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Economic Analysis of Replacing Endophyte-Infected with Endophyte-Free Tall Fescue Pastures

Jun Zhuang,* Mary A. Marchant, Christopher L. Schardl, and Courtney Murrell Butler

ABSTRACT

Cattle (*Bos taurus*) consuming tall fescue pastures infected with the endophyte *Neotyphodium coenophialum* often suffer physiological disorders that reduce animal performance. One solution is to replace endophyte-infected tall fescue pastures with an endophyte-free mixture. A benefit-cost analysis was conducted to determine the profitability of pasture restoration. The profitability of this action depends on the percentage of endophyte in existing pastures, the discount rate, stand life of the endophyte-free tall fescue variety, pasture stocking rates, product price, baseline calving rates, and the initial investment of replacement. In our benefit-cost analysis, assuming the stand life of endophyte-free tall fescue is 12 yr and the stocking rate is 1.20 head ha^{-1}, we determined a critical infestation level of 74%. Thus, under these conditions pasture replacement should be profitable if, in the existing pastures, >74% of the fescue plants are infected with toxic endophyte. In sensitivity analyses, realistic variations in the discount rate, pasture stand life, stocking rate, product price, baseline calving rate, and initial investment of replacement generated new net present values and critical infestation levels. The most influential variable was the stocking rate. The critical infestation level decreased dramatically to 25% at a stocking rate of 4.0 head ha^{-1} and increased dramatically to 93% at a stocking rate of 0.82 head ha^{-1}. Since infestation levels are often >70%, these results imply that for many livestock producers pasture replacement might be profitable compared with retaining endophyte-infected fescue stands.

Tall fescue [*Lolium arundinaceum* (Schreb.) Darbysh = *Festuca arundinacea* (Schreb.)] is commonly used for beef cow/calf production (Hoveland et al., 1997), occupying nearly 10 million ha in the southeastern and east-central regions of the USA (Hannaway et al., 1999). Although tall fescue is a well-adapted pasture grass in the USA, it has a reputation for causing poor performance by grazing livestock because of the presence of the fungal endophyte *Neotyphodium coenophialum* (Lomas et al., 1999), originally identified as a seedborne symbiont in cultivar Kentucky-31 and its derivatives (Bacon et al., 1977). Animals grazing on tall fescue infected with this endophyte often develop physiological disorders that reduce animal performance and profitability. Poor cattle performance is exemplified by reduced weight gains, lower milk production, poorer conception rates, and lengthened gestation terms (Waller and Fribourg, 2002; Hemken et al., 1979). The U.S. economic loss in beef associated with this endophyte was estimated at over $600 million annually (Hoveland, 1993), which demonstrates the relevance of this research to farmers.

Economic losses from animals consuming tall fescue have led to the introduction of endophyte-free tall fescue varieties to replace the stands containing the endophyte (Ball, 1992). Stands of endophyte-infected tall fescue persist for many years. The endophyte has no means to spread horizontally. Once the endophyte-free stand is established it should remain endophyte-free unless endophyte-infected seeds are introduced (Ball et al., 2003).

However, endophyte-free tall fescue is not as tolerant to overgrazing, drought, and other stresses as endophyte-infected tall fescue (Malinowski and Belesky 2000; West et al., 1988). Greenhouse studies confirm the enhanced drought tolerance of endophyte-infected tall fescue due to the presence of the endophyte (Arachevaleta et al., 1989). Also, endophyte-free varieties are more susceptible to certain herbivorous insects, parasitic nematodes, and pathogenic fungi (Jeger, 1999). Researchers have experienced difficulties establishing endophyte-free stands, particularly under conditions such as the drought of 1988 (Chestnut et al., 1991). Also, endophyte-infected tall fescue plants tend to yield greater forage dry matter compared to endophyte-free controls (Bouton et al., 2002). Thus, although endophyte-free tall fescue is better for the health and performance of grazing animals, endophyte-free tall fescue is not as hardy, persistent, or productive as endophyte-infected tall fescue.

In recent years novel, nontoxic endophytes have been introduced into tall fescue breeding stock, and the resulting cultivars have appeared benign to grazing cattle (Bouton et al., 2002). Initial performance assessments of these materials appear promising but variable (Bouton et al., 2002), so additional studies are needed to fully address the economics of these new cultivars. Then, the relative economic benefits of nontoxic endophytes can be compared with those of endophyte-free cultivars as analyzed in this study.

