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The Influence of Water Conservation Practices on US Nurseries' Decision to Sell Native Plants

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Abstract. **Native plants are becoming a highly demanded horticulture product because of the general public's interest and government policies promoting them. As a result, plant growers are increasingly incorporating native plants in their plant offerings. But, what business and environmental factors influence grower adoption of native plants? This gap in the literature is addressed through an investigation of US grower survey data from 2013 and 2018 using a zero-one-inflated beta model. Results indicate that some key factors such as water sources and type of plant products influence the likelihood of native plant adoption across the models, but variables such as rainfall and population density around business locations do not. These results have important implications for policies that promote the growth of native plants and prospective horticultural industry growers.**

The use of native plants in landscapes continues to gain popularity in governmental policy and landscapes. This may be a result, in part, of a heightened interest in proenvironmental products. Perhaps native plants simply "sound" better for the environment compared with exotic or introduced plants. Literature on their increasing popularity is scant, as is consumer research on perceptions and the factors driving the rise in popularity. A native plant is defined as "a plant that is part of the balance of nature that has developed over hundreds or thousands of years in a particular region or ecosystem" (US Department of Agriculture 2023). Native plants tend to be selected for their ability to survive in difficult planting sites in landscapes and can provide a variety of benefits, including being a source of nutrition for wildlife and pollinators, reducing soil erosion, requiring less maintenance (i.e., water and fertilizer usage), and creating ecosystem services because of their coevolution with regional flora and fauna (US Department of Agriculture 2023; Wilde et al. 2015). With demand predicted to increase in coming years, and a noted increase in the annual compound growth rate of native plant purchasing from 2019 to 2023 (3.3%), it is important to explore which production factors may promote, or deter, horticultural firms growing native plants (Whitinger 2024). A feature of these data is the use of multiyear survey data collected from firms within the green industry for 10 years. In our analysis, production variables of interest were related to irrigation methods, water supply, market location, and native plant sales, as well as regional location, urban or rural location, and annual rainfall.

The main objective of our study was to understand the drivers of the adoption of native plants by horticulture producers. This issue is relevant because public policy promotes native plants as a viable source of plant material that maximizes the economic and social benefits of plants while reducing environmental impacts. Currently, the market is limited because of the amount of natives that are sold at popular garden retail centers, which has created a barrier to entry for many growers (Brzuszek and Harkess 2009; Kauth and Perez 2011; Rihn et al. 2024). The empirical results are also relevant because they provide information that can help evaluate the adoption factors using an economic perspective to understand more completely the costs and benefits that can motivate or discourage prospective growers to supply native plants.

Literature Review

Native plants. Increased demand for environmentally friendly products extends beyond household goods to include landscape and gardening products (Carr and Boyd Kramer 2022; Jensen and Sørensen 2020; Thomas et al. 2020). Native plants are largely considered to be a more environmentally responsible choice than non-native species (Davis et al. 2011; Hitchmough 2011; Peterson et al. 2012; Rihn et al. 2023; Yue et al. 2011). North American native plants are those species indigenous to regions or environments of North America before European settlement of the continent (US Forest Service, US Department of Agriculture n.d.). Consequently, native plants provide many ecosystem services, including improved water conservation, biodiversity, pollinator health, and wildlife habitat (Breuste 2004; Goddard et al. 2010; Grimm et al. 2008; Potts et al. 2002; Raymond et al. 2019; Rudd et al. 2002; Vickers 2006), while reducing air and water pollution (Bijoor et al. 2008; Morris and Bagby 2008).

As a result, in part, of these benefits, demand for native plants has increased steadily and is currently estimated at $14.5 billion [US dollars (USD)] or 9.1% of direct output from the ornamental horticulture industry (Hall et al. 2020; Khachatryan et al. 2020). The results of previous studies imply a great diversity in native plant production, from small to large shares of sales. In 2008, Brzuszek and Harkess (2009) surveyed 129 nurseries in the Southeast United States. Nearly 50% of their sample estimated that native plant sales equated to less than $75,000 per year and 13% stated native plant sales were greater than $500,000 per year. From the consumer angle, Yue et al. (2011) used a nonhypothetical experimental auction to elicit consumers'

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willingness to pay for plants with labels of native or non-native and invasive or noninvasive. Consumers in the auction were willing to pay a $0.35 premium for native, noninvasive plants, but needed a discount of $1.01 to $1.66 to purchase a plant labeled invasive for a six-pack plant. The average bid for native, labeled plants was $2.79 vs. native, invasive plants at $1.82; and non-native, invasive plants at $1.28—a 53% premium for noninvasive native plants.

