 cow-calf/ac) 15th Ryegrass may start seed set 15th ± fertilize with 50-65 lbs N/ac

Table 3. Clover or Ryegrass Overseeded in Bermudagrass Management Calendar for Cattle in I-20 Corridor.

Month	Clover	Ryegrass
June	15th to 30th arrowleaf clover matures Bermudagrass is primary forage	1st - ryegrass matures; Hay harvest ±, Bermudagrass is primary forage
July	Bermudagrass is primary forage	1st ± fertilize with 50-65 lbs N/ac if forage for grazing or hay is needed. Bermudagrass as primary forage

Forage DM Production of Ryegrass and Clover

Although annual ryegrass may provide fall grazing when planted on prepared seedbed, most of the forage DM is produced during late winter to late spring (February through May). During a 25-year period at the Overton Center, the average initial date for stocking ryegrass pastures has been February 24th. However, this was at a time when adequate forage had accumulated to provide continuous stocking rates of about 2750 to 3000 lbs/ac BW of cows and calves on high stocked pastures. Thus, when lighter stocking rates are desired, then grazing could be initiated in late January to early February in East Texas. Initiation of grazing and stocking rate are site specific management options due to climate conditions as well as soil fertility and nutrient status for plant growth. In general, forage production of annual ryegrass increases with time from January to early spring (late April in East Texas). Plant maturation processes are usually visible via seedhead formation by early May; however, this is also a function of climate and nitrogen availability. It is not uncommon for annual ryegrass to remain vegetative and at the seedhead stage in moderately to low stocked pastures until late May to early June in East Texas.

In general, annual clovers, except for white clover, usually produce adequate forage for grazing later than that for ryegrass at any specific site. If moisture is available, white clovers from a re-seeding scenario may offer forage for grazing earlier than ryegrass. In East Texas, newly planted clovers are usually available for continuous stocking by late February to early March. Naturally reseeding clover pastures, however, may be available for grazing as early as December, but usually provide adequate DM by late January to early February. Time of grazing initiation is species dependent as well as site specific. Usually, the earlier that clovers provide grazing, the earlier that they mature and vacate the pastures. In East Texas, for example, crimson clover varieties usually initiate flowering by mid-April and do not provide much forage for grazing by mid-May. Arrowleaf clover, on the other hand, may provide grazing until mid-June to early-July but this is temperature and rainfall dependent. The timing of necessary events for clovers pertains primarily to soil pH regulation and soil nutrient availability at emergence.

Method of Use and Stocking Rate for Ryegrass and Clover

Stocking rates for ryegrass or ryegrass mixtures are similar to those mentioned for small grains during the late winter-spring months. Initial stocking rates which allow for an abundance of forage DM will provide stocker ADG of 2.5 to 3.0 lbs/day. In East Texas, this initial stocking rate would be about 1250 to 1500 lbs in early to mid-February. Pastures that are stocked sufficiently heavy to prevent forage heights from being above about 4 inches are likely to limit stocker ADG to less than 2 lbs/day.

Most ryegrass and/or clover pastures are used primarily by cow-calf operators rather than for stockers. A seven-year average of forage and cow-calf responses to multiple stocking rates at the Overton Center showed suckling, fall-born calf ADG of 1.9, 1.2, and 3.2 lbs/day, respectively, at stocking rates of 2.1, 1.3, and 0.8 cow-calf units per acre (1 cow-calf unit = 1500 lbs). On these continuously stocked pastures in East Texas, a conservative stocking rate of 0.75 to 1.25 cow-calf units has been consistently low-risk with respect to the need to de-stock or reduce stocking rate from February to weaning of fall-born calves in June-July. And, at the 0.75 to 1.0 cow-calf unit/ac level, there is usually an abundance of ryegrass-bermudagrass forage that can be harvested as hay by late-May to late-June.

Animal performance from clovers (primarily crimson), during this same time period resulted in suckling calf ADG of 1.7, 2.4, and 3.0 lbs/day, respectively, at stocking rates of 1.9, 1.2, and 0.75 cow-calf units/ac. Although suckling calf gain and pasture stocking rates were relatively similar at low stocking rates, ryegrass was more resistant to severe defoliation regimens than were the clovers. Additionally, with most clovers, except arrowleaf, grazing management decisions usually dictate that cattle be removed for hay purposes or reseeding about 30 days earlier than for ryegrass pastures. Arrowleaf clover usually matures and flowers later than annual ryegrass.

Stocking Management Options and Expectations

As always the case, grazing management options and expectations for forage production and animal response is site specific and is affected by the timing of cultural-management events and climate. For the most part, the expectations of various classes of livestock ADG under moderate stocking conditions would approximate 2.0 to 2.5 lbs/day for stockers and 2.5 to 3.0 lb/day for suckling calves. For the cool-season annual forages, and particularly small grain-ryegrass pastures, one of the most efficient methods of grazing management is to initiate a stocking rate that allows for adequate leaf area for rapid growth during late winter. Once the forage has initiated a “spring burst” of growth, then stocking rate adjustments (increases) may be made in an attempt to “catch” the pasture. However, management should not allow for such an abundance of growth that the small grain (especially rye) initiates premature flowering and flag leaf set.

The perception that rotational stocking is always better than continuous stocking is not a valid assumption. However, rotational stocking may allow for more forage growth, and judicious use of stocking rates may result in extra gain per acre as compared to continuously stocked pastures. Research at the Texas A&M AgriLife Research and Extension Center at Overton suggests that at low (650 to 800 lbs/ac BW at initiation) to moderate stocking rate (1200 lbs/ac BW at initiation) there may be no difference in method of stocking with respect to stocker ADG; however, even at these stocking rates, the rotationally stocked pastures had more forage "residue" for potential haying compared to the continuously stocked pastures. Rotationally stocked pastures at high stocking rates (1800 lbs/ac BW at initiation) have been shown to have greater stocker ADG than stocker calves at similar stocking rates under continuous stocking.

Achieving the economic optimum grazing management and utilization of annual winter pastures is not an especially easy task. A knowledge base of forage growth expectations for a specific site, and the art of managing judicious defoliation regimens allow for the greatest opportunity for positive economic returns as well as an acceptable transition from cool-season to warm-season pastures.

Management Strategies and Options for Wintering Cattle

When the subject of "wintering cattle" is discussed, most producers direct their attention to the cow herd. However, the options for wintering stocker cattle should receive some thoughts and planning for backgrounding programs. Perhaps the program that usually receives the most attention is that of winter pastures. In most of Texas, these "winter pastures" are in reality "spring pastures" with most of the DM production occurring from February through early May. The management challenges for stocker cattle are associated with purchase price, selling price, animal health, and stocking rate adjustments during March-April. Thus, the pre-winter pasture period for stockers includes hay, stockpiled forage, and an energy-protein supplement. This adjustment period actually sets the boundaries for animal performance and profit.

For the cow-calf producer who faces the need to purchase hay or other roughage sources. The knowledge of nutritive value and availability of the forage sets the parameters for the type and amount of supplement that may be needed. With rising costs of all feed and roughage sources, only the productive cows should qualify for "spending the winter on the ranch". For those speculating on increased calf prices for the upcoming few years, then young, pregnant cows may also deserve risk of over-wintering for future herd replacements. If the wintering of cattle was easy and without much expense, then anyone could do it!! But, the reality of costs and availability of forage and feed encourages detailed management strategies with multiple options to optimize positive, economic stability of the operation.

Forage Legumes for Texas 2023

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The successful use of forage legumes in Texas livestock production systems and as supplemental forages for Texas wildlife is influenced by: seasonal rainfall; competition with grasses and weeds; soil type; drainage; and ecoregion location.

Grasslands are primarily composed of grasses and legumes. Forbs and shrubs are also part of the grassland ecosystem on rangeland. Species in the grass and legume families are divided into annuals, perennials, and biennials and each of these categories is further divided into cool- and warm-season forages. Annuals germinate, grow, and mature in one growing season and therefore must be established from seed each year. Perennials have the ability to live more than one year under appropriate climatic conditions. They usually die back (go dormant) sometime during the year and then initiate new growth from roots, rhizomes, or stolons. Biennials require two growing season to complete their life cycle with the first season devoted to vegetative growth and flowering occurring in the second season. Warm-season forages begin growth in the spring and die or go dormant in the autumn with the first killing frost. Cool-season forages generally begin growth in autumn and mature or go dormant in late spring or early summer. A general description of each forage legume class and adaptability of each species and a list of varieties follows.

Cool-Season Annual Legumes

Cool-season annual legumes are the most extensively used legumes in the southeastern United States. They are usually overseeded on warm-season perennial grasses either alone or in mixtures with annual ryegrass. In addition to providing forage with high nutritive value during the spring they can add nitrogen to the pasture system through N_2-fixation in association with Rhizobium bacteria. Other benefits are spring weed control, nitrogen source for organic farming systems, and as supplemental forages for wildlife. They are more soil specific than grasses and generally require a minimum soil pH of 6.0. They must establish from seed each autumn but some of the species have a high percentage of hard seed that permits volunteer reseeding if managed properly.

