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Economic estimates of feral swine damage and control in 11 US states

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A B S T R A C T

We report the results of one of the most comprehensive surveys on feral swine (*Sus scrofa*) damage and control in 11 US states (Alabama, Arkansas, California, Florida, Georgia, Louisiana, Mississippi, Missouri, North Carolina, South Carolina and Texas). The survey was distributed by the USDA National Agricultural Statistical Service in the summer of 2015 to a sample of producers of corn (*Zea mays*), soybeans (*Glycine max*), wheat (*Triticum*), rice (*Oryza sativa*), peanuts (*Arachis hypogaea*), and sorghum (*Sorghum bicolor*) in the 11-state region. Producers that failed to respond to the initial mailing received multiple follow-up phone calls in an attempt to minimize non-response bias, and a total of 4377 responses were obtained. Findings indicate that damage can be substantial. The highest yield loss estimates occur in peanut and corn production in the Southeast and Texas. Control efforts are common, and producers incur considerable costs from shooting and trapping efforts. Extrapolating crop damage estimates to the state-level in 10 states with reportable damage yields an estimated crop loss of $190 million. Though large, this number likely represents only a small fraction of the total damage by feral swine in the 10 states because it only includes crop damage to six crops. We hope findings from this survey will help guide control efforts and research, as well as serve as a benchmark against which the effectiveness of future control efforts can be measured.

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1. Introduction

Feral swine (*Sus scrofa*) have become widespread throughout much of the United States because of their reproductive potential and adaptable biology (Seward et al., 2004). Over the past 30 years, the range of feral swine has increased from 17 to 38 states (Bevins et al., 2014) (Fig. 1). The recent range expansion of feral swine has inflicted substantial costs on agricultural producers in the United States. Though estimates of damage to agricultural production range widely and are largely context specific (Bevins et al., 2014), it is clear that feral swine have the ability to damage most crops, transmit diseases to both livestock and other wildlife, and effectively destroy ecosystems (Barrios-Garcia and Ballari, 2012; Crooks, 2002). At the same time, feral swine provide benefits to some in the form of subsistence and recreational benefits (e.g. hunting), the latter of which might benefit some agricultural producers (Zivin et al., 2000). These opposing negative impacts and positive use values associated with feral swine presence necessitate a better understanding of their impacts to agricultural producers.

While estimates of agricultural damage from feral swine exist, they are either largely individual (as summarized by Bevins et al. (2014)), or back-of-the-envelope style aggregations, as in the widely cited numbers reported by Pimentel et al. (2005). Thus, there is a need for both a precise and broad understanding of the how crop damage by feral swine varies across crops and production regions. This would enhance the efficiency of producer and government led control efforts by allowing resources to be allocated to the most severe problems. Furthermore, this type of information could serve as a baseline against which the effects of future control efforts could be measured. To address this need, the National Agricultural Statistical Service (NASS) administered a survey instrument that was designed by researchers at the USDA/APHIS/WS National Wildlife Research Center.

The survey was designed to simultaneously capture information related to feral swine presence, crop damage, livestock losses, control methods, live sales, and hunting, but the focus of the present analysis is on crop damage and control efforts. Distribution targeted producers of corn (*Zea mays*), soybeans (*Glycine max*), wheat (*Triticum*), rice (*Oryza sativa*), peanuts (*Arachis hypogaea*),