Despite increasing consumer interest and demand, the production of native plants has been limited by several challenges. White et al. (2018) highlighted the perception of limited commercial availability of native species and the regional differences related to the availability of native plants. They emphasized the need for more information on production, demand, and regional differences in consumer demand, what is native within a region, and weather conditions. Norcini (2006) state that limits to the use of native plants in landscapes are related to small markets, nursery limitations (e.g., small size, limited capital), high plant material costs, low familiarity, and misperceptions about aesthetic characteristics of native plants.

To date, very few studies address the actual production practices used by native plant growers. An exception is seen in the work of Rihn et al. (2022), who compared production practices used by US native plant growers relative to those who do not grow native plants. In general, native plant production firms participate in more diverse integrated pest management strategies, grow a wider range of plant types, and use a more diverse range of sales channels to sell their products. They suggest the increased diversity in production methods used by native plant firms may be attributed to smaller firm size, a greater diversity of plants grown (i.e., needing to diversify to address insect and disease pressures), a greater commitment to sustainability, or a strategy that relies on niche markets rather than economies of scale. Their study suggests that native plant growers use unique production practices to grow and market their products. Absent from their study is information on water use and irrigation strategies of native plant growers. Native plant growers and growers producing non-native species could differ in irrigation and water use, given that native plants have been shown to require less water (Bijoor et al. 2008; Morris and Bagby 2008; Vickers 2006) and generally require different production practices relative to other species (Rihn et al. 2022). We address this research gap by investigating how water source, irrigation type, plant form, and firm characteristics affect the proportion of natives produced by firms.

Econometric models to evaluate horticulture firms. We explored variation among firms in the percentage of native plants grown as a function of the different sources of water and the different types of irrigation used. As additional variables, we included sales, average rainfall, urban/rural location of the firm, and regional dummies. The following variables were found to have a significant impact on firms' unconditional predicted percentage of native plants grown: subsurface irrigation, the use of smart irrigation systems, production of balled and "burlapped" plants, and overall sales of the firm. However, our econometric model allows for different processes governing extensive and intensive margin decisions. A larger set of our explanatory variables had a significant association with firms' decision to grow no natives or only natives, and the proportion of natives grown.

Methodology

Protocol. Data collected in this survey are part of a national US survey of nursery and greenhouse growers conducted by a multistate regional research project of the Southern Region's Agriculture Experiment Stations (S1087). The survey is conducted every 5 years, with the most recent collection completed in 2019 and reflecting firm activity in 2018 (Khachatryan et al. 2020). Wholesale, retail, and landscape firms are identified for the survey based on their code in the North American Industry Classification System. In OUR study, we focus on the 2014 and 2019 survey responses to the sources of water used in production (surface, recaptured, reclaimed, city, or well water) and types of irrigation (overhead, drip, subsurface, or smart irrigation). Although survey data were collected before 2014, the variable of "percentage of natives sold at the firm" was not included in the questionnaire until the 2014 iteration. After survey data collection, the data were compared with IMPLAN Group LLC (Huntersville, NC,USA) regional business distribution for stratification. Thus, we are confident that the data are regionally representative of US production.

In addition, survey questions elicited information about the plant types produced, the percentage of total plant sales attributed to native plants (defined in the survey as "plants present in your state before European settlement"), and zip codes. Descriptive information about independent variables, including location of origin, may be found in Supplemental Appendix A, Supplemental Table A1. Data were collected using a mixed mode in which both online and mail survey formats were used to reach a broader sample of green industry firms. Survey procedures and methods were approved by the respective institutional review boards (Hodges et al. 2015; Khachatryan et al. 2020). Further methodology explanations can be found in the seminal articles from the survey iteration in Khachatryan et al. (2020) and Rihn et al. (2021).

In this analysis, variables related to nursery plant irrigation methods, water supply, plant form, and native plant sales were of interest. The percentage of observations for each key variable are found in Supplemental Appendix A, Supplemental Table A2. Specifically, we identified firms currently selling native plants by using the reported percentage of total plant sales in 2018 that were from native plants. Participants stated the percentage of their annual sales attributed to native plants and their estimated annual sales, from which we estimated each firm's total native plant sales. We hypothesized that firms that grow a high percentage of natives use overhead irrigation more than firms that grow a high percentage of non-native plants (they use more drip and subsurface irrigation). We also hypothesized that firms that grow a high percentage of native plants grow more containerized plant forms than any others. Native plants are a growing, emerging area of plant production in ornamental horticulture. Because these firms are willing to participate in an emerging area of production, they may also be more willing than firms that grow fewer or no natives to use new technologies such as smart irrigation. Therefore, we believe firms that grow high percentages of natives are more likely to use smart irrigation.

