Economic Optimization of Forage and Nutrient Availability During Stress Periods for White-tailed Deer

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Abstract: Providing a sufficient quantity of nutritional forage should be an integral component of any white-tailed deer (*Odocoileus virginianus*) management plan that aims to maximize deer condition and quality. Deer managers generally attempt to meet the nutritional needs of their herd through some combination of habitat management, food plot production, and/or supplemental feed provisioning. However, nutritional demands of deer and forage quality and abundance fluctuate throughout the year, creating nutritional stress periods and a dilemma for managers regarding how to maximize the nutritional plane of their herd while minimizing cost. We measured crude protein availability in naturally occurring deer forages found in a mature pine forest managed with prescribed fire and Ladino clover food plots during three nutritionally stressful periods for deer on a 259-ha white-tailed deer enclosure located in east-central Alabama. We then used a cost-benefit analysis to determine how to cost-effectively maximize food production by comparing management options which varied by the percentage of total area planted in food plots (0–5%), percentage of pine stands treated with prescribed fire (0–100%), and the addition of supplemental feed. Naturally occurring forage in pine stands treated with prescribed fire and food plots cost-effectively maximized food production during June and July without the addition of supplemental feed. However, supplemental feed may be important during September to compensate for the decreased availability of high-quality, naturally occurring forage. Deer managers should understand how the relative importance of each nutritional input varies seasonally in order to maximize the nutritional availability of their land for deer in a cost-effective and efficient manner.

Key words: white-tailed deer, nutritional carrying capacity, habitat management, nutrient availability

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Improving the nutritional quality of habitats for white-tailed deer (*Odocoileus virginianus*) is a major focus for deer managers because high-quality diets can significantly improve deer condition and quality (Moen 1978, Johnson et al. 1987, Hewitt 2011). The three primary ways managers can enhance quantity and quality of nutritional resources are by: utilizing habitat management techniques to enhance the quality and abundance of naturally occurring vegetation (hereafter native vegetation/forage), planting food plots, and providing supplemental feed. Native vegetation is an important, sustainable resource for deer, but food plots and supplemental feed can provide additional high-quality resources to supplement native forage during periods when the quality and/or quantity of native vegetation is poor or limited (Hehman and Fulbright 1997, Bartoskewitz et al. 2003, Stephens et al. 2005). Therefore, it is commonly recommended that deer managers use some combination of these three nutritional inputs to provide deer with a variety of resources to meet their nutritional demands (Koerth and Kroll 1998, Yarrow and Yarrow 1999).

In the southeastern United States there are approximately 86.5 million ha of forestland which makes up over 50% of area available for white-tailed deer (Thill 1984, Dickson and Sheffield 2001). Of the available forested lands, approximately 20% are comprised of pine/pine-hardwood woodlands (Thill 1984, Dickson and Sheffield 2001), and native vegetation in pine habitats has been reported to provide an abundance of highly-nutritious forage when managed properly (Halls 1970, Blair and Enghardt 1976, Edwards et al. 2004). There are a variety of habitat management techniques that are commonly implemented to improve habitat quality and enhance forage productivity for white-tailed deer, but prescribed burning is frequently recommended due to its combined effectiveness and low cost (Waldrop et al. 1987, Strickland 2012). Previous research has shown that prescribed fire significantly increases herbaceous forage production, species richness and diversity, and decreases low-quality woody vegetation (Lewis and Harshbarger 1976, Masters et al. 1993, Sparks et al. 1998), all important factors in improving nutritional availability for white-tailed deer.

Food plots and supplemental feed are nutritional supplements that are commonly provided to enhance deer productivity and quality beyond what would normally be achieved through habitat management alone. These supplements are typically greater in nutritional value than native vegetation (Keegan et al. 1989, Bartoskewitz et al. 2003, Stephens et al. 2005) and have been shown to improve body size, fawn production, antler size, and carrying capacity (Ozoga and Verme 1982, Johnson et al. 1987, Keegan et al. 1989, Kammermeyer and Thackston 1995, Hehman and Fulbright 1997, Bartoskewitz et al. 2003). Despite the increased nutritional resources that food plot forages and supplemental feed can provide, deer continue to consume native vegetation even when provided with these additional resources (Ozoga and Verme 1982, Johnson et al. 1987, Bartoskewitz et al. 2003), indicating that management of native forages is important even when nutrition is supplemented. Additionally, food plots and supplemental feed are more costly than native habitat management from a nutritional perspective (Kammermeyer et al. 1993, Kammermeyer and Thackston 1995, McBryde 1995). These mitigating factors suggest that native habitat management combined with supplemental feed and food plot provisioning should provide a variety of nutritious food sources.