Annual Medics - The annual medics are a group of species belonging to the Medicago genus that are native to the Mediterranean region. They are annual relatives of alfalfa. Most species are best adapted to soils with a pH of 7 and higher and persist in lower rainfall areas than most clover species if rainfall occurs in late autumn and winter. Annual medics are more active winter growers than most annual clovers but most annual medic species also lack cold tolerance, which limits their northern adaptation. They produce small yellow flowers that mature into pods. Some of the species found in the United States form spines of various lengths and some do not. Individual plants may produce over a thousand seed pods.

Annual medics are dependable reseeders because they produce a high level of hard seed and have excellent seedling vigor. This excellent seedling vigor makes them one of the easiest winter annual legumes to establish. Annual medics can easily establish with a light disking, broadcast seeding, and then dragging the pasture to cover the seed. These hard seed can remain viable in the soil for several years. Annual medics do have a high bloat potential. However, this can be overcome by proper management of livestock and providing other forage to the grazing animals such as frosted mature grass, hay, or planting ryegrass with the medic.

Annual medics are excellent winter forages for domestic livestock and wildlife. One thing that makes medics well adapted as a grazing crop is that they generally have a prostrate growth habit and will flower and set a good seed crop even under heavy grazing pressure. Most commercial varieties in the world have been developed in Australia, and as a general rule, most Australian varieties lack winter hardiness needed to persist in Texas.

Burr medic, or burr clover, *(M. polymorpha*) was introduced sometime in the ninetieth century and has become naturalized in South Texas and the West Coast. 'Armadillo' burr medic, was selected from a naturalized ecotype in South Texas, and was released by the Texas Agricultural Experiment Station at Beeville in 1998. Armadillo is adapted south of I-20 in Central and South Texas. Recommended seeding rates are 5 to 10 lbs per acre. Armadillo does well when grown with bermudagrass and kleingrass providing the perennial grasses are managed to be grazed short in the autumn to allow the seedlings to establish.

Barrel medic (*M. truncatula*) is less winter hardy than Armadillo burr medic, but some Australian varieties perform well in South Texas. The barrel medics are somewhat better adapted to the high pH sandy soils of Central and South Texas than Armadillo burr medic. The old variety 'Jemalong' has been recommended in South Texas for 10 or more years. There is a new cultivar, 'Jester', that was selected out of Jemalong and it has been performing nearly like Jemalong. Jester and Jemalong mature about 2 weeks later than Armadillo and is recommended from about Austin southward. Another cultivar that is only recommended in deep South Texas is Parabinga. Parabinga is a very active winter grower and matures 2 weeks before Armadillo, so has performed well in the hot drier areas of deep South Texas. Recommended seeding rates on barrel medic are similar to Armadillo.

Spotted burr medic (*M. arabica*) is more cold tolerant, better adapted to sandy soils that are slightly acid than most other medics. At the present time there are no commercial varieties available.

Black medic (*M. lupulina*) is common from South Texas north to Canada. It is the predominant annual medic on much of the blackland soils of Texas. Black medic develops a smooth black cluster of pods with normally only one seed per pod. The only commercial varieties currently available are not well adapted to Texas as they were developed for more northern regions. However, if you have a naturalized stand of black medic, it can be encouraged to contribute to your winter and spring forage base if you manage to allow it to reestablish itself in the autumn.

Button medic (*M. orbicularis*) has a large flat smooth pod and is best adapted to the north central Texas. 'Estes' button medic is currently being marketed for North Central Texas. A problem that is unique to this species is that the pod is very large and fleshy, and it is highly palatable to deer. Nearly complete removal of all pods has been observed when using this legume in deer food plots.

Little burr medic (*M. minima*) has become naturalized in the Texas Hill Country and have smaller leaves and smaller seed than most medics. The pods have long spines and the plant is very pubescent. Devine little burr medic was released in 2005 by Texas Agricultural Experiment Station at Beeville. Devine originated from a kleingrass pasture near Devine, TX, and is best adapted in the I-35 corridor from south of San Antonio to nearly the Oklahoma border. Recommended seeding rates are 3 to 5 lbs per acre. Devine grows well with most perennial grasses provided the grasses are managed to be grazed short in the autumn to allow the seedlings to establish.

Arrowleaf clover (*Trifolium vesiculosum* Savi) is one of the major annual clover species grown in the southeastern U.S. It has large white flowers with a pinkish cast and can grow over 4 ft tall if not grazed or cut. Arrowleaf clover is best adapted to well drained loam and sandy soils but is more sensitive to soil pH than other legumes with a preference of 6.5 to 7 pH. Iron chlorosis can be a problem on soils with a pH above 7.5. Arrowleaf clover is the latest maturing, and usually the highest yielding annual clover with growth continuing through June if moisture is adequate. Seedling growth is slow with seedlings staying in a rosette stage until late February. This results in very little forage production until early March. Arrowleaf clover has excellent reseeding potential with up to 90% hard seed. Volunteer stands may be poor the first reseeding year because of the low percentage of soft seed. Only scarified seed should be planted at 8 to 10 lb/acre. Planting an additional 4 to 5 lb/acre of scarified seed the first reseeding year will ensure that an adequate amount of soft seed is present to obtain a good stand.

Virus diseases are a major problem with older varieties like Yuchi. Leaves of affected plants will be crinkled, have a light and dark green mosaic pattern, and a chlorotic appearance. Root rots have also been a problem. Early symptoms are poor stands in the autumn because of seedling loss. Surviving plants will do poorly during the winter because of root damage and may die when grazing begins. Leaves of arrowleaf clover may turn red because of stress due to disease, low temperatures, or other environmental factors. Early planting from mid-September to mid-October has also improved seedling survival against these diseases. 'Apache' arrowleaf released in 2001 has tolerance to bean yellow mosaic virus disease. 'Blackhawk' arrowleaf clover was released in 2012 and is tolerant to both bean yellow mosaic virus and fungal seedling diseases. Both Apache and Blackhawk are recommended varieties.

Ball clover (*Trifolium nigrescens* Viv.) has small ovate leaflets and small white to yellowish-white flowers. If not cut or grazed, stems can grow up to 3 feet and are prostrate to partially erect, often forming a thick mat. This prevents using ball clover for hay and makes harvesting seed difficult unless it is grazed before flowering. Seed are very small (approximately 1,000,000 per lb) with a recommended seeding rate of only 2 to 3 lb/acre. Ball clover does best on loam and clay soils but has done well on relatively level sandy soils near creek or river bottoms that maintain good soil moisture. It does not have good drought tolerance and growth will be reduced in a hot, dry spring. It prefers a soil pH of 6 or higher. Ball clover can tolerate wet soils but not as well as white clover. It is medium maturity, flowering about a month later than crimson with yields usually slightly less than crimson.

Ball clover has excellent reseeding. Hard seed content is about 60% and it will produce some flowers even under close grazing. Ball clover does have a high bloat potential and should be managed accordingly. Since there are no commercial varieties at this time only common ball clover seed is available.

Berseem clover (*Trifolium alexandrinum* L.) also called Egyptian clover, is believed to have originated in Syria. It was introduced into the Nile Valley in Egypt in the 6th Century and is now grown on half the cultivated land in that country as a winter cover and green manure crop. It has oblong leaflets, hollow stems, large white flowers, and can grow up to 2.5 ft. tall. Berseem clover is not as cold tolerant as the other annual clovers. Bigbee berseem, a joint release by the USDA and the Mississippi Agricultural and Forestry Experiment Station in 1984, has improved cold tolerance. However, even Bigbee berseem is considered less cold hardy than most of the other annual clover species.

Berseem clover is well adapted to river bottoms and clay soils with a pH of 6 to 8. Berseem clover has medium size seed with 207,000 seed/lb. Recommended seeding rate is 12 to 16 lb/acre. Bigbee berseem has excellent seedling vigor with growth 8 to 10 inches tall by December if planted on a prepared seedbed in late September or early October along the Gulf Coast. Grazing should begin when it is 6 to 8 inches tall to stimulate tillering and limit frost damage. Bigbee berseem clover begins flowering in late April. It does well under irrigation in southern California. Bloat potential of berseem clover is low but animal losses due to bloat have been reported. It lacks hard seed and therefore is a poor reseeder. Berseem clover has poor drought tolerance.

Crimson clover (*Trifolium incarnatum* L.) is native to Europe and is the most widely adapted annual clover species grown in the southeastern United States. It has scarlet or deep red flowers and is used extensively for roadside stabilization and beautification throughout the southeastern United States. Crimson clover grows on soils ranging from sands to well-drained clay soils with a pH of 5.5 to 7. Best growth occurs at a pH of 6 to 7. Iron chlorosis has been a problem on calcareous soils at a pH of 7.3 or higher. Recommended seeding rate is 16 to 20 lb/acre. Crimson clover is one of the larger seeded annual clovers with 150,000 seed/lb and has excellent seedling vigor. If planted early, it can produce some forage in the autumn and has earlier forage production in the spring than the other clover species. However, winter temperatures about 15°F or lower have caused some top kill that will reduce early spring growth.