We used the reported zip code of each firm to calculate its regional location, to determine whether its location is urban or rural (based on the US Census Bureau 2023). This is used at the zip code level in the analysis. Because the Southwest and Pacific regions of the United States are highly drought prone, we hypothesized that these firms in these areas grow more natives because of the lower average rainfall. These firms also may be more likely to use renewable water resources such as recaptured or reclaimed water instead of surface or city water.

The data included survey responses from 2014 and 2019. We only retained responses if they were complete responses for all variables in this analysis (N = 1408; for 2019, n = 593; for 2014, n = 815). To analyze the variables, we used STATA v. 16.1 (StataCorp LLC, College Station, TX, USA).

The outcome variable is fractional and zero-one-inflated. Figure 1 shows the distribution of the dependent variable: the fraction (equivalently, percentage) of native plants sold by respondents. The average percentage of natives sold was 24%, with a standard deviation of 31 percentage points. The distribution is right skewed, with a median value of 10%. There is substantial mass at the bounds, with 20.9% of respondents reporting no natives sold and 6.6% reporting only natives sold. Respondents also clustered their responses at convenient values, largely multiples of 0.05, which presumably approximate their actual fraction of native plants sold. When discussing the details of the econometric model, we use fractions between zero and one, because this is how the models are defined. However, when discussing the results and the meaning of the values, we use the equivalent but more intuitive percentage notation.

The nature of the data presents three modeling challenges. First, the data are fractional and are bounded between zero and one (0% and 100%), which requires the regressors to have a nonlinear effect to prevent predictions outside the bounds (Villadsen and Wulff 2021). Second, for fractional data, the conditional variance must be a function of the conditional mean, creating heteroskedasticity in the data (Cook et al. 2008). Third, substantial mass at the two bounds, also

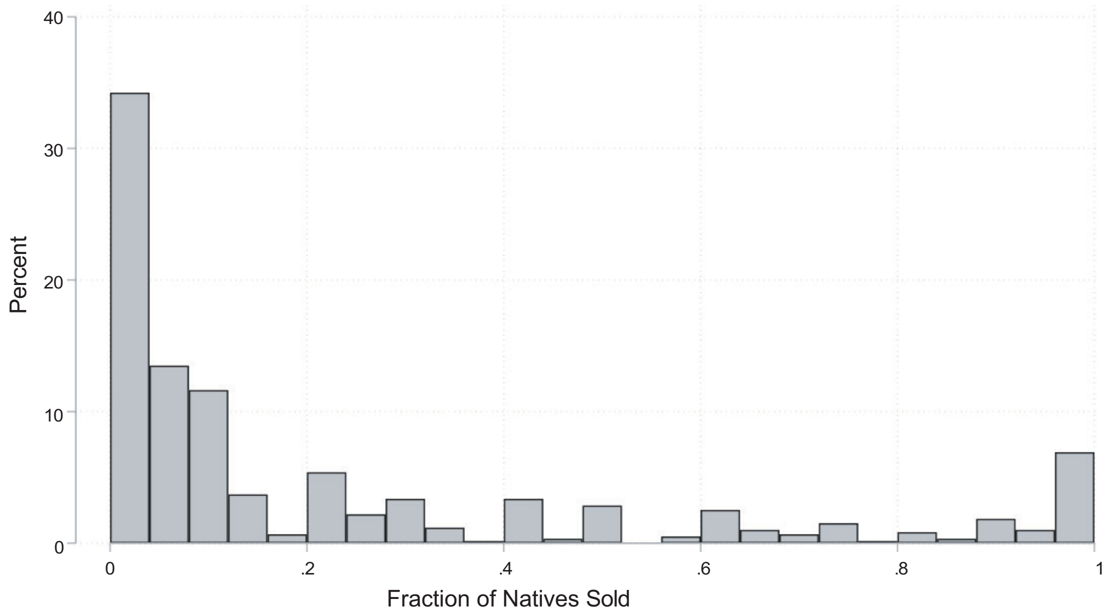

Fig. 1. The fraction of natives sold has substantial mass at zero and one.

known as zero-one inflation, may indicate that extensive margin decisions (nonzero sales of natives) are driven by considerations that are different from intensive margin decisions (the fraction of natives sold) (Wooldridge 2010). Moreover, the mass at the upper bound may indicate differences within the intensive margin between the decision making of firms that choose to sell only natives compared with those that sell an interior fraction of natives.

