Economic Impact of Drought- and Shade-tolerant Bermudagrass Varieties

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ADDITIONAL INDEX WORDS. homeowner survey, discrete choice analysis, mixed logit model, input-output model

SUMMARY. This study estimates potential economic impacts of developing drought- and shade-tolerant bermudagrass (*Cynodon dactylon*) turf varieties in five southern states: Texas, Florida, Georgia, Oklahoma, and North Carolina. First, estimates are provided for the market-level crop values of the newly developed two varieties for each state. Then, an economic impact analysis is conducted using an input-output model to assess additional output values (direct, indirect, and induced impacts), value added, and employment due to the new varieties. Our results indicate that the two new varieties would offer significant economic impacts for the central and eastern regions of the United States. Under the assumption of full adoption, the two new products would generate \$142.4 million of total output, \$91.3 million of value added, and 1258 new jobs. When a lower adoption rate is assumed at 20%, the expected economic impacts would generate \$28.5 million of output, \$18.3 million of value added, and 252 jobs in the region. Our findings quantify the potential economic benefits of development and adoption of new turfgrass varieties with desirable attributes for residential use. The findings suggest that researchers, producers, and policymakers continue their efforts to meet consumers' needs, and in doing so, they will also reduce municipal water consumption in regions suited to bermudagrass varieties.

Turfgrass has been used for many residential and commercial benefits such as wind and water erosion control, various sports activities, and landscapes for homes and business properties. Approximately 50 million acres of land are managed as turf in the form of residential lawns, athletic fields, golf courses, highway roadsides, cemeteries, and parks with an annual estimated value of \$57.9 billion (Haydu et al., 2006). Presently, there are about three times more acres of lawn (including residential and commercial) than irrigated corn (*Zea mays*). This makes turfgrass the single largest irrigated crop in the United States in terms of surface area (Earth Observatory, 2005). As the industry is expanding, turf producers and breeders strive to produce new and improved turf

varieties. In developing new turfgrass varieties, they consider the many challenges for turfgrass cultivation and appearance, which include attributes such as water requirements, salinity, shade, winter stress, and high maintenance cost.

For example, during drought and water shortages, municipalities often prohibit or reduce the use of potable freshwater on the turfgrass landscape, considering it a low priority (Kjellgren et al., 2000). Many cities have imposed mandatory irrigation restrictions, water audits, water bans, and increased prices for potable water to minimize water scarcity during droughts and to meet long-term water demand (Kenny et al., 2009). Thus, the shortage of municipally treated water has resulted in rules or regulations that require homeowners to use effluent or low-quality water such as rainwater or reclaimed water for lawn irrigation purposes. Proper turfgrass management is also affected

by salinity. The use of low-quality water in hot and dry climates (drought conditions) may cause higher concentrations of salt in the soil profile, which not only adversely affects turfgrass growth but also increases maintenance costs. In addition, use of salt for road thawing in winter or intrusion of seawater in coastal cities also increases the salinity problem in turfgrass (Murdoch, 1987). Furthermore, many homeowners are concerned about shaded areas in their landscape because shade tends to require different turf varieties with greater water needs (Harivandi and Gibeault, 1996). Loss of turfgrass during winter due to freezing temperatures, termed winterkill, is also another major problem of lawns (Frank, 2013).

The objective of this study is to estimate the economic effects of developing drought- and shade-tolerant bermudagrass turf varieties in five states: Florida, Georgia, Oklahoma, North Carolina, and Texas. These states were selected because of their active research program in developing new varieties in the respective land grant institutions under the Specialty Crops Research Initiative funded by the National Institutes of Food and Agriculture in the U.S. Department of Agriculture (USDA grant number 2010-51181-21064). Estimating potential economic effects of developing these improved turfgrass varieties is expected to guide publically and privately funded turfgrass research. The study focuses on a warm-season grass, bermudagrass, because bermudagrass comprises a large share of the total sod production in each of these states: 43.0%, 7.0%, 40.0%, 69.0%, and 12.3% in Texas, Florida, Georgia, Oklahoma, and North Carolina, respectively (USDA, 2015). These two (drought- and shade-tolerant) turfgrass varieties were selected based on previous studies (Ghimire, 2015; Ghimire et al., 2016) and a multiuniversity turfgrass research project which (Chandra et al., 2015) demonstrated that these two improvements were the most important as they were the most valued traits

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Units			
To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
0.0929	ft ²	m ²	10.7639
3.7854	gal	L	0.2642

by homeowners in the five southern states (see Chandra et al., 2015 for a detailed description of these two turf varieties).