Crimson clover is the earliest maturing annual clover. The combination of good seedling vigor and early maturity makes it ideal for overseeding warm-season perennial grasses. Present crimson clover varieties are considered poor reseeders because hard seed levels are only about 10%. Most soft seed germinate with the first rain after seed matures in May. Range in maturity of present varieties is about 12 days. Flame and AU Robin are early varieties and Tibbee and Dixie are late varieties.

Persian clover (*Trifolium resupinatum* L.) is native to Asia Minor and the Mediterranean region. The actual time of introduction into the United States is not known, but it was found growing in Wilcox County, Alabama in 1923. Common Persian clover has small leaves and reaches a height of 8 to 12 in. with small, light purple flowers. It is found on loam and clay soils, especially on poorly drained soils with soil pH of 6 to 8. Seedling growth is best at a pH of 7 to 8. Persian clover spreads during flooding because the calyx swells at seed maturity and serves as a float, allowing the seed to move to other flooded areas. It does have high bloat potential. Recommended seeding rate is 6 to 8 lb/acre. The seed are small with 600,000 seed/lb. The only available varieties are from Australia.

Rose clover (*Trifolium hirtum* All.) is native to the Mediterranean region and Asia Minor and is one of the few clover species that is adapted to lower rainfall areas. Most of the rose clover acreage is on the California rangelands that receive at least 10 in. of rain during the winter growing season. Overton R18 was selected for climatic and soil conditions in the southeastern US at the Texas A&M University Agricultural Research and Extension Center at Overton. It matures 4 weeks later with twice the production compared to the early varieties grown in California and Australia. Rose clover is adapted to all soil types with a pH of 5.5 or higher but does not tolerate poorly drained soils. Some iron chlorosis problems have been reported on calcareous soils with soil pH near 8.0. Optimum pH for seedling growth is 5.5 to 7.0. Recommended seeding rates are 12 to 16 lb/acre. Rose clover has a medium size seed with 164,000 seed/lb. Poor seedling growth and nodulation is a major limitation of rose clover that results in later spring growth than the other legume species.

The greatest success with rose clover has been in North Central Texas and Central Oklahoma where the annual rainfall is 25 to 30 in., which limits the growth of most other clovers. The good drought tolerance is due to a deep rooting depth. Rose clover is an excellent reseeder because of a hard seed percentage of 90%. California data have shown that if volunteer clover stands are lost to drought or insects several years in a row, there would still be sufficient hard seed remaining to reestablish the rose clover stand.

Subterranean clover, also called subclover, is native to the Mediterranean region. Subterranean clover is the common name for three Trifolium species, subterraneum, brachycalcycinum, and yanninicum. Most varieties grown in the United States are subterraneum species. Subclover is best adapted to soils ranging from a fine sandy loam to clay with a pH from 5.5 to 7. Like arrowleaf, it usually becomes chlorotic and stunted on soils with a pH above 7.3. The brachycalycinum species of subterranean clover is adapted to soil pH’s above 7.0 but has less cold tolerance. Subclover has a low growth habit which forms a dense sod that seldom exceeds a 10-in. height. Its short height is deceiving. Forage yield of a 5- to 6-in. high subclover pasture is similar to a 12-in. high arrowleaf clover pasture. Reseeding of subterranean clover is generally poor in Texas.

Annual Sweetclover (*Melilotus albus* Medik.) is not a true clover but is an excellent forage legume. At one time, it was the most widely grown forage legume in the United States. It is one of the most drought-tolerant legumes and was grown for forage and soil improvement, particularly in the Great Plains and the Corn Belt. Sweetclover will grow almost anywhere there is a minimum of about 17 in. of rainfall and soil pH is 7.0 or higher. The three general cultivated types of sweetclover are biennial yellow flower, biennial white flower, and annual white flower. Hubam and Floranna are annual white flower types that were grown in the southern USA. In the late 1940's and early 1950's, over 9 million pounds of sweetclover seed were produced in Texas annually. The advent of cheap nitrogen fertilizer after World War II and the spread of the sweetclover weevil (Sitona cylindricollis) eliminated most of the sweetclover acreage in the United States. However, it is still grown in Canada. Both white and yellow flower types are found growing along roadsides throughout the United States.

Sweetclover can be planted in the southern states in October at 12 to 16 lb seed/acre. Successful stands have been obtained in Central Texas when seeded in late January and February. It has a medium seed size with approximately 260,000 seed/lb. Sweetclover plants are 3 to 7 feet tall at maturity depending on variety. Annual sweetclovers are late maturing, flowering from May through June in the southern United States. Sweetclovers contain coumarin that causes a bitter taste to which animals become accustomed. If sweetclover is baled at too high a moisture level and fungal molds develop, the coumarin changes to dicoumarol, a blood anticoagulant. Cows eating the moldy hay can die of internal bleeding. Dicoumarol is not a problem when sweetclover is grazed by cattle or browsed by deer. Dicoumarol can cause toxicity problems only when high coumarin sweetclover is consumed as moldy hay or silage.

Genes for low coumarin have been found in a wild sweetclover type but none of the annual sweetclover varieties contain the low coumarin gene. A breeding program has been initiated at Texas A&M University Agricultural Research and Extension Center at Overton to transfer the low coumarin gene to annual sweetclover. Seed increases and evaluations of low coumarin experimental cultivars are in progress.

Silver River is a new, rust resistant cultivar of white-flowered, annual sweetclover (Melilotus albus Medik.) developed by Texas A&M AgriLife Research at Overton with excellent adaptation to south and central Texas. Sweetclover rust (Uromyces striatus Schroet.) causes a range of plant disease symptoms, including leaf drop, reduced seed and forage yield, and premature plant death. The evaluation of Silver River for rust resistance was conducted at Beeville, TX under severe epiphytotics of sweetclover rust. Two cycles of mass selection at Beeville were used to improve the rust resistance of a sweetclover plant introduction line from Uruguay. The original plant introduction population had 21% rust resistant plants. Silver River averaged 91% resistant plants at Beeville in 2014 and 2015, compared to ‘Hubam’ with a 2-year average of 7% resistance. Silver River is similar to Hubam in forage yield and maturity. This new cultivar will improve the reliability of annual sweetclover in cattle grazing systems and wildlife supplemental forage plantings in south and central Texas. Silver River was released in 2016.

Vetch (*Vicia* spp.) There are many different species of vetch including 15 that are native to the US. Cold-hardy vetch species such as hairy vetch are adapted over a wide area of the US. Common vetch is less cold-hardy and is limited to areas with mild winters such as the Gulf Coast area. Vetch is adapted to a wider range of soil types and pH's than most other forage legumes. It grows on sand, loam, and clay soils from pH 5 to 8. It also has excellent seedling vigor because of its large seed. There are approximately 16,000 seed/lb for hairy vetch with a recommended seeding rate of 20 to 25 lb/acre. Optimum planting depth is 1 to 2 inches because of the large seed. Stems bear leaves with pinnate leaflets and terminate in tendrils that attach themselves to stems of other plants. White or purple flowers, depending on the species, are borne in a cluster or raceme. Hairy vetch flowers during April and May. Seed and pod characteristics vary with species.

The main use for vetch is for a green manure crop because it maintains a high nitrogen concentration through plant maturity. A mature crop of hairy vetch will contain about 150 lb nitrogen/acre. Vetch does not tolerate close grazing and should not be grazed shorter than 6 in. Insects are the main disadvantage of vetch. Pea aphids, corn earworm, fall armyworm and spider mites can be problems. The vetch bruchid or weevil destroys the interior of the seed reducing seed yields, which is the main reason for poor reseeding.

Austrian Winter Peas (*Pisum sativum*) may produce a moderate amount of dry matter used for grazing, as a hay crop, or as a green manure. Winter peas are often used as companion crops with cereal grains and are high in nutritive value. Winter peas are easily established on well-drained loam or sandy loam soils and should be planted during September or October at 20 to 30 lbs of seed/acre in mixed stands with cereal grains or ryegrass and 30-40 lbs/acre in pure stands. Austrian winter peas are adapted to low pH soils.

Cool-Season Perennial Legumes

A few cool-season perennial legume species are grown in the southern United States. Their acreage in the southern United States is limited by preference for loam and clay loam soils. Perennial clovers often act like annuals in this region because of poor summer survival.

Alfalfa (*Medicago sativa* L.) is the best-known forage legume in the United States and is referred to as the "Queen of the Forages". It is the only forage known to have been cultivated before the era of recorded history. Although classified as a cool-season legume, it grows throughout the summer if moisture is available. Because of this long growing season it has the capacity to produce large yields of high quality forage. It is best adapted and grown most extensively in the mid-west US. However, varieties have been developed that are adapted to most climates throughout the United States.