The econometric and statistical literature provide several approaches that account for some or all of these challenges. Our preferred model, zero-one-inflated beta (ZOIB) regression, which was chosen based on consistency with the theoretical concerns outlined earlier, is presented in the next section. As a robustness check, the model was also estimated using fractional regression (Papke and Wooldridge 1996), which has fewer structural assumptions, but is unable have separate processes governing the interior and the bounds. The comparison between models is presented in Supplemental Appendix A, Supplemental Tables A3 and A4, and Supplemental Fig. A1.

The ZOIB model. ZOIB regression overcomes all three limitations identified in the previous section by assuming the dependent variable is distributed as a mixture of a beta distribution (for interior values) and a Bernoulli distribution (for boundary values), effectively "inflating" the beta distribution with additional mass at the boundaries. First, define the beta distribution as

$$f(y;\mu,\phi) = \frac{\Gamma(\mu)}{\Gamma(\mu\phi)\Gamma[(1-\mu)\phi]} y^{\mu\phi-1}(1-y)^{(1-\mu)\phi-1},\ 0 < y < 1, \quad [1]$$

where $E(y) = \mu$ and $\text{var}(y) = \mu(1-\mu)/(1+\phi)$, "so that μ is the mean of the response variable and ϕ can be interpreted as a precision parameter in the sense that, for fixed μ, the larger the value of ϕ, the smaller the variance of y" (Ferrari and Cribari-Neto 2004, p 801). This distribution can flexibly model fractions on the unit interval, and can appear approximately normal, skewed, or bimodal, depending on the values of μ and ϕ. However, beta regression requires the dependent variable to be strictly in the interior of the unit interval, preventing it from modeling data with mass at the boundaries, regardless of whether the boundary data are assumed to derive from the same process as the interior data or from a different process (Papke and Wooldridge 1996). Unlike the beta distribution, the ZOIB mixture distribution is defined on the full unit interval and allows separate processes to generate boundary and interior observations. Following Ospina and Ferrari (2010), the distribution of the ZOIB mixture is given by

$$BEINF(y;\ \alpha,\ \gamma,\ \mu,\ \phi) = \begin{cases} = \alpha(1-\gamma) & \text{if } y = 0 \\ = (1-\alpha)f(y;\mu,\phi) & \text{if } 0 < y < 1, \\ = \alpha\gamma & \text{if } y = 1 \end{cases} \quad [2]$$

with $0 < \alpha, \gamma, \mu < 1$ and $\phi > 0$, where $f(y; \mu, \phi)$ is the beta density function defined in Eq. (1), and γ is the parameter of the Bernoulli distribution. The mixture parameter, α, represents the probability that an observation occurs at a boundary, so $P(y = 0) = \alpha(1-\gamma)$ and $P(y = 1) = \alpha\gamma$.

Results and Discussion

Summary statistics. Table 1 displays the means and standard deviations of firm variables, which include the percentage of total plant sales attributed to native plants, sources of water (surface water, recaptured water, reclaimed water, city water, and well water), types of irrigation (overhead irrigation, drip irrigation, and subsurface irrigation), use of smart irrigation, and forms of plants produced (container grown, balled and burlapped, field bag, bare root, balled and potted, in-ground container, or other product forms), region of the United States in which the firm is located (Appalachia, Great Plains, Midwest, Mountain, Northeast, Southeast, Pacific, or South–Central), the 10-year average annual rainfall across zip codes, population density of firm location (urban/rural), annual sales (in USD), and year of survey collection (2014 or 2019).

Native plant sales averaged 23.22% of total plant sales across the sample. Well water was the most common water source (55.68%), followed by city water (21.87%), surface water (17.56%), recaptured water (3.91%), and reclaimed water (0.89%). The most popular type of irrigation system used was overhead (53.23%), followed by drip irrigation (22.49%), other irrigation (17.82%), and subsurface irrigation (2.19%). Approximately 17% of the sample used smart irrigation systems. Other irrigation systems included hand-watering, capillary mats, foggers or mist, mobile booms, or no irrigation. Approximately 70% of product forms produced by the sample firms were container grown. Balled and burlapped products were the second-most produced (11%), followed by other product forms (7.16%), bare root (6.91%), in-ground container (1.55%), field bag (0.98%), and balled and potted products (0.75%). Other product forms included aquaculture, cut flowers, cut trees, bulbs, and cut foliage.