Few studies estimate homeowners' preferences (or willingness-to-pay) on turfgrass attributes (Ghimire et al., 2016; Yue et al., 2012) or the total value of the turf industry either by state, or on a national basis (Haydu et al., 2006). However, no studies have provided potential economic and social impacts of improving turfgrass on regional markets. Our study estimates the potential economic impact of the improved varieties on the turfgrass industry of each state in terms of output values, value added, and employment. We first survey homeowners to estimate their preferences for the proposed new varieties and then we calculate the potential shares of the turfgrass market that the improved varieties for drought tolerance and shade tolerance could garner. Then, the value of the bermudagrass market in the selected states is estimated followed by the calculation of the crop values for the new varieties under the assumption of full and partial adoption. Finally, economic impacts (i.e., output values, value added, and employment impacts) of the adoption of the new varieties, partial and full, are evaluated using economic impact analysis using IMPLAN software (IMPLAN, Huntersville, NC) with economic multipliers for each state.

Material and methods

HOMEOWNER SURVEY. Homeowners' preferences for drought-tolerant and shade-tolerant varieties were surveyed using a standard survey design in the literature (Finn and Louviere, 1992; McFadden and Train, 2000). Attributes and the level of attributes for turfgrass varieties were initially determined using a literature review on preferences for turfgrass attributes for lawn (Yue et al., 2012) and in consultation with a panel of breeders, physiologists, and other experts working in the turfgrass industry (see Chandra et al., 2015 or Ghimire et al., 2016 for detailed description of the attribute profiles of each variety). A fractional factorial design that consisted of 36 possible combinations of attributes made 18 different choice sets with a D-efficiency of 96.4%. D-efficiency is a measure of the fit of a design scaled from 0 to

100, whereby 100 is the highest or best fit (balanced and orthogonal). Three surveys were created with each containing six different choice sets. The set of 18 scenarios were randomly grouped in three different versions with six different discrete choice experiment (DCE) choice sets in each version. In each choice set, there were three different alternatives: the first two options containing the combination of turfgrass attributes and its different levels and the last representing the status quo or a no change option. For each choice set, participants were asked to choose one of the three profiles or options. Two models (pooled, and first and last two choice set from three versions of surveys) were run to test whether the order of choice sets biased the data. A log likelihood ratio test proved that there is no significant difference in models with the first two choice sets and the last two choice sets from three surveys compared with pooled data. This indicates that data from the subsets of the choice set are not significantly different from pooled data and the order of choice set did not bias the data. An example of the choice set is provided in Fig. 1.

A web-based online survey was conducted with homeowners from Georgia, Oklahoma, North Carolina, Florida, and Texas in Nov. 2013. Respondents were instructed to make their selections as if they were buying turfgrass/sod for their lawn. A total of 1179 complete responses were received from the survey programmed in Qualtrics using a convenience sample obtained from Survey Sampling International (Encino, CA). The demographic characteristics of this sample, such as age and income, were similar to those of homeowners in the southern region of the United States. The median age of homeowners in the southern region is 55 years for 2013 (U.S. Census Bureau, 2013). The median age of the respondents was 52 years with a standard deviation of ≈ 15 years and approximately 64% of them were older than 45 years. Likewise, the median household income for owner-occupied households was \$52,400 for the southern region (U.S. Census Bureau, 2013). The median income of the households in our survey was \$62,500 with a standard deviation of \$48,033. Approximately 55% of households had an annual income of \$50,000 or higher.