Alfalfa does best on deep, well-drained loam to clay loam soils with a pH of 7.0 or higher. In the eastern half of Texas, the optimum sites are well-drained river bottoms of the Brazos, Colorado, and Red Rivers. Alfalfa can be grown on any soil with good internal drainage and a subsoil pH of 5.5 or higher. Lime can be added to raise the surface soil pH to near 7 and nutrients limiting for optimum growth can be applied. When sandy acid soils are limed to pH 7, boron is critical for alfalfa if soil boron is less than 1.0 ppm. Autumn planting dates are preferred over spring because of fewer weed problems. Recommended seeding rates are 16 to 20 lb/acre planted at ¼ in. depth in clay soils to ½ in. depth in sandy soils in a clean, firm seedbed.

Alfalfa can be a very profitable forage crop, but it requires a high level of management. Chemical weed control is required to obtain good clean stands. Most disease problems have been solved by selecting for resistance. Alfalfa weevil and three-cornered alfalfa hopper are the main insect problems but all can be controlled with insecticides. Its primary use is hay for dairy cows and horses. With the development of grazing tolerant varieties, more alfalfa is being used for grazing.

Red clover (*Trifolium pretense* L.) is a weak perennial with stands lasting 2 to 3 years in the northern 2/3 of the United States but usually only 1 year in the Lower South (35 N latitude southward). Red clover is best adapted where summer temperatures are moderately cool to warm with good soil moisture conditions. It prefers loam to clay loam soils as long as they are well drained. It will grow on flat sandy soils (flatwoods) with good moisture. Soil pH needs to be above 6. In the South, red clover reaches a height of 2 to 2.5 ft. with numerous leafy stems rising from the crown. Hairs are present on both leaves and stems. Flower color varies from light pink to rose purple to magenta. It has a tap root that gives it some drought tolerance on loam soils but red clover is sensitive to low soil moisture on sandy soils.

Recommended seeding rate is 10 to 12 lb/acre planted at a ¼ to ½ in. depth. Red clover will grow into June and July if moisture is available. Cherokee red clover is the only variety developed in the South so it begins spring growth earlier than other varieties. Red clover can be used for both hay and grazing but does not tolerate close grazing.

White clover (*Trifolium repens* L.) is a perennial legume grown in the eastern half of the US. While perennial in nature, white clover in the southeastern US generally persists as a re-seeding annual. There are small, medium, and large (ladino) white clover types. Although a shorter stature, short and medium types are better seed producers than large types, which is important for reseeding in the south. Recommended varieties are Louisiana S-1, Neches and Durana. White clover requires good soil moisture, is usually found on clay loam, bottomland soils, and is not productive under droughty, upland conditions.

White clover is often planted at 3-4 lbs/acre into existing tall fescue or bermudagrass stands. Best production will be obtained on fertile, well-drained soils if rainfall is favorable. White clover will tolerate wet soil conditions better than most legume species. Because it is often found on wetter sites, white clover may survive a drought during the summer months better than other forage legumes.

White clover does not exhibit the same erect growth habit as red clover and mixed grass-clover stands should be grazed at a 4 to 6 inch height to prevent competition for sunlight from becoming a limiting factor in white clover production. When cattle graze pure stands of white clover, bloat potential may be reduced using Bloat Guard blocks, feeding grass hay or grown in grass mixtures.

Warm-Season Annual Legumes

Both annual and perennial warm-season legumes are used more for wildlife than livestock. It is difficult to grow warm-season legumes in association with warm-season perennial grasses because the warm-season grasses are so well adapted and competitive.

Cowpea (*Vigna unguiculata*) is an annual viney plant with large leaves. The species is fairly tolerant of drought, heat, low fertility, and moderate soil acidity. Cowpeas, however, do require adequate levels of P and K to be productive. Forage nutritive value is generally high and plants are easily established from May through June. Many times cowpeas are used as a warm-season food plot for white-tailed deer to offset the negative effects of summer stress. Cowpeas do not cause bloat in ruminants, but are not found immediately palatable by cattle.

'Ace' is a small seeded (9000 seed/lb) cultivar of forage cowpea developed for use in wildlife supplemental plantings, cover cropping systems and legume hay production. Ace was developed in the Texas A&M AgriLife Research Forage Legume Breeding Program at Overton and released in May 2018. Ace was evaluated at Texas A&M AgriLife RECs at Overton and Vernon, TX. Ace has full season forage production and flowers in late August.

'Iron & Clay' is an old forage-type cowpea cultivar (technically a variety mix) that remains vegetative during most of the summer and flowers in mid September. Both Ace and Iron & Clay are recommended for Texas.

Lablab (*Lablab purpureus* [L.] Sweet) is a vining, annual tropical legume with high nutritive value as a forage for cattle and goats and browse for deer. The qualities of this tropical forage include: drought tolerance, high palatability, high nutritive value, excellent forage yields and adaptation to diverse environmental conditions.

Currently, seed of the Australian lablab cultivar 'Rongai' is imported into the US primarily for supplemental forage plantings for white-tailed deer. Rongai was released by the New South Wales Department of Agriculture in 1962. Rongai is very late maturing and generally does not flower in northeast Texas before frost.

'Rio Verde' lablab was developed through selection for tolerance to defoliation, forage production potential and Texas seed production. Rio Verde was developed at the Texas A&M University Agricultural Research and Extension Center at Overton, Texas and released by the Texas Agricultural Experiment Station (TAES) in 2006. Rio Verde was the first lablab cultivar developed in the US. Currently (2020) no Rio Verde seed are produced in Texas due to anthracnose disease in west Texas seed production areas. Texas A&M AgriLife Research at Overton has identified resistance in lablab to this foliar and stem blight but new cultivars are still in evaluations.

Soybean (*Glycine max*) is a temperate grain legume that can be used as a grazing and hay crop. This plant is not as tolerant of heat and drought as cowpea and lablab and does not regrow well after defoliation. Soybean is better adapted to heavy clay soils and wet soils relative to cowpea and lablab. There are forage type soybean varieties that require short days (late fall) to flower and mature. They remain in a vegetative stage during the summer in contrast to grain-type soybeans that begin to flower 2 to 3 months after planting. 'Tyrone' is the best adapted forage soybean variety for the southern states.

Warm-Season Perennial Legumes

Bundleflower: There are several species of bundleflower (Desmanthus) that are native to Texas and surrounding states. Two species have been commercialized for use in Texas. 'Sabine' Illinois bundleflower (Desmanthus illinoesis) is adapted to North and Central Texas from about Austin northward. 'BeeWild' bundleflower (D. bicornutus) was developed at Beeville and released by the Texas Agricultural Experiment Station in 2003. BeeWild is consists of four (4) different cultivars that are produced as monocultures for seed production purposes, and then blended to produce BeeWild. The four different cultivars have a 100% range in seed size, and a broad range in flowering and seed maturation time. BeeWild is best adapted south of about Waco in Central Texas. All bundleflowers are poorly adapted to acid sandy soils, so their use is restricted to soils that are sandy clay loams and heavier with a pH near neutral and above. All bundleflowers contain tannin which reduces palatability and essentially eliminates the potential for bloat. Recommended seeding rates for bundleflower is 3 to 5 lbs per acre.

More Information

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SHOULD I SELL CARBON CREDITS?

A Decision Guide for Ranchers

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INTRODUCTION

Increasing public attention to climate issues has amplified pressure on many industries to develop 'climate neutral' systems. A central goal of most 'climate neutral' strategies is for an entity to achieve 'net zero' carbon emissions by reducing direct emissions of greenhouse gases (GHG) where possible, and seeking sources of carbon dioxide (CO_2) emissions offsets (often called 'carbon credits' or 'carbon offsets') to balance emissions that cannot be eliminated. These 'offsets' or 'credits' represent CO_2 being removed from the atmosphere and stored. Land-based carbon accumulation has long been considered an essential element of climate mitigation strategies, and is increasingly viewed as a potential source of purchasable credits for those seeking to offset emissions. Ranch owners and managers need a framework to make the most effective decisions about if, and how, entering into a carbon credit contract fits their business operations.

This article describes the foundational concepts of carbon trading, key considerations for managing the development of credits, risks associated with entering a carbon credit contract, and economic and market considerations. Our goal is to inform ranchers so the best decisions can be made in an emerging and uncertain enterprise.

CARBON CREDITS AND CARBON TRADING

WHAT IS A 'CARBON CREDIT'?

A carbon credit represents one metric ton (1,000 kg) of CO_2 or CO_2 equivalents removed from the atmosphere. From an accounting perspective, if the atmosphere is the 'account', then a release of CO_2 into the atmosphere is a 'debit' to that account, and removal of CO_2 from the atmosphere is a 'credit'. For a corporate entity, debits (CO_2 emissions) occur through: 1) direct use of fuels in manufacturing or distribution processes (Scope 1 emissions); 2) the use of fossil fuels to generate electricity off site that is then consumed by the company (Scope 2 emissions); and for some 3) emissions embedded in their raw materials inputs, or use of their products by consumers (Scope 3 emissions).