Nutritional demands of deer and forage quality and abundance naturally fluctuate throughout the year, creating stress periods during which deer have difficulty meeting their nutritional needs. These periods occur in the Southeast during the summer and early fall when bucks are in the rapid growth stage of antler development, females are trying to meet the high demands of both gestation and lactation, and the nutritional quality of native forage is decreasing (Short 1975, Asleson et al. 1996, Hewitt 2011). While energy is important to support productive processes such as these, protein is commonly more limiting and may also place a greater constraint on these processes when limited (White 1993, Asleson et al. 1996, Barboza and Parker 2008, Lashley et al. 2011). Crude protein requirements for maintenance are approximately 6%, but CP requirements are over 1.5 times greater to support antler growth and over 2.5 times greater for gestation and lactation (Holter et al. 1979, Verme and Ullrey 1984, Asleson et al. 1996). Therefore, ensuring nutritional demands are being met during these stress periods is extremely important.

Wildlife managers are continuously challenged with meeting the nutritional needs of deer herds through some combination of habitat management, food plot production, and/or supplemental feed provisioning, while trying to keep costs to a minimum. This issue becomes even more complex considering that the relative nutritional value of native forage and food plots varies throughout the year, and nutritional needs of deer vary as well. Considering the complexity of the nutritional environment for white-tailed deer, our objectives were to: 1.) determine the relative nutritional value of native forage treated with prescribed fire, food plots, and supplemental feed for deer, 2.) assess how the nutritional value of native and food plot forages changed during the growing season, and 3.) determine how to cost-effectively maximize food production during three key nutritional stress periods.

Methods

Study Area

The study area was located at Three Notch Wildlife Research Foundation (Three Notch) inside a 258.2-ha high-fence enclosure in Bullock County, approximately 10 km east of Union Springs, Alabama. A 3-m deer-proof fence had enclosed the study area since 1997 and year-round access to food plots and supplemental feed was available to deer. Food plots on the property consisted of approximately 6.5 ha and 3.5 ha of alfalfa (*Medicago sativa*) and Ladino clover (*Trifolium repens*), respectively, and 1 ha of winter rye (*Secale cereale*) was planted during the winter. An extensive irrigation system supplemented natural precipitation on all alfalfa and clover plots. A total of 12 permanent feeding troughs equally distributed across the study area provided a high-protein supplemental feed (20% protein; Purina Antlermax, St. Louis, Missouri) ad libitum throughout the year. Average annual rainfall at Three Notch was approximately 1.4 m and temperatures varied from an average annual high of 24.2°C and average annual low of 10.4°C (National Climatic Data Center 2010). Three Notch was 165 m above sea level and topography of the area was primarily flat with a few gently sloping hills. Predominant soils on the property included gently and strongly-to-moderately sloping, moderate to well-drained, loamy sand soils (Soil Survey Staff and National Resource Conservation Service 2013).

Upland areas of mature, open pine-hardwood and dense hardwood stands along creek drainages were the primary forested habitat on the study area. There were approximately 95 ha of pine-hardwood stands, 21.5 ha of pine stands, and 75 ha of mature hardwoods which made up approximately 40%, 10%, and 30% of the total habitat within the study area, respectively. Average pine-hardwood stand basal area was 19.08 m^2 ha^{-1}. Loblolly (*Pinus taeda*) and shortleaf (*Pinus echinata*) pine were the common pine species, and common hardwood species included white oak (*Quercus alba*), water oak (*Quercus nigra*), hickory (*Carya* spp.), sweetgum (*Liquidambar styraciflua*), and yellow poplar (*Liriodendron tulipifera*). To enhance native vegetation quality and quantity and aid in detection of shed antlers, approximately 100–120 ha of mature pine/pine-hardwood habitat were treated with prescribed fire each year in late February–mid March. Prevalent understory species included sweetgum, wax myrtle (*Myrica cerifera*), butterfly pea (*Centrosema virginianum*), pigeonwings (*Clitoria mariana*), greenbrier (*Smilax* spp.), yellow jessamine (*Gelsemium sempervirens*), Japanese honeysuckle (*Lonicera japonica*), and blackberry (*Rubus* spp.). Year-round water sources for deer included the headwaters of the Pea River and an approximately 20-ha pond.