Approximately 63% of the respondents had undergraduate or higher degrees. Respondents reported that they were 85% white and 47% female.

ECONOMETRIC MODEL. Using the homeowner survey data, a mixed logit model was estimated to assess homeowners' preference for the improved varieties. Typical logit models assume homogeneous parameters for all consumers (homeowners in this study), indicating similar preferences for all consumers for the attributes in question. However, heterogeneity in preferences may exist because of differences in taste, attitudes, and other factors. Among several methodologies, the mixed logit procedure is one of the methods that accounts for respondents' preference heterogeneity, which enables the estimation of unbiased estimates that are accurate and reliable for estimating welfare measurements (Greene, 1997).

In the random utility theory, an individual i 's utility from choosing alternative j and choice set t is:

$$U_{ijt} = \beta_i' X_{ijt} + \varepsilon_{ijt}, \quad [1]$$

where X_{ijt} is a vector of observed variables that represent the characteristics of alternative j from choice set c for individual i , β_i is the parameter vector of X_{ijt} for individual i representing that individual's preference, and ε_{ijt} is independent and identically distributed error term that follows a type I extreme value distribution. Allowing model parameters to vary randomly over individuals, the mixed logit model is characterized by accommodating heterogeneity as a continuous function of parameters. The model incorporates unobservable heterogeneity by modeling a distribution of β_i as:

$$\beta_{ik} = \beta_k + \sigma_k \eta_{ik}. \quad [2]$$

The (relative) utility associated with each individual i for attribute k is represented in a discrete choice model by a utility expression of the general form in Eq. [2], where η_{ik} is an error term with distribution $f(\eta_{ik})$. Hence, β_{ik} is a random variable with distribution $f(\beta_{ik})$, mean β_k , and standard deviation σ_k . The normal distribution was chosen for all attributes.

After estimating the random parameters, β_{ik} , market shares for each variety can be estimated. Following

Options A and B represent two different sets of sod/turfgrass characteristics. Which option (A, B, or C) would you be most likely to purchase?

Attributes	Option A	Option B	Option C
Lost lawn area to winter kill (50% probability)	40%	20%	If A or B were the only available options, I would not purchase new sod for my lawn
Sod tolerant to shade	Yes	No	
Watering your lawn (gallons/month)	Low (20,000 gallons)	High (60,000 gallons)	
Sod tolerant to salinity (salty water or soil)	No	Yes	
Maintenance and reoccurring cost (like mowing, spraying, grooming, fertilizing, and weeding, excluding purchase price)	No change	20% more than now	
Total average purchase price of sod for 5000 square foot lawn (\$/ft ²)	\$0.20	\$0.40	

	Option A	Option B	Option C
I would choose	☐	☐	☐

Fig. 1. An example of the discrete choice experiment choice set for eliciting preferences for turfgrass varieties; 1 gal = 3.7854 L, 1 ft² = 0.0929 m², and \$1/ft² = \$10.7639/m².

Berry (1994), market shares of variety l can be calculated as:

$$S_l = \frac{\exp(V_l)}{\sum_{l=1}^L \exp(V_l)}, \quad [3]$$

where $V_l = \beta' X_l$ is the indirect utility of choosing each turfgrass variety; X_l and β are the vectors of turfgrass attributes that are related to variety l and corresponding parameters, respectively. The vector of attributes can include low winterkill, medium winterkill, shade tolerance, low water requirement, medium water requirement, saline tolerance, low maintenance cost, high maintenance cost, and average price. Low winterkill, medium winterkill, and high winterkill represent no damaged turf by winterkill with probability of 50%, 20% lawn damaged by winterkill with probability of 50%, and 40% of lawn damaged with a probability of 50%, respectively; low water requirement and medium water requirement represent water requirements for an average size 5000-ft² lawn at 20,000 and 40,000 gal/month, respectively; and low maintenance cost and high maintenance cost represent 20% reduction of average maintenance cost and 20% increase of average maintenance

cost, respectively. Three turf varieties considered in this study are common bermudagrass (sold as U3), a potential drought-tolerant bermudagrass, and potential shade-tolerant bermudagrass. In consultation with turf researchers, each variety is defined as common bermudagrass—high water requirement, saline-tolerant, and low maintenance cost; drought-tolerant bermudagrass—medium amount (20%) of area of lawn lost to winterkill, low water requirement, saline-tolerant, and high maintenance cost; and shade-tolerant bermudagrass—tolerant to shade and with a high water requirement (J.Q. Moss, personal communication).