Published benefit-cost analysis does not take into account endophyte effects on animal fertility. There is increasingly strong evidence that the presence of the endophyte in tall fescue pastures adversely affects pregnancy rates in cattle and other livestock. For example, conception rates of 67% were reported for cows grazing on tall fescue pastures with a high concentration of endophyte infection, compared with 86% for pastures with low concentration (Gay et al., 1988). Danilson et al. (1986) reports a 43% increase in pregnancy rates of cattle consuming low vs. high endophyte-infected tall fescue pastures.

This research presents an investment analysis of renovating existing endophyte-infected pastures with an en-

J. Zhuang, Dep. of Industrial and Systems Engineering, 456B Mechanical Engineering Bldg., 1513 University Ave., Univ. of Wisconsin, Madison, WI 53706-1572; M.A. Marchant, Dep. of Agricultural Economics, Univ. of Kentucky, Lexington, KY 40546-0276; C.L. Schardl, Dep. of Plant Pathology, Univ. of Kentucky, Lexington, KY 40546-0312; and C. Murrell Butler, Unified Foodservice Purchasing Coop., 12000 West Hwy 42, Goshen, KY 40026. This is journal article no. 04-04-187 of the Kentucky Agric. Exp. Stn. Received 23 Apr. 2004. Economic Analysis. *Corresponding author (jzhuang@wisc.edu).

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Table 1. Investment costs for reestablishing pastures with endophyte-free fescue and clover.†

Season	Actions	Cost
		$ ha^{-1}
Spring	destroy fescue	113.67
April–June	plant corn	653.71
	pasture rent	46.98
	interest	56.98
Total spring cost		871.34
Summer	pasture rent	31.00
July–August	interest	1.26
	harvest and store corn silage	516.70
Total summer cost		548.96
Fall	plant endophyte-free tall fescue and clover	738.58
September–October	pasture rent	31.00
	interest	15.39
Total fall cost		784.97
Total cost		2205.27
Silage value		1205.63
Net renewal cost		1205.64

† Source: Updated data from Murrell (1997) and Standaert (1987).

dophyte-free variety of tall fescue. Our research builds on literature of prior economic analyses (Standaert, 1987; Murrell, 1997) by using updated information concerning endophyte effects on animal fertility. Empirical results of this research contribute to the literature by estimating benefits of economic management strategies that have not been previously assessed. These results are particularly important due to the widespread use of tall fescue and the extensive economic losses associated with animals grazing on tall fescue infected with the endophytic fungus *N. coenophialum.*

MATERIALS AND METHODS

Costs of Pasture Reestablishment with Endophyte-Free Tall Fescue

The costs of reestablishing pastures include the initial investment, which involves destroying existing pastures, planting corn, and seeding with an endophyte-free fescue and clover mix. Other costs include maintenance costs, which are incurred after the initial investment.

Table 1 lists the initial investment during the first year. This includes costs for destroying existing stands and reestablishing pastures with clover and noninfected fescue. In Table 1, each hectare is charged an expense for destroying the existing fescue with two applications of the herbicide paraquat (methyl viologen; 1,1′-dimethyl-4,4′-bipyridinium ion). Corn (*Zea mays* L.) to be used for silage is then planted as a rotation crop to ensure infected plants will not emerge into new fescue stands. Based on farmers' opportunity costs associated with pasture renewal, each hectare is charged for pasture rent while corn is planted; farmers must either move their cattle to alternative pastures, buy more feed, or raise their stocking rates on nonrenewed hectarage. Since pastures are to be seeded with noninfected fescue and clover (*Trifolium* sp.) in the fall, the corn must be harvested and stored before fall arrives. Therefore, the costs of planting, harvesting, and storing silage are included in this analysis along with the silage value, which will either be sold or used by the producer. The value of corn silage is $31.7 Mg^{-1} (Trimble et al., 2000), assuming a yield of 38 Mg of silage ha^{-1} (Standaert, 1987). After the initial investment, maintenance costs are upkeep costs associated with reestablishing the endophyte-free fescue–clover pasture. For example, they include fertilizer and lime applications.