Hunting on the property was restricted to archery by the landowner and family members, and was limited to the harvest of mature bucks (five years or older) and does of any age class. There was a high population density within the exclosure due to selective harvest, low hunting pressure limited to archery, and ample nutritious food sources. A mark-recapture camera survey (Jacobson et al. 1997) in 2007 indicated estimates of at least 1 deer per 1.7 ha, three times that normally found in the region, with a (M:F) sex ratio of 2.64:1 (McCoy et al. 2011).

Vegetation Sampling

For native vegetation sampling, we identified eight mature, upland pine-hardwood stands ranging in size from 0.38–1.14 ha in 2014 and 2015. Four stands were treated with head fires in late February–mid March the year of sampling and four were not treated to represent 1- and 2-year burn rotations. These stands had been previously burned on an annual basis. We also identified three mature hardwood stands and two pre-existing Ladino clover stands ranging in size from 0.14–1.03 ha. New stands were established for the second year of data collection, and prescribed burning treatments were repeated within the pine-hardwood stands. A total of seven 1.52- × 1.52- × 1.37-m exclosures were constructed in each of the 11 forested stands and three 0.31- × 0.31- × 1.37-m exclosures were constructed in each food plot stand to measure total forage production each year. Exclosures were constructed at the beginning of April during the second year of data collection. Exclosure construction was intended to occur during the same period for the first year of data collection, but due to time constraints, exclosures in pine-hardwood stands were not constructed until the third week of May. During 2014, clover exclosures were not constructed until after the first sampling period in June. Therefore, Ladino clover production in June was based on 2015 data only. Forested exclosures were built large enough to enable three separate, primary-growth samples per year due to the large number of exclosures needed. Food plot exclosures were moved to a new random location after each sampling period and were built smaller than forested exclosures to allow for quick removal when the food plots needed to be mowed or sprayed. Exclosure locations within each stand were randomly generated in ArcMap 10.1 (Environmental Systems Research Institute, Inc., Redlands, California).

Sampling occurred for 7–10 days at the beginning of June, July, and September in conjunction with peak antler growth, gestation, and lactation, respectively, for the region. Bucks enter into a period of rapid antler growth during June and July and high-quality resources are needed for quality antler production (Jacobson and Griffin 1983, Demarais and Strickland 2011). Peak breeding across the Southeast is often as late as the end of January (Gray et al. 2002, Diefenbach and Shea 2011), which is when it peaked at the study site. The greatest nutritional demands for gestation occurred during June and July since the average gestation length for deer is 200 days and the greatest demands occur during the third trimester (Ditchkoff 2011, Hewitt 2011). Does bred in late January give birth to fawns in August, and peak milk production is approximately 10–37 days after birth (National Resource Council 2007, Hewitt 2011). Therefore, the greatest nutritional demands for lactation are the beginning of September.

A list of 25 native forage species preferred by deer was composed based on the literature (Miller and Miller 2005) and relative abundance of each plant at Three Notch. All exclosures within forest stands were sampled using the destructive harvest method with 0.25-m^2 quadrats and all current annual vegetation was clipped 2.54 cm above the ground and up to 1.5 m in height (Bonham 1989, Masters et al. 1993). For forested stands, each of the 25 preferred species were individually separated and placed into brown paper bags, and all remaining vegetation was grouped into a grass, forb, or browse category. Ladino clover stands were sampled the same way as native forage but only clover forage was collected. To avoid stand edge bias, sampling did not occur within 15–20 m from any stand edge (Mueller-Dombois and Ellenberg 1974, Masters et al. 1993). If sampling did not produce the required quantity of 10- to 15-g dry weight biomass of each species needed for nutritional analysis, additional biomass was collected randomly from the property. We assumed the nutrient content of forages were the same across the entire property regardless of habitat or burn rotation (Stransky and Halls 1976, Wood 1988, Edwards et al. 2004).