A given company may seek to reduce its emissions through efficiency gains or other means, but may not be able to completely eliminate all emissions. If they wish to achieve 'net zero' emissions, then they will seek 'credits' to their atmospheric account that offset any remaining 'debit' amounts to balance the account. In markets like the European Union and California, governmental regulation requires that companies offset all or a portion of their emissions (often under 'cap and trade' systems), while in many other markets (most of the United States) these corporate actions are voluntary. A company may have incentive to do this as a component of their corporate social responsibility (CSR) or environmental, social, and governance (ESG) policies and reporting requirements, or to improve

> **A carbon credit represents one metric ton (1,000 kg) of CO_2 or CO_2 equivalents removed from the atmosphere.**

their competitive position with customers. These factors affect the demand for purchasable 'carbon credits' and may result in differences in demand (and therefore prices for credits) among markets.

The demand for carbon credits is met through supply – the generation of credits. Primary sources of carbon credits are through engineered or nature-based systems. Engineered systems include direct CO_2 capture from the atmosphere or CO_2 removal from exhaust sources, coupled with long-term underground storage of captured carbon. These systems are collectively referred to as 'CCUS' for 'carbon capture and underground storage'. 'Nature-based' solutions include those associated with forestry or the accumulation of carbon containing compounds in soil through natural processes that begin with photosynthesis of plants. These are the focal point of this decision guide, as they are the most directly accessible for ranchers.

CREATING A CARBON CREDIT

Plants effectively capture CO_2 from the atmosphere, and combine it with water (hydration) through photosynthesis to assemble it into more complex carbon containing molecules (carbohydrates). Some of these carbohydrates are translocated to the root of the plant, and may be excreted or assimilated into the soil as organic matter that contains 'soil carbon'. This is the fundamental mechanism of transferring atmospheric carbon into soil carbon and is the basis of land-based carbon credit generation (Figure 1).

Generating a tradeable carbon credit requires measuring, verifying, certifying, recording, and tracking the amount of carbon accumulated and retained in the soil, and creation of tools to exchange these carbon credits. Much like an exchange traded contract for a commodity, several entities have created 'Standards' for the generation of carbon credits.

CONTRACT STANDARDS

The standards define the credit units (e.g., 1 tonne of CO_2) and the methods for quantifying, measuring, and assessing the data required to assure the soil accumulation and storage of credited CO_2 equivalents. It is important to note that soil measurements are usually expressed in terms of carbon, not CO_2. However, credits are issued in terms of CO_2. Each tonne of soil carbon is equivalent to 3.67 tonnes of CO_2. The standards may also describe the required components of any contractual 'project' intended to generate tradeable credits, the types of projects allowable under the standard, and other policies and procedures governing accumulation and maintenance of soil carbon. In this sense, the standard defines the rules governing the carbon credit contract. Because there are multiple entities that facilitate the trade of carbon credits, more than one standard exists. While the various standards share many similarities, they may also have key differences in definitions of allowable credit generation activities (e.g., grazing practices), acceptable methods of measurement and verification, and duration of performance. Standards also differ in their definitions of 'additionality' and 'permanence' of storage.

Since there are multiple entities that facilitate the trade of carbon credits, more than one standard exists.

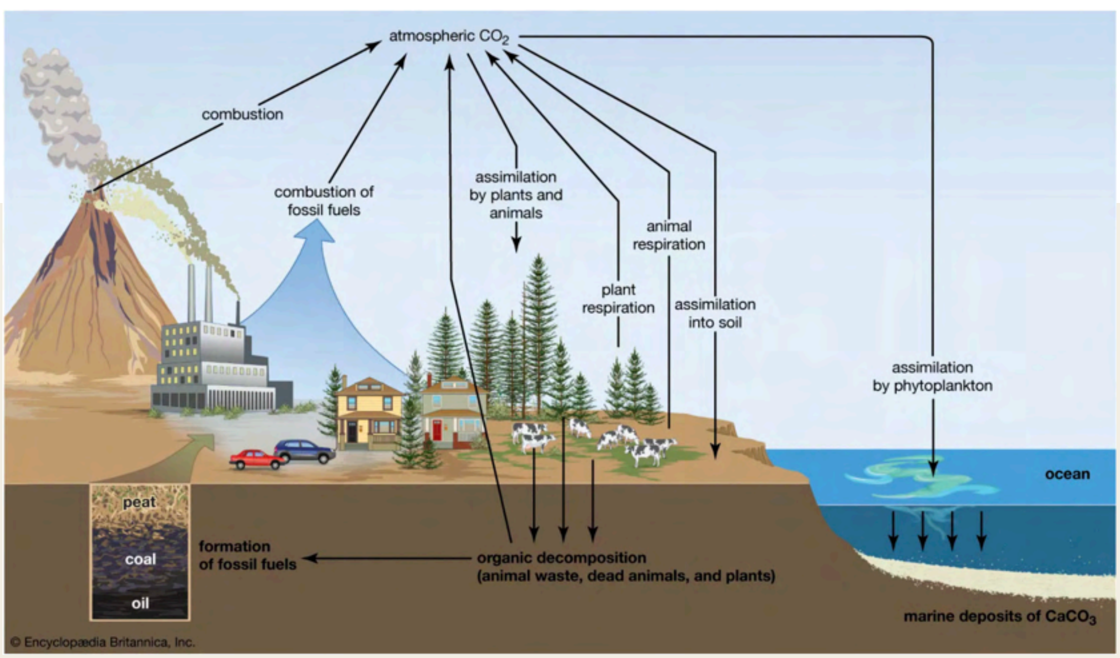


Figure 1. *Schematic of the global carbon cycle. Carbon dioxide from the atmosphere is taken up through photosynthesis and accumulated in biomass and some portion becomes assimilated into the soil or deep ocean. Much of the carbon used in photosynthesis is subsequently consumed and respired back to the atmosphere. Human activities can release additional carbon to the atmosphere, and this results in an imbalance in the cycle. Increasing net accumulation in soil could offset some or all of this imbalance. Photo courtesy of Encyclopædia Britannica, Inc., copyright 2014; used with permission.*

Additionality. Additionality can be a confusing concept and different definitions and interpretations have been developed. One definition of additionality is designed to conform to articles of the Kyoto Protocol, an international agreement intended to operationalize the United Nations Framework Convention on Climate Change. In the Kyoto Protocol, 'additionality' of GHG emission reductions or offsets is defined as reductions in the target GHG exceeding those that would have occurred under a business-as-usual scenario. In the grazing lands example, if carbon accumulation is expected under current management, then only additional accumulation above that expected rate resulting from a change in management could be credited. Adherence to this definition requires estimation of soil carbon accumulation under the business-as-usual scenario, plus measurement of accumulation from the prescribed management in the contract. Definition of additionality may also include a clause that the practice causing accelerated accumulation (e.g., a management change) would not have occurred without payment for a credit. This requirement implies that if a management change was financially viable without the incentive of carbon credit sales, then it would likely have already been implemented and therefore credits should not be issued.

Other standards define additionality more simply as the accumulation of carbon in excess of current levels, rather than in excess of the projected future carbon stock under a business-as-usual scenario. While this is typically a more direct measurement it may not be accepted in certain markets or by certain parties depending on their adherence to the Kyoto Protocol. For example, many member states of the European Union are Party to the Kyoto protocol, but the United States is not. Some standards do not consider the financial incentive element of additionality. Prospective credit purchasers may distinguish among credits generated under different standards, depending on this definition. Understanding the additionality definition of the contract is imperative.

Permanence. Standards may also differ in approaches to assuring the duration of holding accumulated carbon. While the implied goal of CO_2 removal from the atmosphere is to permanently reduce the 'excess' CO_2, determination of permanence is difficult. Land-based removal activities are subject to reversals due to both climatic and management effects. During periods of drought, soil carbon may be released back into the atmosphere as CO_2. Alternately, land use may change and result in a release of previously accumulated carbon. Some contracts or standards may require a permanent easement or other legal mechanism that eliminates certain future use or activity. Other contracts may have a more finite term of performance. Often, a mechanism exists within a standard to set aside a portion of any generated accumulation of CO_2 equivalents into a reserve account as a hedge against future potential reversals of accumulation. While this activity is seen as necessary to ensure the environmental integrity of the issued carbon credits, it reduces the amount of credits potentially generated and marketable by the landowner. Because of the differences among standards, and also among the developers of carbon accumulation contracts, it is important to have clarity on the standard governing the contract.

CARBON MARKET FACILITATORS

Registries. The ultimate purpose of a registry is to prevent double application of a credit, such that each credit is used to offset one unit of emissions, and then be 'retired'. Once carbon credits are generated, a registry system is utilized to track the certified credit, assign or transfer ownership, and to apply the credit to a debit (i.e., 'retire' the credit). Because the entities that develop standards typically review a proposed crediting activity for adherence to the standard, and then certify and issue the credits, these same entities typically create and maintain the registry system for credits issued under their standard. While different registries may utilize different technical processes and notification practices, their purpose is similar.