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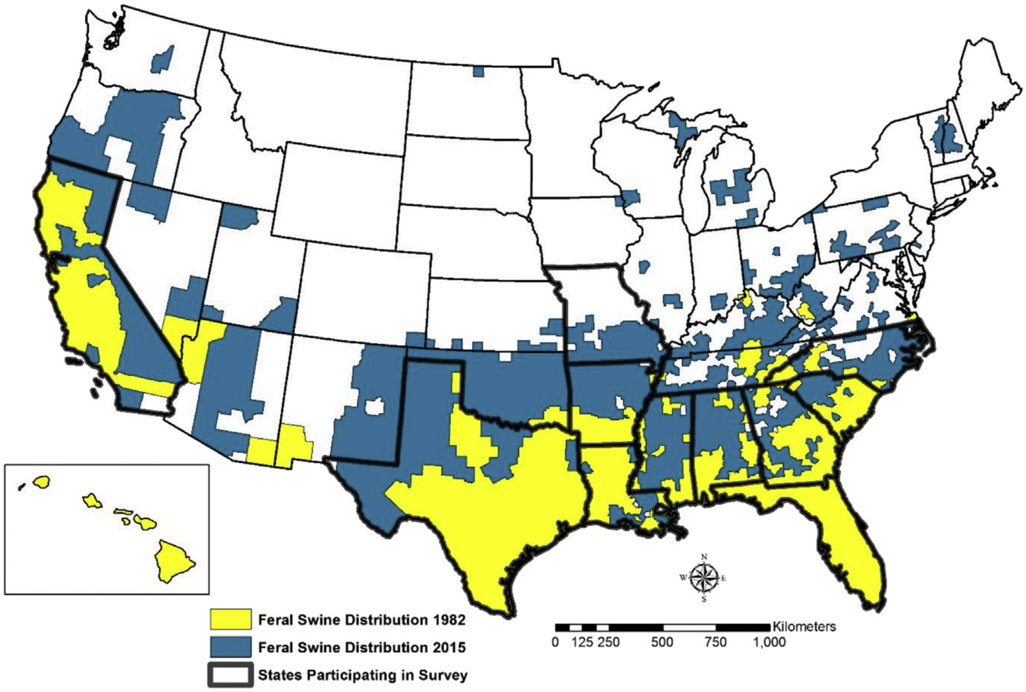

Fig. 1. Feral swine distribution in 1982 and 2015.

and sorghum (*Sorghum bicolor*) in Alabama, Arkansas, California, Florida, Georgia, Louisiana, Mississippi.

Missouri, North Carolina, South Carolina, and Texas.[1] States and crops were selected by a subjective evaluation of economic importance (United States Department of Agriculture (2014)), vulnerability to feral swine (see Fig. 1), and political considerations. However, the instrument was designed to accommodate responses for any crop the respondents considered economically important on their operation. We proceed with a discussion of the survey instrument, survey distribution, and NASS rules related to disclosure of information. Results are then presented, followed by a discussion of the implications of the findings.

1.1. Methods

Information on crop damage was solicited by the questions listed inFig. 2. Producers could choose to respond for up to three of their highest valued crops harvested on their operation in 2014. The structure of the questions enabled us to capture information from producers that experienced no crop damage from feral swine so that we could use the survey results to extrapolate to the state-level. The questions also go beyond simply soliciting a percentage yield loss response. Instead, producers were asked how many of the acres of each crop were damaged by feral swine, as well as actual yield with the damage and expected yield without the damage on those acres. Self-reporting wildlife damages the crops is common and has been shown to be accurate (Conover, 2002; Johnson-Nistler et al., 2005; Tzilkowski et al., 2002; Wywialowski, 1994).

To calculate feral swine damage to crops, we compared actual yield reported by each producer to the expected yield reported if no feral swine damage had occurred. Specifically, each producer reported total acres harvested for each of up to three crops, as well as average yield per acre, giving total yield. For crop j on producer i's operation, this is:

$$Yield_{ij} = (acres\ harvested_{ij})(avg.yield\ per\ acre_{ij}). \quad (1)$$

If some acres were reported damaged by wild pigs, producers reported: (i) the number of acres damaged, (ii) average yield per acre on damaged acres, and (iii) expected yield per acre if these acres had not been damaged. Hypothetical yield losses for each producer's crops are then calculated as:

$$Loss_{ij} = (acres\ damaged_{ij})(avg.yield\ not\ damaged_{ij} - avg.yield\ \ w/damage_{ij}). \quad (2)$$