After sampling each day, samples were dried at 50°C for 48 hours and then weighed to obtain a dry matter biomass weight. After the June sampling period during the first year of data collection, a few species were added to the list and were not included in the June nutritional analysis for the first year. The nitrogen content of each sample was determined by the Dumas combustion method (Horneck and Miller 1998) using a 2400 Series Perkin Elmer elemental analyzer (PerkinElmer, Waltham, Massachusetts) by the Auburn University School of Forestry and Wildlife Science's Elemental Analysis Laboratory. Crude protein was then calculated by multiplying the nitrogen content of each sample by 6.25 (Robbins 1993). The list of 25 preferred forages and associated nutritional values were reported by Glow (2016).

Cost-Benefit Analysis

We used a cost-benefit analysis to determine the relative nutritional value of native forage in pine-hardwood stands treated with prescribed fire, food plots, and supplemental feed and how to cost-effectively maximize food production during each nutritional stress period. Ladino clover was used as the representative for food plots and Purina Antlermax 20% CP was used for supplemental feed because that is what the landowner at our study site had planted and provided during the duration of the study. We assumed a theoretical 259-ha property and, based on the distribution of habitat types at the study area, we assumed pine-hardwood stands made up a total of 121 ha. Pine-hardwood stands were assumed to be maintained on a two-year burn interval. We then considered 0–100% of the total 121 ha of pine-hardwood stands to be treated with a one-year burn interval, at 20% increments, for a total of six options. This decision was made because we found that high-quality biomass production was greater in stands maintained on a one-year compared to two-year burn interval. Because it is generally recommended to landowners that 1%–5% of their total property be planted in food plots for white-tailed deer management (Kammermeyer and Thackston 1995, Harper 2006), we considered 0–5% of the total property area planted in Ladino clover at 1% increments for a total of six food plot options. Additionally, we determined the average amount of supplemental feed that was placed out on a two-week basis between June and September at the study area, which we considered as a "high" option (3100 kg) for supplemental feed provisioning. We reduced that amount by 50% for a "low" option (1550 kg), and also considered the addition of no supplemental feed, for a total of three supplemental feed options. We then determined all possible combinations of treatments with the three nutritional inputs for a total of 105 combinations (we did not include 0% burn, 0% food plot, and zero supplemental feed as an option, nor did we consider any option of supplemental feed by itself).

Hobbs and Swift (1985) nutritional constraints models were used to calculate the mean biomass on a kg/ha basis available for deer to attain nutritional planes of 14%, 16%, and 18% CP within the pine-hardwood stands treated with either a one- or two-year burn interval during each nutritional stress period. An abundance of vegetation may be available for consumption, but if it is primarily of low quality, only a limited number of deer will be supported at a high nutritional plane (Hobbs and Swift 1985). Therefore, the quantity and quality of each forage must be accounted for individually rather than as a mean value (Hobbs et al. 1982, Hobbs and Swift 1985). Ladino clover forage and supplemental feed exceeded 18% CP during each stress period, so nutritional constraint models were not needed because all of the feed and forage could be utilized to meet each of the three nutritional planes. We chose these diet qualities because 14% and 16% are the lower and upper recommended CP levels to support lactation, which is also sufficient for quality antler production and gestation (Verme and Ullrey 1984, Harmel et al. 1988, Asleson et al. 1996). We also wanted to consider 18% CP to simulate an even more intensive management option. Mature hardwood stands were not included as a nutritional input because they were unable to produce any biomass to support a 16% or 18% CP diet quality, and less than 2 kg/ha of biomass to support a 14% CP diet quality during any of the three nutritional stress periods.

The cost for prescribed burning was assumed to be US\$74.13 ha^{-1} (Strickland 2012), and the cost to establish Ladino clover food plots was assumed to be \$805.56 ha^{-1}, which included the price of seed, lime, fertilizer, herbicide, labor, fuel, and equipment costs. Prices of seed, lime, fertilizer, and herbicides were based on local co-op prices near the study site in January 2016. Labor, fuel, and equipment included the costs of two herbicide applications, one fertilizer treatment, spreading lime, disking fields, planting seed, and mowing twice per year (Harper 2008). The costs for each were determined based on a 2015 Iowa farm custom rate survey (Plastina and Johanns 2015). Supplemental feed costs were assumed to be \$500 per 907 kg (1 ton).