Savings from Pasture Reestablishment with Endophyte-Free Tall Fescue

Given the above costs, our attention now focuses on the benefits of reestablishing pastures with endophyte-free tall fescue. There are two kinds of benefits, gross revenue (gr_i) and reestablishment benefits (rb_i), described below. Standaert (1987) decomposed the gross revenues (gr_i) per hectare for each infestation level i into four parts: the sales income from steers (s), heifers (h), cull cows (c), and replacement heifers (r). We define w_{si}, w_{hi}, w_{ci}, and w_{ri} as the ending weights for each of these four animal types, respectively, at infestation level i. We next define p_s, p_h, p_c, and p_r as the price per kilogram for each of these four respective animal types. Using the historical livestock price data reported by the Kentucky Department of Agriculture (www.uky.edu/Ag/AgEcon/pubs/software/livestock.html; verified 17 Jan. 2005), the prices for the four animal types organized by weight are specified in Table 2.

Next we define c_i as the baseline calving rates at endophyte infestation level i, where $c_{ci} = (1 - c_i)$ represents the cull cows group (Fig. 1). We assume that all cull cows are sold. Thus, $c_{ci} + c_i = 1$ cow unit. Then we define r_i as the heifer replacement rate at endophyte infestation level i. Relationships among the baseline calving rate (c_i), the heifer replacement rate (r_i), and the proportion of steers (c_{si}), heifers (c_{hi}) and replacement heifers (c_{ri}) per cow unit at endophyte infestation level i are described in Fig. 1 and as follows:

$$c_{si} = 0.5 \times c_i \quad [1]$$

whereby half of newborn calves are assumed male (c_{si}) and half female. We assume that all steers are sold.

$$c_{hi} = 0.5 \times c_i - r_i \quad [2]$$

identifies the heifer group sold after subtracting heifers used for replacement (r_i). Replacement heifers can be sent back to the original herd or sold.

$$c_{ri} = r_i - c_{ci} \quad [3]$$

identifies the replacement heifer group sold after subtracting the heifers used for replacement within the farmers' original herd. This number may be negative in some cases, implying that heifers are purchased to maintain a constant number of heifers.

Following Schmidt and Danilson's (1986) research, we assume that baseline calving rates (c_i) equaled 90, 82, and 55% when the infestation level ranged from 0 to 20%, from 30 to 70%, and from 80 to 100%, respectively. We also assume

Table 2. Average prices ($ kg^{-1}) of cattle organized by weight across years 1995–2002 (2002 prices).†

Animal type	136–182 kg	182–227 kg	227–274 kg	274–318 kg	318–363 kg	363–408 kg	408–454 kg
	$						
Steers	$2.19	$2.00	$1.85	$1.71	$1.64	$1.58	–
Heifers	1.89	1.77	1.67	1.58	1.51	1.51	–
Cull cow	–	–	–	–	–	–	$0.85
Replacement heifers	same as heifers						

† Source: Historical livestock price data reported by the Kentucky Department of Agriculture: (www.uky.edu/Ag/AgEcon/pubs/software/livestock.html; verified 17 Jan. 2005).