ANALYSIS OF ECONOMIC IMPACT. The share of the market adoption for each variety, estimated in Eq. [3], is applied to the total value of bermudagrass for each selected state to compute the potential market value of improved varieties. Then, overall statewide economic impacts of the adoption of the new varieties are evaluated using the IMPLAN system and associated state-level datasets.

The economic impact modeling system estimates state-level input-output models using a set of extensive input-output databases including

various economic variables for more than 500 different industries. Total economic activity in each state from sales to final demand from foreign and domestic markets is generated from economic multipliers that result from the input-output modeling system. The analysis includes three components of total change within each selected state. First, direct impacts represent the direct or actual revenues generated by turfgrass cultivation itself due to the initial change in the industry. The direct impact of developing improved varieties would include the increased sales value of improved varieties in the turfgrass industry sectors. Second, indirect impacts include additional input purchases made by all industries due to the changes in interindustry transactions as a result of the supplying industries' responses to increased demands from related industries. For example, the increased sales in the turfgrass sector would require more purchases of inputs such as labor, fertilizer, and chemicals. Finally, induced impacts reflect changes in local spending that result from income changes in the directly and indirectly affected industry sectors. For example, the induced impacts are generated

when local business owners, suppliers, and employees spend the additional income that they earned as a result of newly introduced turfgrasses. The economic impact modeling system used allows for the estimation of three different multipliers: Type I (only direct and indirect impacts), Type II (direct, indirect, and induced impacts), and Type SAM (Social Accounting Matrix) (direct, indirect, and induced impacts as well as further account for commuting, social security and income taxes, and savings by households). The regional models used in this study are constructed to derive Type II multipliers (i.e., total output that combines direct, indirect, and induced impacts), value added, and employment effect. The value-added impact is the net income effect that subtracts out the cost of goods sold from the total output impact and the employment effect is the number of jobs created because of the adoption of the improved varieties.

Results

Table 1 reports parameter estimates from mixed logit model for each of the five states. From all states, most attribute variables that represent characteristics of varieties are statistically significant, mostly at 1% or 5% level, in determining individual's utility. Estimates in Table 1 are applied to Eq. [3] to obtain potential market shares for two new products: drought-tolerant and shade-tolerant varieties.

Table 2 reports estimated market shares of the two new varieties relative to the baseline current varieties, which was defined as the aggregated common variety in the market. Once the value that the buyers of turfgrass place on the benefit of drought- and shade resistance was calculated, an estimation of how the market for bermudagrass would change for the common (baseline) variety and for the improved varieties yet to be developed was estimated under assumptions of 100%, 50%, 20%, and 10% adoption. The adoption rates could be influenced by many factors such as price, development of new varieties, sales channels, and license and patent issues. Further study of sod producers would be needed to predict adoption levels by each state. Therefore, we estimated market shares and economic values of the turfgrass varieties under four different adoption scenarios. Results of the market share estimation under these adoption rates are shown in Table 2. Under the assumption of full adoption, four out of five states, i.e., Texas, Georgia, Oklahoma, and North Carolina show higher market shares for the shade-tolerant variety than for the drought-tolerant variety. Florida show 25.49% of market share for the shade-tolerant variety, whereas it expects 35.63% of market share for the drought-tolerant variety. The expected market shares for the two varieties under the partial

adoption 50%, 20%, and 10% have been calculated by multiplying the partial adoption rates to the expected market shares estimated under the full adoption assumption. Therefore, market shares of common-baseline variety are again remaining shares after market shares of the two new varieties are considered. For example, when a 10% adoption is assumed for the new varieties, each of the two new products is expected to take around 3% to 4% of market share in Florida, Oklahoma, and North Carolina, whereas the baseline (common) product takes the remaining market share at around 93% to 94%. However, under the same adoption rate, market shares of drought- and shade-tolerant products become 2.23% and 5.54%, respectively, in Texas and 1.41% and 6.61%, respectively, in Georgia, whereas leaving the remaining market share to the common product.