The total food production on a kg ha^{-1} basis and associated cost of each management option was then determined. For native forage in pine-hardwood stands, we multiplied mean biomass production (kg ha^{-1}) for a one-year burn interval at each CP diet quality by each of the six respective treatment areas (0–100% of 121 ha; i.e. 20% of 121 ha = 24.2 ha × kg/ha). We repeated this process for native forage from pine-hardwood stands maintained on a two-year burn interval, but it was dependent upon the amount of area treated with a one-year burn interval, such that if 20% was treated with a one-year burn interval, then the remaining contribution of native forage was calculated based on 80% being maintained on a two-year burn interval. The Ladino clover input was calculated the same as the native forage input for each of the six food plot options (0–5%). Costs for prescribed burning and food plots were determined the same way total food production was calculated, but with prices for each input rather than biomass (i.e., 20% prescribed burning: 20% of 121 ha = 24.2 ha × \$74.13 ha^{-1} = \$1793.95). Supplemental feed costs were determined by the total amount of feed provided over the four-month period of interest (June–September), which was approximately 24,675 and 12,337.5 kg for the high and low feed option, respectively. The respective amounts of forage or feed from each nutritional input and associated costs were then added together to calculate the total food production on a property-wide basis and cost for each management combination. We then ranked the management options in order of greatest total food production during each stress period, took the top ten management options, and ranked them in order of lowest cost in terms of unit cost.

Results

In June, native forage production in pine-hardwood stands maintained on a one-year burn interval to support CP diet qualities of 14%, 16%, and 18% was 234.6 kg ha^{-1}, 115.3 kg ha^{-1}, and 11.0 kg ha^{-1}, respectively (Table 1). Ladino clover forage production was 2,156 kg ha^{-1} at each diet quality. Forage production was very similar in July, except that native forage production at 18% CP was 0 kg ha^{-1}. In September, native forage production was reduced by at least 50% at 14% and 16% CP, and was again 0 kg ha^{-1} at 18% CP. Production of Ladino clover forage was also reduced by nearly 75% in September due to a *Rhizoctonia* sp. fungal outbreak in three of the four research stands in both 2014 and 2015, resulting in an average production between the four stands of 575.4 kg ha^{-1}.

At 14% CP, there was an approximately 15% difference in food production among the top 10 management plans during each nutritional stress period compared to an approximately 40% difference in total cost (Table 2). Food production in June and July ranged from 194.0 kg ha^{-1} to 229.5 kg ha^{-1}, and costs were between \$0.34 and \$0.58 kg^{-1}. For September, food production was reduced and ranged from 90.3 kg ha^{-1} to 107.5 kg ha^{-1} and costs increased to \$0.79 to \$1.23 kg^{-1}. All management plans during each stress period at 14% CP included 60%, 80%, or 100% of the total pine-hardwood stands maintained on a one-year burn interval and 3%, 4%, or 5% or the total property planted in food plots. Supplemental feed was absent in the top three most cost-effective management options followed by the low option of supplemental feed in the next three options in both June and July, but was only absent in the top option in September.

Table 1. Crude protein nutritional carrying capacity estimates (kg ha^{-1}) in pine-hardwood stands burned on a one- ($n=8$) or two-year ($n=8$) interval and Ladino clover food plots during three months in 2014 and 2015 at Three Notch Wildlife Research Foundation in east-central Alabama.

	Crude protein diet quality					
	14%		16%		18%	
Nutritional input	x̄	SE	x̄	SE	x̄	SE
June						
Pine-hardwood (1-yr burn)	234.6	92.2	115.3	64.6	11.0	6.1
Pine-hardwood (2-yr burn)	53.6	17.0	21.8	9.0	4.2	2.9
Ladino clover	2156.1	107.4	2156.1	107.4	2156.1	107.4
July						
Pine-hardwood (1-yr burn)	239.2	94.5	147.7	71.7	0.0	0.0
Pine-hardwood (2-yr burn)	70.3	14.0	32.9	10.7	0.0	0.0
Ladino clover	2051.8	219.0	2051.8	219.0	2051.8	219.0
September						
Pine-hardwood (1-yr burn)	142.5	49.0	8.5	5.8	0.0	0.0
Pine-hardwood (2-yr burn)	45.0	17.0	7.2	4.3	0.0	0.0
Ladino clover	575.4	199.4	575.4	199.4	575.4	199.4

Table 2. Top 10 management plans ranked in order of most cost-effective at 14% crude protein (CP) during three months in 2014 and 2015 at Three Notch Wildlife Research Foundation in east-central Alabama.