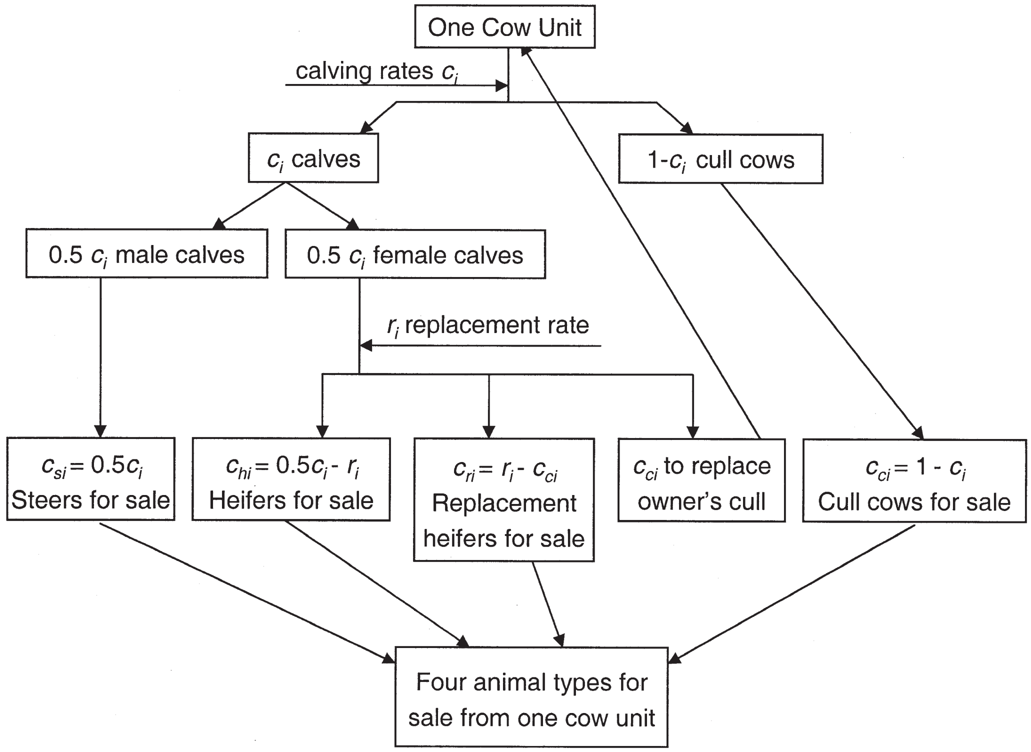

Fig. 1. Calving rate diagram.

that replacement rates (r_i) equaled 15, 20, and 25% when the infestation level equaled the above ranges, respectively.

We next define s as the season average stocking rates, for example, the number of head per hectare, which is assumed in the baseline analysis to be 1.20 head ha^{-1} (www.uky.edu/Agriculture/AnimalSciences/extension/pubpdfs/kybeefbook11.pdf; verified 17 Jan. 2005). Thus, the gross revenues per hectare for each infestation level may be calculated as the sum of sales income from these four animal types. Considering that the sales income for each animal type is obtained by multiplying its ending weight (w_{li}), price (p_l), proportion per cow unit (c_{li}), and the stocking rates (s = 1.20 head ha^{-1}), the total gross revenues per hectare at infestation level i is calculated as:

$$gr_i = s\sum w_{li} p_l c_{li} \quad [4]$$

for each animal type $l = s,h,c,r$ at infestation level i.

Given various infestation levels i, w_{li}, and c_{li} parameter levels are adapted from Standaert (1987) and Murrell (1997). Using Eq. [4], gross revenues per hectare (gr_i) at infestation level i are computed and listed in Table 3.

The formula for determining reestablishment benefits per year follows:

$$rb_i = gr_0 - gr_i \quad [5]$$

where the variables rb_i and gr_i are the reestablishment benefits and gross revenues, respectively, at infestation level i, ranging from 0 to 100%. Using Eq. [5], reestablishment benefits (rb_i) were calculated and listed in Table 3.

Net Present Value and Standaert's Model

The net present value (NPV) of the economic returns and costs for a farmer's investment to replace endophyte-infected pasture with endophyte-free tall fescue at a specific discount rate (d = 0.10) and specific pasture stand life (N = 12) follows:

$$\text{NPV}_i = Inv_0 + \sum_{t=1}^{N} \frac{fs_i + mc_t}{(1 + d)^t} \quad [6]$$

where Inv_0 is the initial investment ($404.70, as identified in

Table 3. Annual savings and gross revenues per hectare of reestablishing pastures at various levels of endophyte infestation.†

Infestation level	Ending weight for four animal types‡	Proportion per cow unit for four animal types	Gross revenues, gr_i	Reestablishment benefits, rb_i
%	kg	%	$ ha^{-1}	
	w_{si}, w_{hi}, w_{ci}, w_{ri}	c_{si}, c_{hi}, c_{ci}, c_{ri}		
0	267 239, 454, 384	45, 30, 10, 5	490.75	0
10	257 229, 454, 374	45, 30, 10, 5	473.96	16.89
20	247 218, 454, 364	45, 30, 10, 5	464.76	26.00
30	237 209, 454, 354	41, 21, 18, 2	404.71	86.04
40	227 199, 454, 344	41, 21, 18, 2	390.78	99.97
50	218 190, 454, 335	41, 21, 18, 2	394.00	96.75
60	208 180, 454, 325	41, 21, 18, 2	384.62	106.13
70	199 170, 454, 315	41, 21, 18, 2	371.22	119.53
80	189 160, 454, 305	27.5, 2.5, 45, −20§	225.14	265.61
90	179 150, 454, 296	27.5, 2.5, 45, −20	232.92	257.83
100	169 141, 454, 286	27.5, 2.5, 45, −20	228.97	261.78

† Source: Updated data from Murrell (1997) and Standaert (1987).
‡ Four animal types: s = steers, h = heifers, c = cull cows, r = replacement heifers.
§ Negative replacement heifer rates mean that farmers have to buy replacement heifers to replace cows because of the low calving rate.