Fourteen percent of the sample was located in the Appalachian region of the United States. Three percent of the sample firms were in the Great Plains region, whereas 18% were in the Midwest. Four percent were in the Mountain region. Twenty-one percent of the sample firms were in the Northeast and 22% of the firms were in the Southeast United States. Ten percent of the firms were in the Pacific region and 8% were in the South–Central region. The 10-year average

Table 1. Summary of variables within the model, including natives, water sources, irrigation types, plant forms, annual sales estimate, and geographic locations in the United States.

Variable	Mean	Standard deviation
Natives (%)	23.22	31.27
Water source (%)		
Surface	17.56	34.05
Recaptured	3.91	15.01
Reclaimed	0.89	7.43
City	21.87	39.28
Well	55.68	46.26
Irrigation type		
Overhead (%)	53.23	41.88
Drip (%)	22.49	32.82
Subsurface (%)	2.19	12.06
Other (%)	17.82	35.56
Smart (=1)	0.17	0.37
Plant form (%)		
Containerized	70.55	38.83
Balled and burlapped	11.00	25.38
Field bag	0.98	7.99
Bare root	6.91	21.95
Balled and potted	0.75	6.19
In-ground container	1.55	9.35
Other product form	7.16	23.29
Geography		
Appalachia (=1)	0.14	0.34
Great Plains (=1)	0.03	0.17
Midwest (=1)	0.18	0.39
Mountain (=1)	0.04	0.20
Northeast (=1)	0.21	0.41
Southeast (=1)	0.22	0.42
Pacific (=1)	0.10	0.30
South-Central (=1)	0.08	0.27
10-Year avg. rainfall (inch)	3.85	1.40
Urban (=1)	0.44	0.50
Annual sales (USD, est.)	1,790,000	6,120,000
Year		
2019 (=1)	0.42	0.49

est. = estimated; USD = US dollars.

annual rainfall was 3.85 inches across all zip codes in the sample. Forty-four percent of the sample was in a Metropolitan area. The average annual sales across firms in the sample was USD1,790,000. Forty-two percent of the sample was collected in 2019; 58% was collected in 2014. For all independent variables included in the model, we calculated the variance inflation factor (VIF). The factors varied from 1.05 to 3.42. We did not find evidence of multicollinearity in the explanatory variables, because all VIF values were less than the usual threshold of 10 (Chatterjee and Hadi 2006).

Marginal effects of the ZOIB model and its components. Table 2 reports the average marginal effects for the ZOIB model and each of its components. This is calculated in two steps. First, the marginal effect of increasing variable *xj* on the fraction of sales that is native for all observations is calculated, then

Table 2. Average marginal effects of the zero-one-inflated beta (ZOIB) model and its components, including water source, irrigation type, plant forms, annual sales estimate, and geographic location in the United States by 0% natives grown [$P(y = 0)$], 100% natives grown [($P(y = 1)$], and between 1% and 99% of natives grown [$E(y|0 < y < 1)$].

Components	ZOIB value dy/dx (*SE*)	$E(y/0 < y < 1)$ dy/dx (*SE*)	$P(y = 0)$ dy/dx (*SE*)	$P(y = 1)$ dy/dx (*SE*)
Water source (%)				
Surface	0.043 (0.023)*	0.118 (0.104)	–0.003 (0.223)	0.559 (0.300)*
Recaptured	–0.114 (0.080)	0.120 (0.208)	–0.278 (0.554)	–2.986 (1.485)**
Reclaimed	0.098 (0.082)	0.621 (0.462)	0.364 (1.029)	0.678 (0.804)
City	–0.022 (0.022)	–0.101 (0.077)	0.099 (0.186)	–0.064 (0.356)
Irrigation type				
Overhead (%)	0.004 (0.022)	–0.070 (0.089)	0.033 (0.199)	0.320 (0.342)
Drip (%)	0.025 (0.030)	0.155 (0.118)	0.156 (0.266)	0.249 (0.450)
Subsurface (%)	0.124 (0.055)**	0.143 (0.248)	–0.260 (0.656)	1.875 (0.684)***
Smart (=1)	0.053 (0.023)**	0.236 (0.083)***	–0.121 (0.190)	0.302 (0.290)
Plant form (%)				
Containerized	0.003 (0.030)	0.061 (0.161)	–0.982 (0.254)***	–1.170 (0.365)***

E is expected value, *P* is probability, and *y* is the random variable, listed as components in the right-hand column of the table. dy/dx is the marginal effect value, and *SE* is standard error.