Rank	% burn[a]	% food plot[b]	Feed[c]	Food production (kg ha^{-1})	Unit cost (\$ kg^{-1})
June					
1	80	5	0	200.4	0.34
2	100	4	0	196.0	0.34
3	100	5	0	217.5	0.34
4	100	5	1	223.5	0.45
5	80	5	1	206.4	0.46
6	100	4	1	202.0	0.46
7	100	5	2	229.5	0.56
8	80	5	2	212.4	0.57
9	100	4	2	208.0	0.57
10	60	5	2	195.5	0.58
July					
1	80	5	0	198.6	0.34
2	100	4	0	194.0	0.35
3	100	5	0	214.4	0.35
4	100	5	1	220.4	0.46
5	80	5	1	204.6	0.46
6	100	4	1	200.0	0.47
7	100	5	2	226.4	0.56
8	80	5	2	210.6	0.57
9	100	4	2	206.0	0.58
10	60	5	2	194.7	0.58
September					
1	100	5	0	95.5	0.79
2	100	4	1	95.7	0.97
3	100	5	1	101.5	1.00
4	80	5	1	92.4	1.02
5	100	2	2	90.3	1.14
6	100	3	2	96.0	1.16
7	100	4	2	101.7	1.17
8	100	5	2	107.5	1.19
9	80	4	2	92.6	1.22
10	80	5	2	98.4	1.23

a. Percent of theoretical 121-ha pine-hardwood forest maintained on a one-year burn interval. Remaining hectares maintained on a two-year burn interval.
b. Percent of theoretical 259-ha property planted in food plots.
c. Amount of supplemental feed included in each management plan. 0 = no supplemental feed, 1 = "low" option (1550 kg), 2 = "high" option (3100 kg).

Trends at 16% CP in June and July were similar to 14% CP but less food was available due to an increased nutritional plane. Food production during June and July ranged from 147.1 kg ha^{-1} to 183.5 kg ha^{-1} and costs were between \$0.42 and \$0.79 kg^{-1} (Table 3). However, there was a reduction in the percentage of prescribed burning in the top management plans at 16% CP during September, and overall food production was also reduced to between 38.7 kg ha^{-1} and 44.7 kg ha^{-1}. Food plots were still an impor-

Table 3. Top 10 management plans ranked in order of most cost-effective at 16% crude protein (CP) during three months in 2014 and 2015 at Three Notch Wildlife Research Foundation in east-central Alabama.

Rank	% burn[a]	% food plot[b]	Feed[c]	Food production (kg ha^{-1})	Unit cost (\$ kg^{-1})
June					
1	80	5	0	152.7	0.45
2	100	5	0	161.5	0.46
3	60	5	1	150.0	0.58
4	80	5	1	158.7	0.59
5	100	5	1	167.5	0.60
6	40	5	2	147.1	0.73
7	60	5	2	156.0	0.73
8	80	5	2	164.7	0.73
9	100	5	2	173.5	0.74
10	100	4	2	152.0	0.79
July					
1	80	5	0	160.7	0.42
2	100	5	0	171.5	0.44
3	60	5	1	156.0	0.56
4	80	5	1	166.7	0.57
5	100	5	1	177.5	0.57
6	100	4	1	157.1	0.59
7	100	5	2	183.5	0.70
8	80	5	2	172.7	0.70
9	60	5	2	162.0	0.70
10	100	4	2	163.1	0.73
September					
1	0	5	2	44.1	2.10
2	20	5	2	44.2	2.26
3	40	5	2	44.5	2.40
4	40	4	2	38.7	2.55
5	60	5	2	44.5	2.55
6	100	5	1	38.7	2.62
7	80	5	2	44.6	2.70
8	100	5	2	44.7	2.85
9	80	4	2	38.8	2.90
10	100	4	2	38.9	3.07

a. Percent of theoretical 121-ha pine-hardwood forest maintained on a one-year burn interval. Remaining hectares maintained on a two-year burn interval.
b. Percent of theoretical 259-ha property planted in food plots.
c. Amount of supplemental feed included in each management plan. 0 = no supplemental feed, 1 = "low" option (1550 kg), 2 = "high" option (3100 kg).

Table 4. Top 10 management plans ranked in order of most cost-effective at 18% crude protein (CP) during three months in 2014 and 2015 at Three Notch Wildlife Research Foundation in east-central Alabama.