Table 4. Net present values and critical infestation level of reestablishment at various infestation levels.

Infestation level	Net present value of reestablishment	Critical infestation level = 74%
%	\$ ha^{-1}	↑
0	−1206	
10	−1091	
20	−1029	negative NPV
30	−619	
40	−525	
50	−546	
60	−483	↓
70	−391	74%
80	604	↑
90	551	positive NPV
100	578	↓

Table 1) during the first year, and mc_t is the maintenance cost differences at year t of replacing endophyte-infected with endophyte-free pastures. Here we assume that the maintenance cost of endophyte-infected pastures equals the maintenance cost of the replaced pastures; thus, $mc_t = 0$. We recognize that there may exist cost differences between infected and endophyte-free pastures, and such cost differences can be easily incorporated into the above model. Thus, when such data are available in the future, this model can be readily modified.

A two-point-linear-interpolation method was then used to approximate the critical infestation level (I_{cr}), where NPV = 0. That is:

$$I_{cr} = I_{i1} + \frac{0 - (\mathrm{NPV}_{i1})}{\mathrm{NPV}_{i2} - (\mathrm{NPV}_{i1})} \times (I_{i2} - I_{i1}), \qquad [7]$$

where I_{i1} and I_{i2} are the two contiguous infestation levels (%) with $\mathrm{NPV}_{i1} < 0$ and $\mathrm{NPV}_{i2} > 0$, respectively. In other words, point I_{i1} has a negative NPV value and point I_{i2} has a positive NPV value. Thus, there exists a point between I_{i1} and I_{i2}, with a corresponding NPV equal to zero, and this is the critical value.

Therefore, the criterion for pasture restoration is the following: If the current infestation level is greater than I_{cr}, then it will be profitable to replace endophyte-infected tall fescue pastures with an endophyte-free mixture. Table 4 lists the NPV in dollar terms and the critical infestation levels (I_{cr}) in percent for reestablishing pastures with an endophyte-free fescue–clover mixture given various infection levels of the initial pasture.

Sensitivity Analyses

Sensitivity analyses were conducted to provide more information to farmers. The profitability of reestablishing pastures with an endophyte-free variety of tall fescue and clover depends on several factors. Our sensitivity analyses were conducted by altering individual variables, while holding others constant. The variables altered in these sensitivity analyses were the discount rate, the pasture stand life, the stocking rates, the final product prices, and the baseline calving rates.

For our baseline analysis, a discount rate of 0.10 was used to calculate the NPV with results presented in Table 4. Theoretically, raising the discount rate would lower the NPV and therefore increase the critical infestation level (I_{cr}). A discount rate of 0.05 and 0.15 were used in these sensitivity analyses to determine the effects on the NPV and the I_{cr}.

A pasture stand life of 12 yr was used in our baseline analysis. For our sensitivity analyses, 15 and 9 yr, respectively, were used to determine the effect of the pasture stand life on NPV and I_{cr}. We expect that an increase in stand life will increase NPV and thereby lower the I_{cr}, whereas a decrease in stand life will decrease NPV and thereby increase the I_{cr}.

A stocking rate (s) of 1.20 head ha^{-1} was used in our baseline analysis. For our sensitivity analyses, 0.82 and 4.00 head ha^{-1}, respectively, were used to determine the effect of the pasture stand life on NPV and I_{cr}. To further determine the effects of changes in final product prices (p_l), baseline calving rates (c_i) and initial investment of replacement (I_0) on the NPV and the I_{cr}, each of these three variables was increased and decreased by 10%, while holding other variables constant. Gross revenues per hectare (gr_i) and reestablishment benefits per year (rb_i) were recalculated accordingly and thus new values of NPV and I_{cr} were derived.

RESULTS AND DISCUSSION

Cattle producers considering replacement of endophyte-infected with endophyte-free tall fescue pastures should base their decisions on the net present value (NPV) for these options. According to the above formulas and assumptions used to calculate NPV and the critical infestation level (I_{cr}), if the percentage of endophyte in pastures falls below 74%, then pasture replacement is not economically profitable as shown in Table 4 given baseline assumptions. However, if the percentage of endophyte in existing pastures exceeds 74%, then pasture replacement with endophyte-free tall fescue would generate greater returns annually compared with retaining endophyte infected fescue stands.