POTENTIAL CROP VALUES OF IMPROVED VARIETIES. To estimate crop values of the improved varieties, we first estimate the size (value) of total bermudagrass market by state by multiplying total crop value of turfgrass industry by state to the share of each state's bermudagrass. The market share of bermudagrass is considered for each state because not all of the sod production in each state is for warm-season turfgrass and only a portion of such is bermudagrass. Then,

Table 1. Parameter estimates of mixed logit model to determine shares of consumer adoption of bermudagrass varieties by trait in Texas, Florida, Georgia, Oklahoma, and North Carolina collected by internet survey in 2013.

Variable ^z	Coefficient [mean (SE)] ^y				
	Texas	Florida	Georgia	Oklahoma	North Carolina
No change	0.281 (0.304)	0.885 (0.486)*	0.344 (0.292)	0.599** (0.279)	-0.028 (0.182)
Lawn lost by winterkill (low vs. high)	0.552** (0.247)	1.015** (0.431)	1.110*** (0.309)	1.081*** (0.311)	0.438*** (0.151)
Lawn lost by winterkill (medium vs. high)	0.329 (0.277)	0.235 (0.322)	0.211 (0.245)	0.252 (0.207)	0.211 (0.145)
Shade tolerance	0.674** (0.283)	0.773** (0.337)	1.067*** (0.300)	0.917*** (0.284)	0.394*** (0.099)
Water requirement (low vs. high)	1.743*** (0.636)	2.631** (1.047)	1.635*** (0.346)	2.050*** (0.522)	1.004*** (0.184)
Water requirement (medium vs. high)	1.066** (0.429)	1.232** (0.527)	0.574** (0.226)	1.153*** (0.338)	0.525*** (0.156)
Saline tolerance	-0.247 (0.255)	0.425 (0.263)	-0.233 (0.198)	0.089 (0.150)	-0.002 (0.107)
Maintenance cost (low vs. no change)	0.008 (0.188)	0.770** (0.377)	0.097 (0.208)	0.372* (0.215)	0.248* (0.142)
Maintenance cost (high vs. no change)	-0.993* (0.514)	-0.951 (0.589)	-1.519*** (0.564)	-1.153** (0.455)	-0.476* (0.252)
Average purchase price	-1.762 (0.796)	-2.463** (1.069)	-2.084*** (0.617)	-2.435*** (0.751)	-1.507*** (0.316)

^zLow, medium, and high maintenance cost represent 20% reduction, 0% to 20% increase, and more than 20% increase of average maintenance cost, respectively.

^yParameter estimates and corresponding SE are mean values from the mixed logit model.

***, **, and * represent statistical significance at 1%, 5%, and 10%, respectively.

Table 2. Expected market shares of new bermudagrass turf varieties in Texas, Florida, Georgia, Oklahoma, and North Carolina by varied sod producer adoption rates (100%, 50%, 20%, and 10%).

Adoption rate	State	Common variety (%)	Drought-tolerant variety (%)	Shade-tolerant variety (%)
Full adoption (100%)	Texas	22.24	22.34	55.42
	Florida	38.88	35.63	25.49
	Georgia	19.86	14.06	66.08
	Oklahoma	30.62	21.03	48.35
	North Carolina	31.98	30.92	37.10
Partial adoption (50%)	Texas	61.12	11.17	27.71
	Florida	69.44	17.82	12.75
	Georgia	59.93	7.03	33.04
	Oklahoma	65.31	10.52	24.18
	North Carolina	65.99	15.46	18.55
Partial adoption (20%)	Texas	84.45	4.47	11.08
	Florida	87.78	7.13	5.10
	Georgia	83.97	2.81	13.22
	Oklahoma	86.12	4.21	9.67
	North Carolina	86.40	6.18	7.42
Partial adoption (10%)	Texas	92.22	2.23	5.54
	Florida	93.89	3.56	2.55
	Georgia	91.99	1.41	6.61
	Oklahoma	93.06	2.10	4.84
	North Carolina	93.20	3.09	3.71