Since actual yield on damaged acres was included in the original calculation of total yield in (1), hypothetical yield without feral swine damage is the sum of (1) and (2). Hypothetical yield loss due to feral swine damage as a percentage of total (hypothetical) yield is then:

$$Percent\ Loss_{ij} = 100 \times \frac{Loss_{ij}}{Yield_{ij} + Loss_{ij}}. \quad (3)$$

Equation (3) gives the portion of yield lost to feral swine damage at the producer-crop level. To calculate the portion of yield lost for each crop within each state, we summed yield and hypothetical loss across all producers of each crop in each state as in (1) and (2), and used these to calculate the portion of each crop's yield lost to feral swine across the state. Along with the producer level responses needed to calculate (3), each producer was given a calculated weight based on a non-response adjustment and Multivariate Probability Proportional to Size (MPPS) weight, as in Kott et al. (1998). These weights are used in the calculations that follow, specifically by weighting each producer's yields and losses in (1) and (2) by their unique weight in order to obtain a representative value at the state level.

To estimate the dollar value of production lost to feral swine damage for the selected crops at the state level, we must assume

[1] Sorghum producers were only surveyed in Texas.

Please report for up to three crops harvested in 2014 with the highest value of production in 2014		Unit	Crop 1	Crop 2	Crop 3
a.	In 2014, which crop(s) harvested on your operation produced the highest value of production? Report for up to three crops.	Crop			
b.	How many total acres of this crop were **planted**?	Acres			
c.	How many total acres of this crop were **harvested**?	Acres			
(i)	What was the average yield per acre of this crop?	Number	. __	. __	. __
(ii)	What was the unit for the yield reported in row c(i) above?	Unit	□ Bushels □ Pounds □ Tons □ Other (Specify: _____)	□ Bushels □ Pounds □ Tons □ Other (Specify: _____)	□ Bushels □ Pounds □ Tons □ Other (Specify: _____)
(iii)	What was the average price received (or expected to be received) for this crop harvested in 2014?	Dollars per unit	$ _ _ /unit	$ _ _ /unit	$ _ _ /unit
(iv)	Was this crop certified as organic?		□ Yes □ No	□ Yes □ No	□ Yes □No
d.	Were wild pigs present on any field of this crop? (If **Yes**, continue. If **No** or **Don't Know**, go to Item X.)		□ Yes □ No □ Don't Know	□ Yes □ No □ Don't Know	□ Yes □ No □ Don't Know
(i)	Was this crop damaged by wild pigs? (If **Yes**, continue. If **No** or **Don't Know**, go to Item X.)		□ Yes □ No □ Don't Know	□ Yes □ No □ Don't Know	□ Yes □ No □ Don't Know
(ii)	How many acres of this crop were damaged by wild pigs?	Acres			
(iii)	What was the average yield per acre of the acres damaged by wild pigs?	Number	. __	. __	. __
(iv)	If these acres had not been damaged, what would have been their yield per acre?	Number	. __	. __	. __

Fig. 2. Feral swine crop damage questions from survey instrument.

that the weights used to account for non-response and farm size are also applicable to feral swine damage. In other words, we must assume that the damage experienced by the weighted sample of observed producers is representative of all producers of the same crop in their state. Under this assumption, estimated production value lost to feral swine is the percentage loss by state and crop from Table 3. For crop j in state s, the calculation of percentage loss analogous to (3) is:

$$Percent\ Loss_{js} = 100 \times \frac{Loss_{js}}{Yield_{js} + Loss_{js}}. \tag{4}$$

The dollar value of lost production is then

$$Loss_{js} = \frac{(Percent\ Loss_{js})(Yield_{js})}{100 - Percent\ Loss_{js}}.$$

Current production value for the selected crops and states were obtained from NASS Quick Stats for the year 2012 (the most recent available census year at the time of writing).

Table 2
Usable observations for calculating percent lost.