Verifiers. To achieve certification and issuance of carbon credits in accordance with a standard, an independent verification is often required. Verification consists of review of the contract application materials and consistency of the methodology to ensure adherence to the standard. The verifier, typically a third-party entity, issues a finding and then the registry certifies and issues credits in accordance with their policies. The registry may have specific eligibility requirements for verifiers and may maintain a list of verifiers approved to evaluate projects according to one or more standards that they oversee. The cost of verification cannot depend on the outcome; thus, verification costs will be assumed even if no credits are issued.

Developers, Aggregators, and Brokers. Contracts for generating certified carbon credits have a number of technical requirements that may be specific to the standard, registry, and protocol chosen. Project developers may either seek land managers that have a common interest or capacity to follow a certain protocol, or may be able to access several different protocols in accordance with the features of a given ranch. There is nothing that prevents a ranch from serving as its own developer, but this requires deep familiarity with the details of the target standard and protocols for sampling, measurement, reporting, and verification. Ranchers may prefer to work with a developer instead of taking on these requirements themselves. Contract developers may try to increase scale by assembling several ranches into one project; in this case they might be referred to as an aggregator, putting several smaller projects together to form one large project. This can create market access for smaller operators or acreages.

Contract developers may provide access to carbon credit markets. In some cases, the agreement with a developer may give the developer the exclusive right to market the generated credits. In these situations, the 'developer' is also the 'broker' of the credits. Alternately, there may be brokers who facilitate transactions between buyers and sellers of credits, but are not directly involved in carbon credit generation. It is important for land managers to understand who will serve in each role; the ranch independently, a single service provider, or several providers that all have a different role (Figure 2).

Entry into a carbon credit contract is similar to a commodity production contract with committed future delivery. As with a contract for future delivery of livestock, a rancher may work with a developer to identify a marketing opportunity. The terms of delivery are governed by a standard, and performance to the standard is verified by an independent party, after which the soil carbon accumulation is certified and can be marketed. The registry maintains the accounting of certified credits, their allocation, application, and retirement. From the landowner perspective, the commitment is to accumulate a specified amount of CO_2 equivalents in the form of soil-borne carbon (or other form, dependent upon the standard) and maintain the accumulated carbon for a specified period of time. The ranch is subject to risks similar to those in other production enterprises, including production (accumulation) risk, price risk, and

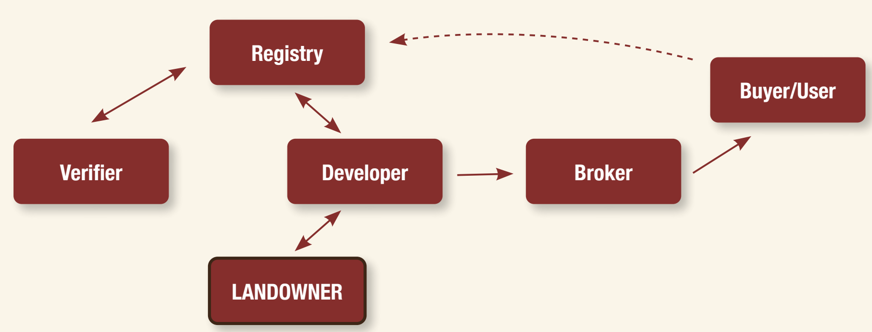


Figure 2. *Carbon market participants. Landowners provide the space and mechanism for soil carbon accumulation and may work with a developer to establish a process for measuring that accumulation according to a standard. The process and measurements are submitted to a registry, who seeks third party verification of adherence to the standards, and then certifies and tracks the issued carbon credits. Brokers seek to connect those offering credits and those seeking to buy them. Once purchased and applied as an offset, the user of the credit notifies the registry so that the credit is retired, avoiding duplication.*

transaction risks that may be contained in, or mitigated by, the specific contract terms.

PRODUCTION RISK

The fundamental consideration for a rancher contemplating a carbon credit enterprise is the physical capacity of the ranch to accumulate soil carbon above current levels. The potential is unique to each site. Important factors include climate, soil type and depth (clays typically have greater potential, sandy soils less). A primary determinant of capacity for accumulation may be the current state of the soil relative to long term potential – sites that have suffered from degradation in the past may have greater opportunity for accumulating soil carbon under changes in management. Sites in better condition may be closer to capacity and have less soil carbon accumulation potential. Estimated accumulation rates for grazing lands vary geographically from 0.2 to 0.6 tonnes of CO_2 per acre, but some observations as high as 5 to 7 tonnes of CO_2 per acre have been reported in response to various management practices. Periods of drought or soil disturbance can result in losses of soil carbon. Strategies associated with 'good' grazingland management, that increase forage growth and reduce bare ground, are expected to promote soil carbon accumulation. The uncertainty of soil carbon accumulation rates, and factors beyond the control of managers that can impact these rates, create 'production risk'. Managers should consider this uncertainty in the development of the soil carbon accumulation enterprise.

> **Soil carbon variability across the landscape makes detection of small changes difficult, and inability to detect change prevents certification of credits.**

It is difficult to gain precise measurement of soil carbon across large landscapes, and measurements can vary considerably across a single property or management unit. Measures of change in soil carbon must be statistically reliable in order for credits to be issued. The change in soil carbon measurement (% carbon in a soil sample) that represents 1 tonne of CO_2 per acre is very small – 0.014 % if measured to 30-centimeters depth, 0.004% if measured to 1-meter depth. Reliable detection of small changes generally requires a large number of samples, and the inherent variability creates considerable risk that small changes cannot be detected. While aggressive research efforts are ongoing to increase sampling reliability and reduce sampling costs, this variability and uncertainty remains an area of risk for managers. Soil sampling is likely to be the greatest expense incurred in the development of a carbon credit project, and clarity about the magnitude of soil carbon increase that can be expected coupled with the number of samples required to detect that change are essential in the decision-making process. A commitment to accumulate carbon is similar to a commitment to produce and deliver a commodity. Managers face 'production risk' due to the factors that can impact plant growth and soil carbon accumulation, many of which are beyond their control. Soil carbon variability across the landscape makes detection of small changes difficult, and inability to detect change prevents certification of credits. While uncertainty cannot be eliminated, managers should consider these factors, seek reliable estimates of soil carbon accumulation potential and have clear understanding of sampling requirements to make the best decisions about entering a carbon contract.

TRANSACTIONAL RISK

As with almost any contract, the devil is in the details in carbon storage contracts. This is particularly important in the developing carbon credit marketplace. Several terms in currently offered carbon contracts are unique and may be unfamiliar to some ranchers. It is important to seek counsel from an attorney with experience in negotiating these types of agreements. The items below provide a starting point for contract evaluation.

Required & Prohibited Practices. Determine what activities are required and what activities will be prohibited pursuant to the contract. Ranchers should ensure the contract clearly describes required practices. For example, a contract requiring "regenerative grazing" may not spell out the specific requirements of the ranch. Ensuring clear definition of requirements is important so both parties are assured of expected performance. Ranchers should consider potential land use opportunities they may forego by entering a carbon contract. For example, what if a landowner enters into a carbon contract and is later approached by a solar company offering 50 times more compensation per year (which is entirely possible in some regions)? How will a carbon contract interact with hunting leases or oil and gas production? These considerations should be carefully analyzed and addressed in the contract.

Payments. The payments being offered to landowners can essentially be put into two buckets: 'payments for practice' and 'payments for outcome'. A payment for practice contract is one where a set payment is guaranteed if a rancher adopts the required practice. A payment for outcome contract offers a payment per metric ton of CO_2 equivalent captured in the soil or no longer emitted from production activities. These payments will be based on soil measurements, computer modeling, or a combination of both, according to the contract standard. Unlike a payment for practice contract, a payment for outcome contract is variable and depends on the actual amount of carbon stored or emissions reduced.

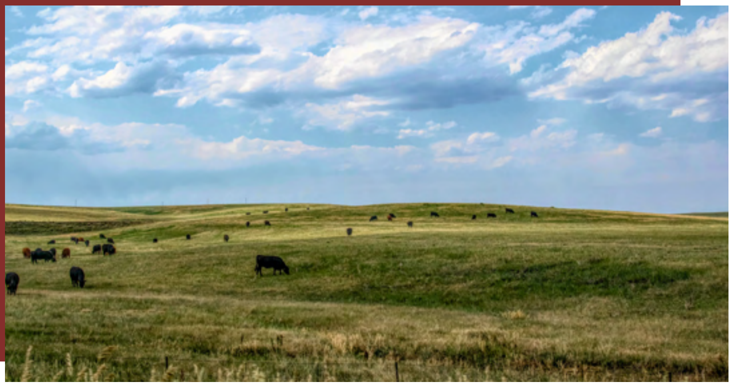
Term. Another important consideration is the length of the contract. Most currently offered contracts last 10 to 15 years. Some contracts require landowner participation until a certain amount of carbon is stored, regardless of the time that may take. Others may have ongoing requirements, even after the performance period of the contract has expired. Ranchers should also look for extensions included in a contract that may allow the company the right to automatically extend the length of the contract, and seek to delete such extensions during negotiation.