we apply expected market shares of the improved new varieties, reported in Table 2, to the estimated value of total bermudagrass market. Table 3 shows total sales value of turfgrass industry, market share of bermudagrass, and total sales value of bermudagrass by state. The total crop values of turfgrass industry are from the National Agricultural Statistics Service agricultural census conducted in 2012 (USDA, 2015). Several sources were consulted for the state-level market shares of bermudagrass using the best available data: Texas (Falconer and Niemeyer, 2006), Florida (Satterthwaite et al., 2009), Georgia (Waltz and Johnson, 2015), Oklahoma (Luper et al., 2015), and North Carolina (Toth, 2015). The adoption of new varieties could change the overall market share of bermudagrass as a function of all turf produced in Table 3. At this point, we do not have any guidance on the change in market share of bermudagrass due to the new varieties from the literature. It is possible to estimate this change using technology-diffusion models framed with a sector model. However, we feel that this task is beyond the scope of our present study. Therefore, in our study, we assumed that market share of bermudagrass as a function of all turfgrasses sold remained the same after introducing the new varieties, but that the varieties within bermudagrass changed.

Table 3. Crop values of total turfgrass and bermudagrass turf in Texas, Florida, Georgia, Oklahoma, and North Carolina in 2015 (U.S. Department of Agriculture, 2015).

State	Total sales value of turfgrass (×\$1,000)	Market share of bermudagrass (%)	Total sales value of bermudagrass (×\$1,000)
Texas	\$120,800	43.0	\$51,944
Florida	\$170,944	7.0	\$11,966
Georgia	\$44,147	40.0	\$17,659
Oklahoma	\$34,088	69.0	\$23,521
North Carolina	\$34,842	12.3	\$4,286
Total region	\$404,821		\$109,375

Texas and Florida have significantly larger turfgrass industries than other three states, whereas Texas, Georgia, and Oklahoma have larger market shares of bermudagrass than two other states. As a result, the first largest market for bermudagrass is Texas with total sales values of \$52 million, the second is Oklahoma with \$24 million, followed by Georgia with \$18 million.

Combining Tables 2 and 3, we can estimate potential crop values of the improved new products for each state under various adoption rates, and results are reported in Table 4. Under the scenario of the full adoption, drought- and shade-tolerant products are valued at \$24.6 million and \$56.5 million each year from all five states. Among the five states, as expected, Texas reaps the largest amount of values at \$11.6 million and \$28.8 million from drought- and

shade-tolerant varieties, respectively, whereas North Carolina takes the smallest values at \$1.3 million and \$1.6 million, respectively. Values under partial adoptions have been calculated by multiplying the values with the full adoption to each of the three adoption rates.

ECONOMIC IMPACT OF INTRODUCING THE NEW VARIETIES. Using the crop values from Table 4, economic impacts of the new drought- and shade-tolerant varieties have been estimated by state under the four adoption rate scenarios: 100%, 50%, 20%, and 10%, and results of this estimation are shown in Table 5. The economic impacts include the value of output (direct, indirect, and induced effects), the value added (net income effect), and employment (additional number of jobs) created from the two improved varieties.

Table 4. Potential market value of improved drought- and shade-tolerant bermudagrass turf varieties in Texas, Florida, Georgia, Oklahoma, and North Carolina by adoption rates in 2015.