Rank	% burn[a]	% food plot[b]	Feed[c]	Food production (kg ha^{-1})	Unit cost (\$ kg^{-1})
June					
1	40	5	1	116.7	0.69
2	60	5	1	117.3	0.74
3	0	5	2	121.4	0.76
4	80	5	1	117.9	0.80
5	20	5	2	122.0	0.82
6	100	5	1	118.6	0.85
7	40	5	2	122.7	0.87
8	60	5	2	123.3	0.92
9	80	5	2	123.9	0.97
10	100	5	2	124.6	1.02
July					
1	0	5	1	108.2	0.61
2	20	5	1	108.2	0.68
3	40	5	1	108.2	0.74
4	60	5	1	108.2	0.81
5	0	5	2	114.2	0.81
6	20	5	2	114.2	0.87
7	40	5	2	114.2	0.93
8	60	5	2	114.2	1.00
9	80	5	2	114.2	1.06
10	100	5	2	114.2	1.12
September					
1	0	5	2	40.7	2.28
2	0	4	2	34.9	2.43
3	20	5	2	40.7	2.45
4	40	5	2	40.7	2.62
5	20	4	2	34.9	2.63
6	60	5	2	40.7	2.79
7	40	4	2	34.9	2.83
8	80	5	2	40.7	2.96
9	60	4	2	34.9	3.03
10	100	5	2	40.7	3.13

a. Percent of theoretical 121-ha pine-hardwood forest maintained on a one-year burn interval. Remaining hectares maintained on a two-year burn interval.
b. Percent of theoretical 259-ha property planted in food plots.
c. Amount of supplemental feed included in each management plan. 0 = no supplemental feed, 1 = "low" option (1550 kg), 2 = "high" option (3100 kg).

tant forage source during this time, with 5% in all 10 management plans, but supplemental feed options also became more important to maximize food production and were included in all 10 management plans. Total costs increased in September to \$2.10 to \$3.07 kg^{-1} due to the addition of supplemental feed and reduction of native forage production. The top management plans at 18% CP during all three nutritional stress periods followed the same trends as 16% CP in September, except that less food was available again due to an increased nutritional plane (Table 4).

Discussion

Native forage in pine-hardwood stands treated with prescribed fire and food plots cost-effectively maximized food production at 14% and 16% CP in June and July. Both of these options provided deer with an abundance of forage to meet their nutritional demands for quality production without the addition of supplemental feed. Numerous studies have shown that prescribed fire is an effective management option to increase the abundance of quality native forage (Masters et al. 1996, Sparks et al. 1998, Haywood et al. 2001). Haywood et al. (2001) found that biennial burns in Louisiana longleaf pine (*Pinus palustris*) stands maintained on a long-term burning regime produced more than 90 times more herbaceous vegetation compared to unburned stands. Sparks et al. (1998) similarly reported that species richness, species diversity, and forb and legume production increased in stands treated with fire in restored pine-grassland communities in Arkansas. Because it is also an extremely cost-effective option (Strickland 2012), an abundance of high-quality native forage was produced due to the large area that could be burned at a low cost. However, our native forage estimates may have been inflated due to the use of exclosures for sampling. The exclosures did not account for vegetation that would have been consumed by deer during earlier months, but we wanted to measure forage production rather than availability during each stress period. In addition to native forage, food plots produced over 2000 kg ha^{-1} of clover forage exceeding 20% CP and were also more cost-effective than supplemental feed at maximizing food production. McBryde (1995) also found that in most cases, food plots are more economical than supplemental feed. Although management options that included supplemental feed increased total feed output, it was considerably more expensive with a much lower return value compared to prescribed fire and food plots during June and July.

In contrast to our results from June and July, declines in native forage quality during September resulted in a substantial decrease in native forage availability. As a result, there was a greater dependence on food plots during this time to compensate for the decreased availability of high-quality native forage. It has been well-documented that food plots provide an important source of forage for deer when high quality native forage is limited (Waer et al. 1992, Hehman and Fulbright 1997, Stephens et al. 2005). Native forage production was abundant during this period but the nutritional quality was considerably decreased. While a few native forage species exceeded 14% CP in September, the average CP content of native species was 10.2%, compared to nearly 22% CP for Ladino clover forage. Native forage quality has been commonly reported to decrease throughout the growing season (Short 1975, Jones et al. 2008), but other studies have also shown that clover forage can equal or exceed 20% CP during September (Waer et al. 1992, Stephens et al. 2005).