	Corn	Soybeans	Wheat	Rice	Sorghum	Peanuts
Alabama	114	121	50	NA	NA	58
Arkansas	44	96	16	53	NA	NA
California	NA	NA	NA	26	NA	NA
Florida	23	20	NA	NA	NA	51
Georgia	123	63	23	NA	NA	NA
Louisiana	32	58	13	16	NA	NA
Mississippi	69	103	11	15	NA	NA
Missouri	368	404	97	37	NA	NA
North Carolina	202	304	117	NA	NA	58
South Carolina	154	152	49	NA	NA	NA
Texas	209	45	230	39	149	53

Additional questions solicited information on feral swine control efforts (Figs. 3 and 4). Producers were asked about the use of each method, the cost of each method, and their perceptions about the effectiveness of each method. Questions about fencing (both

Table 1
Total responses and percent from each state reporting damage and control.

	Responses	Feral swine on land	Crop damage by feral swine	Property damage by feral swine	Attempt to control feral swine	Hunt feral swine
Alabama	337	45%	29%	21%	32%	51%
Arkansas	202	32%	21%	15%	19%	43%
California	485	9%	4%	5%	6%	20%
Florida	159	65%	45%	35%	44%	60%
Georgia	386	67%	51%	36%	51%	62%
Louisiana	129	60%	41%	36%	38%	54%
Mississippi	184	46%	28%	21%	26%	58%
Missouri	674	5%	2%	1%	1%	45%
North Carolina	494	16%	10%	3%	8%	54%
South Carolina	373	47%	28%	19%	29%	58%
Texas	954	66%	49%	39%	49%	48%

Table 3
Percent of crop lost to feral swine.

	Corn	Soybeans	Wheat	Rice	Sorghum	Peanuts
AL	0.93%	1.38%	0.62%	NA	NA	6.17%
AR	1.09%	0.27%	0.75%	0.27%	NA	NA
CA	NA	NA	NA	0%	NA	NA
FL	4.41%	3.43%	NA	NA	NA	1.84%
GA	4.73%	1.07%	4.39%	NA	NA	NA
LA	0.83%	0.74%	0.94%	1.26%	NA	NA
MS	1.34%	0.4%	0.7%	0.12%	NA	NA
MO	0%	0.02%	0.01%	0%	NA	NA
NC	0.38%	0.09%	0.15%	NA	NA	0.49%
SC	1.59%	1.52%	1.71%	NA	NA	NA
TX	1.65%	1.1%	3.05%	2.46%	2.87%	9.28%

reporting: feral swine on their operation, damage from feral swine on crops harvested, property damage from feral swine during 2014, any control methods used to reduce or prevent damage from wild pigs in 2014, and hunting of feral swine on their operations. Responses from Florida, Georgia, and Texas were most likely to indicate both the presence of feral swine on their land (65%, 67%, and 66% respectively) as well as damage by feral swine (45%, 51%, and 49% respectively). Producers from these three states were also most likely to attempt to control feral swine, and hunting feral swine was most common in the Southeast.

Of the responses summarized in Table 1, some observations of crop-level data were unusable (e.g. a producer reported feral swine damage to a crop but no acres damaged or a producer reported on

In 2014, which of the following control methods were used on your operation in order to reduce or prevent damage from wild pigs? If the method was used in 2014, how much did that method cost (including labor) and how effective was it?

	Control Method	Used on operation in 2014?	Cost (Include labor) (Dollars)	How effective was the control method? Check one per row			
				Not Effective	Slightly Effective	Moderately Effective	Very Effective
a.	Shooting wild pigs on sight	□ Yes □ No	$	□	□	□	□
b.	Hunting wild pigs **with** dogs	□ Yes □ No	$	□	□	□	□
c.	Hunting wild pigs **without** dogs	□ Yes □ No	$	□	□	□	□
d.	Aerial hunting	□ Yes □ No	$	□	□	□	□
e.	Trapping and removing wild pigs	□ Yes □ No	$	□	□	□	□
f.	Repellents for wild pigs	□ Yes □ No	$	□	□	□	□
g.	Other (Specify ________________)	□ Yes □ No	$	□	□	□	□

Fig. 3. Non-fencing feral swine control questions from survey instrument.