* Signifies statistical significance at the $P < 0.05$ level, ** signifies statistical significance at the $P < 0.01$ level, and *** signifies statistical significance at the $P < 0.001$ level.

the average of all these marginal effects is calculated. These effects and their 95% confidence intervals are displayed graphically in Supplemental Fig. A2. The ZOIB model has three components: the expected fraction of natives sold conditional on selling an interior, nonboundary quantity of natives (column 2, Supplemental Fig. A2); the probability that a firm sells 0% natives (column 3, Supplemental Fig. A2); and the probability that a firm sells 100% natives (column 4, Supplemental Fig. A2). The total average effect, which is the weighted sum of the three components, is reported in column 1 of Supplemental Fig. A2.

For the categorical variables in the regression, the variables of well water, other irrigation, other plant form, and location in the South–Central region were omitted from the analysis as the base variables. Percentage variables were rescaled as fractions [i.e., variables reported from 0% to 100% became fractions (0–1)]. The coefficients for the model are reported in Supplemental Table A3 in Appendix A.

The variables with coefficients exhibiting a *P* value of 0.05 or less are described here. A 1 percentage point increase in a firm's use of subsurface irrigation increased the percentage of native plant sales, on average, by 0.12 percentage point. The use of a smart irrigation system increased the percentage of native plants sold by 5.3 percentage points. Observing a firm selling 1 percentage point more balled and burlapped products increased their predicted percentage of native plant sales by 0.13 percentage point. Last, doubling total sales decreased the predicted percentage of native plant sales by 1.4 percentage points. Although the geographic variables had no significant effect on the unconditional prediction of native plant sales, several of these variables had a significant association with the predicted percentage of native plant sales, conditional on the firm selling a nonboundary fraction of native plant.

Conditional on a firm selling a nonboundary fraction of native plants, using a smart irrigation system increased the percentage of native plant sales by 23.6 percentage points, and a 1 percentage point increase in balled and burlapped products grown increased native sales by 0.502 percentage point. A location in the Great Plains region of the United States decreased the expected, nonboundary percentage of native sales by the firm by 41.6 percentage points, whereas a location in the Mountain, Northeast, or Pacific region decreased native sales by 56.2, 30.3, and 55.6 percentage points, respectively, relative to the baseline South–Central region. A location in a metro–urban area increased the expected, nonboundary percentage of native sales by 16.7 percentage points. Each doubling of firms' sales decreased the nonboundary native sales by 5.5 percentage points.

Among the independent variables, only product form affects the probability that firms produce 0% natives. Growing container-grown, balled and burlapped, and in-ground container products decreased significantly the probability of selling no natives, with a 1 percentage point increase in sales of these forms decreasing the probability of growing zero natives by 0.982, 2.635, and 2.909 percentage points, respectively. More diverse variables affect the probability that firms produce 100% native plants. For example, a 1 percentage point increase in use of recaptured water reduced the probability that a firm would sell 100% natives by 2.986 percentage points, whereas using subsurface irrigation increased this probability by 1.875 percentage points. A 1 percentage point increase in container-grown or balled and burlapped products grown reduced by 1.170 and 1.636 percentage points, respectively, the probability that a firm would sell 100% natives, whereas a 1 percentage point increase in growing balled and potted products increased this probability by 2.194 percentage points. Last, each doubling of total sales reduced by 18.5 percentage points the probability that a firm would sell 100% native plants.

Growing container-grown, balled and burlapped, and in-ground container products had a negative effect on the probability of no native plant sales. In layperson's terms, this means that firms that grow more plants in these product forms are more likely to grow some natives. Although the effects of product form on the probability of no native sales is small in magnitude, it is worth noting that most of horticulture production is accomplished within the product forms of container-grown (70.55%) and balled and burlapped (11.00%) plants. This may give researchers and stakeholders insight into the product categories in which native plants are most likely sold: container-grown, balled and burlapped, and in-ground container plants. This information can be used to influence policy (as governmental agencies in Delaware, New Jersey, North Carolina, and other states create legislation around native plant use in landscapes) as well as to inform industry associations about production practices of industry members.

Our results indicate that the water source used by firms generally has little effect on the proportion of native plants they sell. Firms often have limited choices in their available water sources, meaning their total water use or water efficiency may not correlate directly with the type of water source chosen. However, one notable and surprising exception was recaptured water, which was associated with a significant decrease in the likelihood of firms growing exclusively native plants. Recaptured water, collected after initial irrigation and treated to remove fertilizer residues before reuse, is an efficient source that reduces overall water consumption and financial costs associated with pumping from wells or surface water. One possible explanation for this finding is that native plants, already perceived as requiring less water, might make the additional savings provided by recaptured water seem unnecessary.