Potential penalties. Ranchers should carefully consider any potential penalties they could face under a particular carbon contract. Again, contracts differ greatly, but in every contract there will likely be various penalties that could be triggered based upon actions by the rancher. For example, a proposed contract may allow early termination by the rancher but may impose penalties for doing so. Taking the time to understand exactly what actions a rancher must take – or not take – to avoid penalties is critical.

Ranchers should also consider potential land use opportunities they may forego by entering into a carbon contract.

Some contracts contain "no-reversal" clauses. These clauses essentially provide that in the event the amount of carbon stored in the soil decreases from one measurement period to the next, the rancher is liable for that carbon loss. The specific liability depends on the contract, but could result in the contract termination, monetary penalties, forfeiture of prior payments, and even some instances where a rancher might be required to indemnify the purchaser for any lawsuits against the purchaser related to the purchase of the contracted carbon credits. Ranchers must consider these clauses very carefully in the context of the production risks for carbon accumulation in their particular circumstances.

Stacking prohibition. Most, if not all, contracts will include a stacking provision. These provisions generally provide that a rancher cannot enroll the same land in multiple carbon contracts. For example, a rancher with a section of land cannot sign a carbon contract with ABC Carbon and XYZ Carbon for the same acreage. Some stacking provisions are written much more broadly, and may state that the rancher may not participate in any other carbon contract or program. This could prohibit the landowner from signing up for any future government program offering carbon payments. Some contracts disallow participation in any government programs and prohibit the receipt of any government payments. This type of broad provision could have major impacts on certain landowners.



All contracts will require landowners to provide extensive data about their land and their operation, including information about prior management practices, pesticide and herbicide records, stocking rates, and production records.

Data provision and ownership. All contracts will require landowners to provide extensive data about their land and their operation, including information about prior management practices, pesticide and herbicide records, stocking rates, and production records. Many contracts allow the purchaser to enter the property for inspection and allow for aerial views by unmanned aerial vehicles (UAVs; drones). Most contracts provide that all data generated and collected under these agreements is the property of the landowner.

Measurement and verification. Measurement and verification are central to any carbon contract. Clear reference to a standard outlining these requirements, or inclusion of contract specific details, is important. Contracts should specify which party will pay for the cost of any measurements. Ranchers should reserve the right to audit or appeal measurement procedures, particularly given the uncertainty and frequently changing technology related to measurements.

Taxes and insurance. A landowner should require the counterparty to the contract or the purchaser of carbon credits to be liable for any change in property valuation and/or increases in ad valorem taxes that result from the carbon enterprise. Ranchers should require the purchaser and any contractors entering the property to carry insurance and to list the manager as an additional insured.

Choice of law and venue clauses. Contracts will likely include a clause determining which state's law will be applicable in the event of a contractual dispute and will identify a particular county and/or court where lawsuits must be filed. These provisions are generally enforceable, so ranchers should negotiate them appropriately.

Class action waivers. Interestingly, some contracts contain a class action waiver whereby a rancher agrees not to be part of any class action lawsuit against the purchaser related to the contract or carbon purchases. This term limits future legal options for the rancher.

Amendments and assignments. There are some contracts with amendment provisions that essentially allow the developer to make any contractual modifications they choose. Most, if not all, contracts allow the company to assign their rights without any approval from the rancher. The opposite, however, is likely not true. Most contracts have at least some limitations on the rights of a rancher to make a similar assignment. Ranchers should pay attention to provisions related to how contracts may be amended.

Overall, the wide variety of opportunities in the emerging carbon marketplace have resulted in a variety of contracts offered to landowners. There are no 'standard' contracts, and care should be taken to review the terms and gain clear understanding of the proposed agreement. Ranchers can mitigate some risks through the contracting process, but should be aware of terms that create long term liabilities, and understand limitations that may be imposed by an agreement.

MARKET RISK AND VALUE OF CARBON CREDITS

Entering into a carbon credit contract is an additional enterprise to the ranch portfolio. The gross revenue is the contracted price of a carbon credit times the number of credits secured. The gross unit price of a carbon credit in the United States is currently $18 to $22. Some fraction (often 20%) of generated credits are not eligible for sale, but are placed into a 'reserve pool' as a hedge against future potential accumulation reversals (for example, due to drought). This reduces the effective volume of credits marketed from a given ranch. Additionally, fees are assessed by developers, verifiers, and registries, and sampling costs are incurred. While the details of these arrangements should be described in the contract, and may include sampling expenses, these costs and fees may represent an additional 20% or more of gross potential revenue. The net price for generated credits is therefore 60 to 80% of the gross price (i.e., $12 to $16 if the unit price of a carbon credit is $20). The net returns per acre for grazingland may be much less. For example, if the grazingland can be expected to accumulate 0.1 tonnes of CO_2 per acre then the net price of the carbon credit, at $12 per tonne, would be $1.20 per acre. As with any commodity, because carbon credits are intended to be interchangeable, price volatility can be expected.

The carbon price is determined by a market with the characteristics of many other markets, both new and long established. Price discovery, the low number of sellers and buyers, and transparency are all issues in this emerging market. Companies buying carbon credits may have market power to set prices to ranchers, until the 'true value' of the credit to their firm is discovered. Like any other market there is a supply of and demand for soil carbon credits - their intersection results in the carbon credit price.

Supply of credits comes from land managers who implement practices to increase soil carbon accumulation. But changing practices comes with implementation cost. Because operators tend to be technically efficient, it is likely that cost-effective management practices have already been adopted. The least cost, most profitable management practices are implemented first at a lower carbon price. Over time, it gets more expensive to provide or store additional carbon, and prices must rise to provide adequate incentive for the rancher to adopt additional practices to generate more salable credits. Demand from carbon credits by companies is expected to continue to grow, leading to higher prices. Higher carbon prices will allow more costly practices for accumulating soil carbon to become feasible, therefore increasing the supply of carbon credits to meet growing demand. These same forces will likely create additional competition among potential generators of carbon credits. There may be other land uses, technologies or processes that emerge and enable carbon accumulation at a lower unit cost than current ranch management strategies. The ability of these other systems to store carbon at a lower cost than grazing land management will limit price upside.

> **Demand from carbon credits by companies is expected to continue to grow, leading to higher prices.**

The developing market for carbon may evolve in a number of ways. There are a few key market questions for ranchers to consider:

- Does the realized price cover profit and risk of adopting a new enterprise?
- Does the rancher pay money back if the purchased level of carbon accumulation is not achieved and how is that risk best managed?
- Does it work in a portfolio of ranch profit centers that might include livestock, hunting, and other activities?
- Should a rancher consider selling (contracting) only a portion of the carbon holding acreage on the ranch and retaining the remaining acreage as an option to capitalize on future higher prices?

There are multiple companies in this market paying producers to store carbon. There are differences in the contract terms that may make a given strategy more or less valuable for a given ranch. These different opportunities should be explored to find the highest value proposition, which may not always be at the highest transaction price.

SUMMARY

The emerging market for carbon credits may offer an important opportunity to ranchers. As with the decision to add any enterprise to the ranch portfolio, the costs, benefits and risks should be explored. The carbon enterprise is essentially a contract to produce a commodity (carbon credits) and managers are faced with production and market risks associated with such activities. The details of actions or practices that must be taken or avoided in the production process, and how production itself will be evaluated and compensated, are unique to specific contracts and should be reviewed carefully. Managers should consider the potential for price escalation – or decline – as they consider the timing of sales, and should also consider the potential costs and liabilities associated with this emerging enterprise.

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UNDERSTANDING & EVALUATING CARBON CONTRACTS

Tiffany Dowell Lashmet[1] and Karli Kaase[2]

Carbon contracts have been a popular topic of conversation for farmers and ranchers around the country. As with any agreement, several legal and economic issues arise and should be carefully considered by producers before entering into a carbon contract. A critical consideration is that producers and landowners should never rely on verbal representations made by anyone related to a contract; assume only the written contractual terms will be enforceable. Remember, this is new territory, and many unknowns still exist about the carbon market and these carbon agreements. It is recommended to engage an attorney to review any carbon contract prior to signing.

KEY CONCEPTS

When reviewing a carbon contract, producers and landowners may notice it seems to speak a different language than most agricultural contracts. Understanding some of the basic concepts related to carbon contracts is an essential starting place. Importantly, each contract will likely have specific definitions of these terms. It is critical for landowners and producers to carefully review the definitions in any contract before signing.

Additionality – The concept of additionality refers to some companies only paying for new carbon-sequestering practices. If additionality is required, the farmer or rancher would have to undertake a new practice to qualify, such as converting from conventional farming to no-till farming, for example. A producer who has already adopted carbon-sequestering practices would need to seek a contract that pays for these previously adopted practices or allows for a look-back period and does not have an additionality requirement.