In 2014, did you use electric fencing on your operation specifically to reduce damage by wild pigs?		□ Yes □ No
a.	How much did it cost to install this **electric** fencing?	$
b.	At the time of installation, how many years was the expected useful life of this **electric** fencing?	_____ years
In 2014, did you use non-electric fencing on your operation specifically to reduce damage by wild pigs?		□ Yes □ No
a.	How much did it cost to install this **non-electric** fencing?	$
b.	At the time of installation, how many years was the expected useful life of this **non-electric** fencing?	_____ years

Fig. 4. Fencing feral swine control questions from survey instrument.

electric and non-electric) were formatted differently because of the fixed-cost nature of control via fencing.

The sample of producers was based on the MPPS sampling design (Bailey and Kott, 1997) and NASS's list of known operations in the 11 states with the selected crops. 9720 surveys were mailed during summer of 2015 and, upon non-response, followed by up to 10 phone calls for an interview. NASS does not allow disclosure of any statistic if the maximum value of all values used to calculate the statistic divided by the sum of those same values is greater than 0.42 or if fewer than four producers who answer the question answered the question the same way. For this reason, summary statistics at the state-crop level cannot be reported in some cases, since the low response rate results in some categories being dominated by a single producer. Thus, when zeroes are reported, they should be interpreted as such. Alternatively, reported NA's could be zeroes or non-zeroes, but NASS would not allow the data to be disclosed.

2. Results

A total of 9720 surveys were mailed and 4377 producers responded to the survey (45% response rate). Table 1 presents a summary of responses by state, including percentages of producers

crops other than those listed in Table 2). Table 2 reports the number of usable observations for calculating percentage yield loss at the state-crop level. Corn and soybeans provide the largest sample sizes, although we also had reasonable numbers of responses for wheat in some states. Given the pronounced regional nature of their production, sample sizes for the remaining crops were unsurprisingly small or non-existent in some states.

The results of the yield loss calculations for the crops of interest are presented in Table 3. Mean reported damage to corn was markedly higher in Georgia (4.73%) and Florida (4.41%) than in other states (next highest is Texas with 1.65% damage), while reported soybean damage was substantially higher in Florida (3.43%) than in other states (next highest is South Carolina with 1.52%). Reported wheat damage was most severe in Georgia (4.39%) and Texas (3.05%), and rice damage was most severe in Texas (2.46%) and Louisiana (1.26%). Of all the state and crop combinations, the highest mean reported damage occurred in peanut production in Texas (9.28%) and Alabama (6.17%). In fact, peanuts appear to incur the most damage among the reported crops, followed by corn. Most of these findings are expected given what we know about feral swine behavior, distribution and the geographic distribution of the production of these crops.

Estimates of production value lost to feral swine, as calculated in

Table 4
Approximate value of production lost to feral swine state-wide (1000 US $).

	Corn	Soybeans	Wheat	Rice	Sorghum	Peanuts	Sum
AL	$1949	$3080	$453	NA	NA	$15,841	$21,322
AR	$9284	$5305	$1265	$3721	NA	NA	$19,575
CA	NA	NA	NA	$0	NA	NA	$0
FL	$1592	$388	NA	NA	NA	$4006	$5985
GA	$22	$1273	$3855	NA	NA	NA	$5150
LA	$5295	$5682	NA	$4693	NA	NA	$15,670
MS	$12,364	$5110	$881	$163	NA	NA	$18,518
MO	$0	$459	$27	$0	NA	NA	$486
NC	$2737	$787	$430	NA	NA	$730	$4684
SC	$4583	$2815	$1349	NA	NA	NA	$8747
TX	$23,884	$464	$20,232	$4300	$20,775	$20,162	$89,817
sum	$61,710	$25,363	$28,491	$12,877	$20,775	$40,739	$189,955