In contrast, the method of irrigation used had a greater association with native plant production. Specifically, subsurface irrigation and smart irrigation systems both affect positively the proportion of native plants grown. Firms using smart irrigation systems grew nearly 25 percentage points more native plants on average compared with firms that did not use these systems, although this does not influence the likelihood of a firm growing exclusively native or non-native plants. This aligns with common horticultural beliefs that native plants typically require less water input than non-native species (Cavaleri and Sack 2010; Shapiro et al. 2015; Shelef et al. 2017). In addition, firms growing native plants might be more open to adopting new technologies and expanding their product lines, reflecting a greater willingness to undertake financial risk associated with innovative approaches such as smart irrigation.

Nevertheless, the overall relationship between irrigation efficiency and native plant sales remains complex. Although subsurface, drip, and smart irrigation all provide precise and conservative water application, only subsurface and smart irrigation methods were associated with an increase in native plant production, whereas drip irrigation showed no significant effect. This might suggest that non-native plants, often requiring greater water input, benefit more clearly from irrigation methods that minimize water waste through precision application. Given these mixed findings, further research is necessary to clarify firms' irrigation decisions relative to native plant sales. Policy encouraging smart irrigation use appears promising for promoting native plant production, whereas regulating irrigation methods alone is unlikely to influence growers' native plant production decisions substantially. Consequently, policymakers should be cautious in focusing regulatory efforts solely on irrigation methods as a means of increasing native plant production.

Drought conditions and water restrictions in the Pacific region of the United States led us to expect that firms in the Pacific region would participate more in native plant production, which was not observed in our data application. In addition, the 10-year average rainfall, which reflects drought effects seen in regions across the United States, did not affect the percentage of native sales when included in the model. Therefore, it very well may be that the firms in the Pacific region are growing a lower percentage of natives not because of a lack of regionally available water, but as a result of other causes. These causes could potentially include policy changes, social pressure, consumer demand, or intrinsic grower choices. These potential causes were not observed in the context of our analysis and therefore cannot be concluded decisively.

Firms located in an urban area, defined here as having a zip code within the US Census Top 20 Metropolitan Areas list (US Census Bureau 2023), exhibited no difference in the overall fraction of native plant sales compared with rural firms. However, among firms selling some native plants, their location within an urban region was associated with a large, 16.2 percentage point increase in native plant sales relative to their rural counterparts. This is consistent with urban consumers having a greater interest in native plants and proenvironmental attitudes compared with rural consumers (Rihn et al. 2023).

The year of survey data collection did not affect native plant sales, which may suggest that native plant sales in the US horticulture industry are at a plateau, or at least that the industry is not selling a larger fraction of native plants as it grows. Moreover, for every doubling of total plant sales by firms, the percentage of sales that was native declined by 1.4 percentage points. This unconditional effect was driven by two margins. For firms selling an intermediate fraction of native plants, a doubling of firm size was associated with a 5.5 percentage point decline in the percentage of sales that were native. Much larger was the effect on firms selling only native plants, with a doubling of firm size associated with a 18.5 percentage point reduction in the probability that a firm would sell only native plants, indicating that, all else being equal, smaller firms are much more likely to specialize in native plant production compared with larger firms.

Native plants accounted for 9.1% of ornamental horticulture output in an analysis by Khachatryan et al. (2020), but 23.22% in our sample. The observed difference may be the result, in part, of the definition of a native plant and/or how each company chooses to characterize plants as natives. For example, *Cersis canadensis* L. is native to most of the US Midwest and Southeast (Dickson 2023), but cultivars such as 'Carolina Sweetheart'® or 'Flame Thrower'® are not considered native redbuds because of their hybridized nature and/or clonal method of propagation. In other words, a nursery selling redbud cultivars may report selling some redbuds (e.g., balled and burlapped flowering trees), but may not indicate they are selling native plants.

Conclusion

The 2019 Census of Horticulture reported that the wholesale market for nursery plants totaled USD4.545 billion in sales, of which 68.3% were of container-grown products (National Agricultural Statistics Service, US Department of Agriculture 2019). These figures are consistent with our study, in which 70% of native plant products were container-grown (plus 1.55% in-ground containers). In other words, nurseries do not appear to alter their production system for native plant production. Most container forms appear to have little impact on the percentage of natives sold by firms. The exception is the balled and burlapped product form, where a 1 percentage point increase in sales of this product type was associated with an average 0.13 percentage point increase in native sales. This may indicate that a larger proportion of trees and shrubs sold by firms are native, compared with the average product type sold by firms. For smaller nurseries, not needing to develop or incorporate new production systems for native plants (e.g., balled and potted) is a great advantage to a firm that wishes to produce native plants for the first time or that seeks to expand its product offerings. Fitting native plant production into containers sets the commercial nursery up for more rapid success in native plant production.