Carbon market – Currently, most carbon markets are voluntary programs where brokers essentially serve as intermediaries between companies seeking carbon credits and farmers and ranchers willing to generate these credits. A producer agrees to undertake certain practices which sequester carbon or reduce carbon emissions; the company then pays the producer and claims the carbon credit generated by the producer helps to offset the company's carbon footprint.

Carbon practices – These are farming or ranching practices that can reduce carbon emissions and/or sequester carbon. The most common carbon practices include no-till farming, planting cover crops, crop rotation, planting buffer strips, and regenerative grazing.

Carbon credit – A carbon credit is a frequently used measurement unit to quantify carbon. Typically, one carbon credit is equal to one metric ton of carbon or carbon equivalent that is sequestered.

All photos by Jourdan Bell, Texas A&M AgriLife Extension Service

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Carbon emissions – The release of carbon into the atmosphere.

Carbon sequestration – The process of capturing carbon from the atmosphere.

Permanence – The length of time a carbon reduction lasts. Some contracts may require a producer to abstain from certain activities for an extended period of time to ensure the continuation of storing sequestered carbon.

Stacking – The concept of stacking refers to one producer enrolling the same land in more than one program or contract. Many contracts prohibit stacking, meaning the producer may enter into only one carbon contract for a specific piece of property. The breadth of a stacking prohibition can vary greatly by contract, with some prohibiting only other carbon contracts, while others may prohibit participation in any government programs.

Verification – The process of confirming carbon reduction or sequestration.

KEY CONTRACT TERMS TO CONSIDER

Control of land – Brokers or companies seeking carbon agreements will likely require some proof that the party entering into the contract either owns or controls the land. This may include a copy of a written lease agreement, for example. Some companies or brokers may require both the tenant and the landowner to sign any contractual agreement. This is particularly true if the lease in place is for a shorter timeframe than the carbon contract.

Data ownership – Data collection is a requirement for any carbon contract, and a carbon agreement should address issues related to the ownership and use of such data. Issues like who will be given access to the data, how the data may be used, and who has ownership rights in the data should all be addressed.

Indemnification – Indemnification clauses essentially shift potential liability and costs from one party in the contract to another. These clauses are an agreement to reimburse another party for damages they sustained as a result of the indemnifying party's actions. It is critical to analyze the breadth of an indemnity clause. First, indemnification clauses should be mutual, meaning each party agrees to indemnify the other. Second, some provisions may be so broadly written as to require a landowner to indemnify the company for any damages or injury which are not a result of the developer's contract, including actions taken by third parties over whom the landowner has no control.

Impact on energy production – Producers should carefully consider what impact a carbon contract may have on energy production on the land. Depending on the mineral ownership or the potential energy production activities, this may require identifying carve-out areas where oil or gas wells, or potentially even wind turbines or solar panels, can be placed.

Land title implications – Producers should be careful to determine if there are contractual provisions that may impact their ability to sell or otherwise transfer ownership of the land. For example, contracts may allow the purchaser to place a restrictive covenant or a lien on the property or require the landowner to enter into a conservation easement for the term of the contract. Certainly, these types of limitations could impact the marketability and potential sales price for the land.

Negotiation costs – Some companies and brokers offer to pay a certain portion of a producer's legal fees associated with negotiating a carbon contract. This would likely be an agreement separate from the contract itself but might be worth producers requesting from the company or broker. Regardless, a producer should consider using an attorney to assist with reviewing or drafting any carbon contract.

Other allowable uses – Producers may wish to make other uses of the property at issue in a carbon contract. Many farms and ranches have added various agritourism activities to diversify income. For example, many producers may wish to reserve the right to hunt or fish on the land. The contract should address any desired allowable uses for the producer to ensure both parties are on the same page.

Payment – The payment provisions of the contract are extremely important for the producer. There are several different potential payment methods that could be included in an agreement. There could be a per-acre payment for adopting certain carbon practices or a payment per metric ton of carbon as measured and verified. Another option could be a payment based on the carbon market at an identified time.

Producers should ensure the contract sets forth the exact details about how payment will be calculated. For any contracts based on actual carbon sequestered, producers should investigate the amount of carbon likely to be sequestered in their particular area. For example, agronomists report the amount of carbon likely to be sequestered in the Texas Panhandle and South Plains to be far less than the 1 ton of carbon per year it takes to create a carbon credit. Also important is to determine what costs or expenses may be deducted from the producer's payment. Ensure the provision also addresses when and how payments will be made.

Parties – A producer should certainly do his or her homework to investigate any party with whom they will enter into a carbon agreement. Understand the party's position in the market. Many contracts are being offered by brokers or aggregators, but there are also agricultural retailers offering these types of contracts. Try to speak to other producers who have entered into contracts with the company to ask about their experience.

Penalties – All contracts contain penalties if certain conditions are not met. It is important to understand these penalties and the risk associated with them. For example, if a party agrees to undertake a certain practice but an external reason such as weather prevents them from doing so for an amount of time, there could be a specific penalty for that. Some contracts may require a certain increase in the amount of carbon in the soil and include a penalty if that amount is not realized or is released during the term of the contract. Carefully review the contract to understand under which circumstances a producer could potentially be liable if this occurs. Contracts will likely also contain early termination penalties if the producer is unable to comply with the contractual requirements for the term of the contract.

Required practices – An agreement will set forth the required practices a producer agrees to undertake as part of the contract. Again, this differs by contract and must be carefully reviewed. Some contracts may list very specific requirements, while others may contain a more general description, such as conservation practices. Producers should be careful to analyze the additional costs that may come with adopting a required practice as compared to the potential carbon contract payment they would receive. Finally, producers should pay attention to whether the required practices are set throughout the entire contract or whether they may change from year to year.

Stacking prohibition – Often, carbon contracts will include a prohibition on stacking—meaning a producer may not enroll the same land in multiple carbon contracts or programs. It is important to carefully review any stacking prohibitions in a contract, as some may be worded broadly enough to prohibit participation in other government programs, such as the Environmental Quality Incentives Program (EQIP) or Carbon Reduction Program (CRP), for example.

Standard legal clauses – There are several standard legal clauses that are common in most contracts.

- **Attorney's fee provision** – Generally, regardless of the outcome, parties in a lawsuit pay their own attorney's fees. One way to modify this approach is if parties to a contract agree, the prevailing party may recover his or her reasonable attorney's fees.
- **Choice of law** – A choice of law provision is an agreement between the parties to a contract as to which state's law will govern the agreement. For example, if a farmer in Texas signs a contract with a broker in California, they could agree on either Texas or California law applying to the contract.

- **Dispute resolution** – Many contracts include a dispute resolution clause. Frequently, this is an agreement to participate in either mediation or arbitration. Mediation allows the parties to meet with a third-party mediator in an attempt to resolve their dispute. If no agreement is reached between the parties, then either party may proceed to file a lawsuit in court. Arbitration, typically, is agreeing to have a dispute heard before an arbitrator rather than in court. Both approaches are designed to be more efficient than a trial to resolve disputes, but each has different pros and cons to consider.
- **Insurance** – The producer likely wants to ensure the purchaser has an insurance policy and seeks to be added as an "additional insured" on this policy. Additionally, the producer may seek a waiver of subrogation, which essentially is a clause stating that the purchaser's insurance company will not seek recovery from the landowner for negligence.
- **Venue** – A venue clause states where any legal dispute over the contract must be filed. For example, a farmer could request that any legal dispute be filed in his or her home county.

Term of the agreement – It is important to understand the length of the contractual agreement. An agreement will likely set forth a given number of years practices must be undertaken. Keep in mind that lengthy contracts may have estate planning implications as well. Some agreements may require the continuation of identified practices even once the term of the agreement ends to ensure permanence. Also, watch for any opt-out provisions that allow parties to terminate the contract prior to the end date if certain requirements are met. Some contracts allow either party to cancel merely by giving notice. Others may require certain conditions to be met. On the other hand, there could be provisions allowing for extensions to be granted, so watch for those provisions as well.

Verification – Provisions regarding measurement and verification are some of the most important in a carbon agreement. As an initial matter, the contract should set forth exactly what is being included in the measurements. For example, will the verifier simply measure the carbon in the soil, or will the entire system be looked at, including the impacts of livestock on the property or the impacts of using nitrogen fertilizer? Understanding exactly what will be measured is critical.

Next, parties should agree upon who will conduct any testing and verification, what methodology will be used to do so, and when and where such data collection will occur. Some contracts may offer payments based on modeling, while others will take actual measurements.

Measurements may be done in a number of ways, including algorithmically by taking actual physical soil samples and using satellites. The manner in which samples are taken can impact the results, and considerations related to the time of year (and even time of day), location in the field, and soil depth are all important to consider and understand. Parties should consider who will bear the costs of the data collection and verification. Generally, these costs fall to the purchaser. Finally, the producer may want to ensure there is a provision allowing an audit of the data and payments to ensure requirements are being followed and a process for how a producer can challenge or appeal determinations they believe are inaccurate.