The large jump in NPV between the 70 and 80% infestation levels reflects the large differences in calving rates (fertility) of cows grazed on 30 to 70% infested pastures vs. 80 to 100% infested pastures. The Schmidt and Danilson (1986) study, from which these calving rates were obtained, involved only three discrete infestation groups (0–20, 30–70, and 80–100%), and data are not yet available for a more continuous spectrum of infestation levels. Whenever such data are available they can be readily incorporated in our model.

In our sensitivity analyses, we independently adjust each of the five variables (discount rate, pasture stand life, stocking rate, product price, baseline calving rate, and initial investment of replacement). Results are listed in Table 5. Upon decreasing the discount rate from 0.10 to 0.05, we find that the NPV increases and that the critical infestation level decreases to 71%. Upon increasing the discount rate from 0.10 to 0.15, we find that the NPV decreases and that the critical infestation level increases to 77%. We then adjust the pasture stand life from 12 yr in the baseline analysis to 9 and 15 yr, respectively. When the pasture stand life is reduced to 9 yr, the NPV decreases and the critical infestation level increases to 76%. When the pasture stand life is increased to 15 yr, the NPV increases and the critical infestation level decreases to 73%.

We then adjust the stocking rate from 1.20 head ha^{-1} in the baseline analysis to 0.82 and 4.00 head ha^{-1}, respectively. When the stocking rate is reduced to 0.82 head ha^{-1}, NPV decreases and the critical infestation level increases to 93%. When the stocking rate is increased dramatically to 4.0 head ha^{-1}, the NPV increases and the critical infestation level decreases dramatically to 25%. This indicates that the stocking rate is a very

Table 5. Sensitivity analyses for net present values and critical infestation levels of reestablishment.

	Net present value, $ ha^{-1}												
		Changing discount rate		Changing Stand life		Changing stocking rate		Changing product price		Changing calving rates		Changing initial investment	
Infestation level	Baseline analysis	0.05	0.15	9	15	0.82	4.00	−10%	+10%	−10%	+10%	−10%	+10%
%				yr		head ha^{-1}		$				$	
0	−1206	−1206	−1206	−1206	−1206	−1206	−1206	−1206	−1206	−1206	−1206	−1085	−1326
10	−1091	−1056	−1114	−1108	−1077	−1127	−822	−1102	−1079	−1115	−1067	−970	−1211
20	−1029	−975	−1065	−1056	−1008	−1085	−615	−1046	−1011	−1069	−988	−908	−1149
30	−619	−443	−739	−710	−551	−805	749	−678	−561	−720	−519	−499	−740
40	−525	−319	−664	−630	−445	−740	1065	−593	−456	−647	−402	−404	−645
50	−546	−348	−681	−649	−470	−755	992	−612	−481	−678	−415	−426	−667
60	−483	−265	−630	−594	−398	−712	1205	−554	−410	−630	−335	−362	−603
70	−391	−146	−558	−517	−297	−649	1509	−473	−310	−545	−237	−271	−512
80	604	1149	234	324	815	31	4827	423	785	330	879	725	484
90	551	1080	192	279	755	−5	4650	375	727	269	833	672	431
100	578	1115	213	302	786	13	4740	400	756	281	876	699	458
	%												
Critical infestation level	74	71	77	76	73	93	25	75	73	76	72	73	75

influential variable in determining the model results. We also increase and decrease the (i) product prices, (ii) calving rates, and (iii) initial investment to replace endophyte-infected pastures by 10%. The results are listed in Table 5 and indicate that these variables do not dramatically influence model results.

CONCLUSIONS

Our investment analysis under certain realistic assumptions indicates that in order for producers' investment in reestablishing pastures to be profitable, existing tall fescue pastures must be more than 74% infected with the endophyte *Neotyphodium coenophialum*. Since infestation levels are often greater than 70% (Hiatt et al., 1999; Spyreas et al., 2001), this result implies that pasture replacement might be profitable compared with retaining endophyte-infected fescue stands. Additionally, changing the discount rate, pasture stand life, stocking rate, product price, baseline calving rates, and initial investment for pasture replacement generates new net present values and critical infestation levels. Sensitivity analyses show that the most influential variable is the stocking rate, whereby farmers who maintain a high stocking rate (4.0 head ha^{-1}) may find it worth the investment to replace pastures with infestation levels exceeding 25%.

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