Adoption rate	State	Potential market value (×\$1,000)		
		Common variety	Drought-tolerant variety	Shade-tolerant variety
Full adoption (100%)	Texas	11,552	11,604	28,787
	Florida	4,652	4,264	3,050
	Georgia	3,507	2,483	11,669
	Oklahoma	7,202	4,946	11,372
	North Carolina	1,371	1,325	1,590
	Total region	28,284	24,622	56,469
Partial adoption (50%)	Texas	31,748	5,802	14,394
	Florida	8,309	2,132	1,525
	Georgia	10,583	1,241	5,834
	Oklahoma	15,362	2,473	5,686
	North Carolina	\$2,828	663	795
	Total region	68,830	12,311	28,234
Partial adoption (20%)	Texas	43,866	2,321	5,757
	Florida	10,503	853	610
	Georgia	14,829	497	2,334
	Oklahoma	20,257	989	2,274
	North Carolina	3,703	265	318
	Total region	93,157	4,924	11,294
Partial adoption (10%)	Texas	47,905	1,160	2,879
	Florida	11,235	426	305
	Georgia	16,244	248	1,167
	Oklahoma	21,889	495	1,137
	North Carolina	3,994	133	159
	Total region	101,266	2,462	5,647

Under the assumption of full adoption, total output impacts for the region are estimated at \$142.4 million that includes \$42.7 million from the drought-tolerant variety and \$99.7 million from the shade-tolerant variety. Total value-added impacts are estimated at \$91.3 million with \$27.4 million and \$63.9 million from the drought- and shade-tolerant products, respectively. Total employment impacts are 1258 new jobs: 378 and 880 from drought- and shade-tolerant products, respectively. Following potential crop values reported in Table 4, the estimated economic values generated from the shade-tolerant product are more than two times bigger than those from the drought-tolerant product. Of the five states, Texas is the biggest beneficiary of introducing these two improved varieties to the turfgrass industry with \$71.2 million of total output value, \$45.6 million of value added, 660 additional jobs, whereas North Carolina expects the lowest benefit with \$4.9 million of total output value, \$3.2 million of value added, and 32 additional jobs. At the 50% of adoption rate, the total output economic impacts for the region are estimated at \$71.2 million:

\$21.4 million from drought-tolerant variety and \$49.8 million from shade-tolerant variety. Total value-added impacts are estimated at \$45.7 million: \$13.7 million from drought-tolerant variety and \$32.0 million from the shade-tolerant variety. Total additional jobs created are 629: 189 and 440 from drought- and shade-tolerant products, respectively. As the adoption rate decreases to 20% and 10% of the total bermudagrass market, the size of estimated economic impacts of the improved varieties diminishes accordingly. However, even when only 10% of adoption of the improved varieties is assumed in the market, there would still be a sizable economic impact generated in the region. Under the 10% adoption rate, output, value-added, and employment impacts are \$14.02 million, \$9.1 million, and 126 jobs, respectively.

Conclusion

The goal of this study was to assess economic impacts of adopting drought- and shade-tolerant bermudagrass turf varieties in Texas, Florida, Georgia, Oklahoma, and North Carolina. To estimate the economic impacts, we first surveyed homeowners

and estimated their preferences for the proposed new varieties. Then, using the estimates of homeowners' preferences, we calculated potential market shares of the improved varieties, and the market-level crop values of the improved two varieties were calculated by multiplying the estimated market shares to total crop values of bermudagrass market for each of the five states under full and partial adoption scenarios. Finally, economic impacts, values of output and value-added impacts, and number of jobs created, because of the adoption of the new varieties, were evaluated using an input-output program using the crop values of the two improved varieties. The major contribution of this study is to provide crop values of the drought- and shade-tolerant varieties and their impacts on the economy of each of the five states. We found that the proposed varieties would offer significant economic impacts on the region. For example, under the assumption of full adoption, the two new products would generate \$142.4 million of total output, \$91.3 million of value added, and 1258 new jobs. When a lower adoption rate is assumed at 20%, the expected economic impacts

Table 5. Economic and employment impacts by adoption rates for potential market value of bermudagrass drought- and shade-tolerant varieties estimated using input-output analysis in Texas, Florida, Georgia, Oklahoma, and North Carolina in 2015.