(5) are presented in Table 4. For the selected crops and states which are reportable, an estimated $190 million in crop production was lost to feral swine damage in 2014. Note that this does not capture the full impact of feral swine to producers of these crops in these states. Feral swine damage to livestock and property, as well as costs incurred from control measures aimed at preventing additional damage, all contribute to the overall cost of feral swine, which, given the proportions reported in Table 1, are likely substantial. A comparison across crops shows that corn has the highest value of reported crop losses ($61,710), followed by peanuts ($40,739). However, given the total value of production in the 11 states of the different crops, peanut production suffers much larger monetary losses as a percentage of total production value. The results also indicate that Texas suffers substantially larger monetary losses than other states ($89,817; the next highest loss occurs in Alabama with $21,322), despite the fact that percentage losses are not typically more severe than states in the Southeast.

The percentage of responding producers reporting use of each control method are reported in Table 5. Shooting feral swine on sight was the most common method, followed about equally by focused hunting and trapping. Aerial hunting was rarely reported outside of Texas, likely because of its high cost (Campbell et al., 2010). Neither type of fencing (electric and non-electric) was commonly used, although the use of non-electric fencing was more common than electric. Given the crops that we focused on, this was not a surprising result. Spending on each method of control during 2014 is reported in Table 6. Responding growers spent the most on shooting on sight, followed by trapping. We choose not to extrapolate control spending to the state level because we lack data on control methods in the context of specific crops, and it is thus unclear how to extrapolate correctly. However, we instead calculate the average spending per producer represented by the sample (Table 7).

3. Conclusion

Our findings suggest that of the states included in this study, feral swine impose the largest burden on agricultural producers in the Southeast and Texas. Reported damage was generally lower in the California, Arkansas, and Missouri. However, in the case of California, this result may be affected by the diversity of agricultural production in the state. Fruit and vegetable production is common throughout many parts of California, and it is possible that by targeting grain and soybean producers, we were simply not sampling the relevant producers in California. In the case of Arkansas and Missouri, the relatively low damage is (at least in part) explained by Fig. 1. In much of Arkansas and all of Missouri, feral swine are a relatively recent phenomenon. Thus, it may be the case that densities are lower than in the Southeastern states, or producers may simply be less aware of the damage because it has not occurred historically.

Furthermore, responses suggest that corn and peanuts suffer more damage than the other crops we focused on. This finding could have several causes. First, these crops may be inherently more attractive or vulnerable to damage than the other crops, or

Table 5
Percentage of responses reporting use of control methods.

	Shoot on sight	Hunt w/dogs	Hunt w/out dogs	Aerial	Trap	Repellants	Electric fence	Non-electric fence
AL	29%	13%	18%	1%	21%	1%	2%	6%
AR	18%	8%	13%	NA	13%	1%	1%	NA
CA	4%	NA	3%	NA	1%	NA	1%	1%
FL	39%	21%	27%	NA	31%	2%	2%	8%
GA	47%	30%	32%	NA	29%	2%	2%	7%
LA	36%	22%	19%	NA	25%	NA	NA	3%
MS	24%	14%	16%	NA	14%	NA	NA	NA
MO	1%	NA	NA	NA	0%	NA	NA	1%
NC	7%	3%	2%	NA	2%	1%	1%	1%
SC	24%	19%	13%	NA	15%	NA	2%	6%
TX	43%	15%	27%	17%	29%	1%	2%	8%

Table 6
Total cost of feral swine control by method.

	Shoot on sight	Hunt w/dogs	Hunt w/out dogs	Aerial	Trap	Repellants	Electric fence	Non-electric fence
AL	$117,742	$52,200	$47,780	NA	$129,095	NA	$8150	NA
AR	NA	NA	$5630	$0	$29,350	NA	NA	NA
CA	NA	$0	NA	$0	$0	NA	NA	NA
FL	$19,901	NA	$9775	$0	$35,550	NA	NA	$7395
GA	$347,066	$139,100	$166,956	$0	$130,300	NA	NA	$11,908
LA	NA	$7150	NA	NA	$22,210	NA	$0	NA
MS	$43,983	NA	$15,900	$0	$30,200	NA	NA	NA
MO	NA	$0	$0	$0	$0	$0	$0	NA
NC	NA	NA	NA	$0	NA	NA	NA	NA
SC	$55,905	$21,700	NA	$0	$60,004	NA	NA	$8048
TX	$461,372	$94,103	$253,873	$344,000	$254,401	$3400	NA	$59,845

Table 7
Average spending on feral swine control by method.