Nursery production firms are not equally distributed across the United States For example, employment in the production of nursery plants is greatest in the Midwest (Hall et al. 2020). According to the same source, the output of all nursery wholesale firms increased by 17% from 2013 to 2018. White et al. (2018) noted that native species are limited regionally, and we also found regional differences, with the greatest native plant sales in the Southeast to only 3% native plant sales in the Great Plains. Perhaps geography could influence the adoption of more water-saving irrigation systems. The relationship between geography and the adoption of smart water, or water-saving, irrigation systems has yet to be explored.

Firms may also consider focusing on the state-centric definition of native plants rather than the national-centric definition of natives. As shown in our results, if a firm is growing some natives (more than zero but less than 100), they tend to sell a high fraction of natives. Firms might be focusing on the state-centric definition of natives used in the survey, rather than a US-centric definition. This difference may be the result of regional differences in cultivars, as indicated in the discussion regarding redbud varieties and cultivars.

Because many native plants may require less water (Bijoor et al. 2008; Morris and Bagby 2008; Vickers 2006), we sought to investigate water source and irrigation methods in relation to native plant production. White et al. (2019) found that 45% of nursery producers reported using surface water for irrigation whereas 40% used well water, and that some operations used multiple water sources. In our study, water source use varied from minimal use ($< 1\%$) of reclaimed water to $\geq$ 50% use of well water. The use of surface water was third, after city water, and much less than the percentage found by White et al. (2019). The difference in findings may reflect the location of nurseries included in both samples and the water source options that were available to them, rather than a desire to use one source over another. In other words, the nurseries may not have had a choice of water source, consistent with water source having little to no influence on the percentage of native plant sales.

The method of irrigation affected the largest increase in native plant sales. Wheeler et al. (2020) reported a 50% reduction in the volume of water applied during irrigation with the use of sensor-based (smart) irrigation systems. Our results show that the use of smart irrigation systems favors native plant production because it not only enhanced the overall share of native plants sold by 5.3 percentage points, but also the share of native plants sold by firms selling an intermediate fraction of natives by almost 25 percentage points. Similarly, although subsurface irrigation systems were used by only 2% of the firms in our study, their use likewise increased native plant sales, even more than the use of smart irrigation systems. Clearly, more precise application of irrigation, as found in subsurface and smart irrigation systems, favors native plant production. On the other hand, drip irrigation—another efficient irrigation method—had no measurable association with the fraction of natives sold. This may reflect the more widespread adoption of drip (22% of respondents) relative to subsurface (2.19%) and smart (0.17%) irrigation. Moreover, firms may choose irrigation systems for reasons unrelated to water conservation, such as ease of maintenance or cost.

Water concerns are increasing among nursery and greenhouse producers, especially those related to water management and sources of water that producers use, with ~3% of total production costs related to water (White et al. 2019). Studies consistently report reduced water input during the production of native plants, which themselves may provide consumers with options more aligned with the support of ecosystem services benefits provided by many native plant species. Perhaps policymakers and extension specialists can facilitate the adoption of native plant production in the future through the encouragement of adopting smart irrigation systems. The presence of smart irrigation systems was associated with native plant production, and these irrigation systems can be integrated into production systems feasibly with taxation relief or other economic incentives. Extension personnel can help connect current innovative production facilities with growers considering the adoption of smart irrigation systems if they are interested.

Smaller firms, by nature, are more flexible and adapt to change faster compared with large, well-established firms. We found that smaller firms were more likely to sell native plants. Building on the discussion for extension personnel to encourage the adoption of smart irrigation, smaller firms might be persuaded more easily to begin selling native plant species or to increase their native plant sales offerings. Trialing both smart irrigation systems and native plant production could produce some examples of success that might be highlighted in extension seminars and publications.

A limitation of this publication is that the term "native plant" was not predefined for the participants. However, the term "native" varies across states and in levels of legislation. Thus, there may be ambiguity in this term that may have influenced how producers answered.

Consumer education regarding the reduced water inputs needed by many native plants could spur demand from the market side. Water conservation benefits producers and consumers. The adoption of native plants in commercial and residential landscapes could contribute to reduced water needs, especially in drought-prone regions. Consumers, the environment, and the producers who choose to grow native plants all benefit from native plant production. How firm size and sales growth influence native plant production merits further investigation, because it remains unexplained why the percentage of sales attributed to native plants decreased as firm size increased.

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