Adoption rate	Variety	State	Potential market value (×\$1,000)					Total region
			Texas	Florida	Georgia	Oklahoma	North Carolina	
Full adoption (100%)	Drought-tolerant	Output	20,467	7,277	4,873	7,875	2,250	42,742
		Value added	13,102	4,730	3,113	5,049	1,465	27,458
		Employment	190	63	39	72	15	378
	Shade-tolerant	Output	50,775	5,206	22,902	18,106	2,700	99,688
		Value added	32,503	3,384	14,629	11,607	1,758	63,880
		Employment	470	45	181	166	17	880
	Total	Output	71,242	12,482	27,775	25,981	4,950	142,431
		Value added	45,604	8,114	17,742	16,656	3,223	91,338
		Employment	660	109	220	238	32	1,258
Partial adoption (50%)	Drought-tolerant	Output	10,234	3,638	2,437	3,938	1,125	21,371
		Value added	6,551	2,365	1,556	2,524	732	13,729
		Employment	95	32	19	36	7	189
	Shade-tolerant	Output	25,387	2,603	11,451	9,053	1,350	49,844
		Value added	16,251	1,692	7,314	5,804	879	31,940
		Employment	235	23	91	83	9	440
	Total	Output	35,621	6,241	13,888	12,991	2,475	71,215
		Value added	22,802	4,057	8,871	8,328	1,611	45,669
		Employment	330	54	110	119	16	629
Partial adoption (20%)	Drought-tolerant	Output	4,093	1,455	975	1,575	450	8,548
		Value added	2,620	946	623	1,010	293	5,492
		Employment	38	13	8	14	3	76
	Shade-tolerant	Output	10,155	1,041	4,580	3,621	540	19,938
		Value added	6,501	677	2,926	2,321	352	12,776
		Employment	94	9	36	33	3	176
	Total	Output	14,248	2,496	5,555	5,196	990	28,486
		Value added	9,121	1,623	3,548	3,331	645	18,268
		Employment	132	22	44	48	6	252
Partial adoption (10%)	Drought-tolerant	Output	2,047	728	487	788	225	4,274
		Value added	1,310	473	311	505	146	2,746
		Employment	19	6	4	7	1	38
	Shade-tolerant	Output	5,077	521	2,290	1,811	270	9,969
		Value added	3,250	338	1,463	1,161	176	6,388
		Employment	47	5	18	17	2	88
	Total	Output	7,124	1,248	2,778	2,598	495	14,243
		Value added	4,560	811	1,774	1,666	322	9,134
		Employment	66	11	22	24	3	126

would generate \$28.5 million of output, \$18.3 million of value added, and 252 jobs. The findings of our study suggest that researchers, producers, and policymakers can effectively partner to understand consumer preferences for agricultural products (in our case, grass attributes) to develop new varieties with additional benefits to society at large. First, government grant programs can use the feedback to establish priorities for research and outreach efforts. Second, a consumer-oriented approach would enable a larger demand impact in terms of adoption of the new varieties. In this regard, there may be economic and environmental benefits of adopting new varieties. In the case of turfgrass,

the new varieties would reduce irrigation and hence the water cost of homeowners, whereas increasing water available for other needs. Breeders and other researchers working with industry partners can provide input on the feasibility and cost of developing the new varieties. Finally, the multidisciplinary effort provides a way to evaluate the aggregate potential welfare impacts of the adoption of new varieties and provides measures of returns on investment.

One limitation of this study could be that we used different scenarios for adoption rates in this study and economic benefits of the varieties. Note, however, that this sensitivity analysis can be used for welfare

analysis to assess what would the level of adoption have to be in order for the implementation of the new varieties to be economically feasible. In that regard, we provide insightful information for industry, researchers, and policymakers. One direction for future studies, therefore, could be to develop a technology-diffusion type model considering various factors such as price, substitution, license, and patent and apply the outcome of this model to the evaluation model we used in this study. This way, one can estimate the adoption path of new products and can apply different level of adoption rates each year. Another direction for future studies might be to consider the cost of developing

these new technologies and valuing the water saved per region or drought-resistant varieties. Combining potential cost and benefit data together could lead to a complete benefit-cost analysis in assessing economics of new turfgrass varieties.

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