	Shoot on sight	Hunt w/dogs	Hunt w/out dogs	Aerial	Trap	Repellants	Electric fence	Non-electric fence
AL	$349.38	$154.90	$141.78	NA	$383.07	NA	$24.18	NA
AR	NA	NA	$27.87	$0.00	$145.30	NA	NA	NA
CA	NA	$0.00	NA	$0.00	$0.00	NA	NA	NA
FL	$125.16	NA	$61.48	$0.00	$223.58	NA	NA	$46.51
GA	$899.13	$360.36	$432.53	$0.00	$337.56	NA	NA	$30.85
LA	NA	$55.43	NA	NA	$172.17	NA	$0.00	NA
MS	$239.04	NA	$86.41	$0.00	$164.13	NA	NA	NA
MO	NA	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	NA
NC	NA	NA	NA	$0.00	NA	NA	NA	NA
SC	$149.88	$58.18	NA	$0.00	$160.87	NA	NA	$21.58
TX	$483.62	$98.64	$266.11	$360.59	$266.67	$3.56	NA	$62.73

they may be relatively more common in areas with high swine densities. Alternatively (or additionally), producers of these crop may be more willing to incur damage or less able to invest in control effort. Admittedly, a final reason may be that damage is simply more observable in certain crops. This is perhaps a believable explanation for corn in particular, since trampled areas would be more apparent than for other crops. Nevertheless, responses suggest that feral swine damage to crops is widespread. A total production loss of nearly $190 million represents a substantial loss for crop producers, many of which typically operate on very small profit margins.

The economic burden of crop damage from feral swine is not limited to the lost production; it also includes the substantial cost of control efforts. Many growers reported applying a suite of control methods, with shooting and trapping representing the largest fraction of control costs. Taken together, the crop losses and control costs are a substantial additional production cost for producers within the current distribution of feral swine. Although such effects are unaccounted for here, a small but real shift in production has probably occurred as the range and density of feral swine has increased. It has been shown that any change in relative production costs of agricultural commodities will alter the distribution of production. Thus, feral swine damage has probably lead to both a decrease in production of vulnerable crops where they are present and an (not-necessarily equal) increase elsewhere. The impacts are also not limited to producers. Ultimately, some portion of any increase in production will be passed to consumers in the form of higher prices.

Several limitations of the survey and its analysis should be acknowledged. First, producers may not have accurate perceptions of damage, and their estimates of control costs could be biased. Such biases may be intentional or unintentional. Additionally, we are unable to fully characterize all non-response bias that may be present. NASS expended considerable effort to minimize the number of non-responses, and the response rate was about 45% which is quite good. However, the possibility of bias remains because responders may have been more likely to incur damage than non-respondents. Finally, sample sizes for some questions and state-crop combinations is quite small, and in some cases NASS rules prevent disclosure of any information garnered from specific questions.

Our hope is that the results we present here will serve several purposes. First, an understanding of which areas and crops experience the most damage will make any management more efficient. Producers and government agencies expend considerable time and effort managing feral swine damage, and knowing where the problem is most severe will help these entities allocate their resources more appropriately. Second, USDA/APHIS Wildlife Services has recently initiated a widespread feral swine control campaign. In addition to guiding the implementation of this program, the findings we present can serve as a benchmark for evaluating this control program. Thus, our hope is that this survey can be repeated at regular intervals to ensure that the objectives of the control program are being met and progress is being made against the threat that feral swine represent to US agricultural producers.

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