Supplemental feed also became an important option during September to maximize food production. In addition to food plots, supplemental feed helped compensate for the decreased availability of quality native forage. Ozoga and Verme (1982) reported that deer in an enclosure located in Michigan increased utilization of supplemental feed throughout the summer as native forage quality declined. Supplemental feed also became increasingly important to compensate for a reduction in clover production due to a *Rhizoctonia* sp. fungal outbreak at our study area. Based on other studies, clover production in September would be expected to be similar to production in June and July if the fungal outbreak had not occurred (Waer et al. 1992, Kammermeyer et al. 1993). Therefore, our results suggesting that supplemental feed was important during September may have been influenced by the fungal outbreak. Supplemental feed was still important to compensate for the decline in native forage availability, but a considerable amount of additional clover forage would have been available if the fungal outbreak had not occurred. However, an advantage to supplemental feed is that it can provide a high-quality source of feed on a consistent basis, regardless of season or environmental conditions, whereas food plot quality can vary (McBryde 1995, Hehman and Fulbright 1997). Unlike supplemental feed, food plots have the potential for crop failure due to drought, insects, or disease (Koerth and Kroll 1998).

September was a critical period to provide nutritional resources for lactating females at our study area, but it may not be as important in other parts of the Southeast where breeding occurs earlier. Peak breeding typically occurs between November and December across many other parts of the Southeast, compared to the end January at our study area (Gray et al. 2002, Diefenbach and Shea 2011). As a result, most females in areas where breeding occurs earlier are past the peak of lactation. However, it is still an important time to provide high-quality nutritional resources for adequate fawn growth. Crude protein requirements for fawn growth range from approximately 13%–25% CP, and after weaning, fawns may grow up to 210 g day^{-1} (French et al. 1956, Ullrey et al. 1967, Smith et al. 1975, Hewitt 2011). Ullrey et al. (1967) found that the body weight of weaned fawns was strongly associated with the level of protein in their diet. Kirkpatrick et al. (1975) similarly found that female fawns on a high CP diet (18.2%) had greater body weights than fawns on a low CP diet (9.6%).

Ladino clover was selected for this particular study, but there are a wide variety of warm-season food plot forages that can be utilized to provide high-quality forage for deer. Numerous food plot forages, including cowpeas (*Vigna unguiculata*), lablab (*Lablab purpureus*), and alyceclover (*Alysicarpus vaginalis*) have all been reported to have similar output and nutritional quality as the Ladino clover reported in our study (Beals et al. 1993, McDonald and Miller 1995, Edwards et al. 2004). Additionally, rather than planting a single species, it is often recommended to plant a variety of food plot forages, including both annual and perennial forages. This is because monthly forage production, costs to establish and maintain food plots, and responses to varying rainfall, soil conditions, and browsing pressure vary by species (Stephens et al. 2005, Kammermeyer et al. 2006, Harper 2008). A combination of food plot forages will help ensure a variety of nutritious forage is available for deer during nutritional stress periods.

During each stress period, 4%–5% of the total land planted in food plots were part of the top 10 management plans to maximize food production, but this may not be practical or required for many deer managers. Johnson et al. (1987) found that as little as 1% of the total area planted in food plots increased body weights and diet quality of free-ranging yearling bucks in Louisiana. Approximately 1% of the total land area planted in food plots may be sufficient, especially if deer densities are relatively low and habitat management techniques are being used to enhance native forage production. Other land-use practices may also limit the percentage of area planted in food plots, such as timber or agricultural production. If so, supplemental feed may become increasingly important, especially if a high density of deer needs to be supported. Additionally, financial limitations may restrict the area that can be converted to food plots or the quantity of supplemental feed that can be provided.

Providing a sufficient quantity of nutritional resources should be an integral component of any management plan that aims to maximize deer condition and quality. Wildlife managers have numerous choices when attempting to meet the nutritional demands of their deer herd, including habitat management options such as prescribed fire to enhance the quality and quantity of native forage. They may also provide additional high-quality resources by planting food plots and providing supplemental feed. However, the relative importance of each nutritional input varies seasonally, which is important for managers to understand when determining how to maximize food production during nutritional stress periods. Our study demonstrated the varying importance of different nutritional inputs during key nutritional stress periods for deer. However, our results and conclusions may be somewhat limited to more broad management applications and somewhat specific to our study area. The degree to which managers invest in each nutritional input will be dependent upon their property layout, financial resources, management goals, and deer density, such that each property will require a unique management plan.

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