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Survey of Pesticide Application Practices and Technologies in Georgia Agricultural Crops

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Abstract.

Pesticide regulations and application technologies are changing rapidly due to growing concerns around off-target movement and increased focus on improving the efficiency of pesticide applications. To develop appropriate research and extension efforts, a survey to assess utilization of pesticide application technologies and common practices among growers in Georgia, USA was conducted in 2021. An online survey was created in Qualtrics and distributed among the growers across the state via Extension agents. Few of the major findings from the survey were as follows: 1) 29% of respondents received their information from University Extension; 2) 42% of respondents used a separate sprayer for applying restrictive pesticides such as dicamba or 2,4-D; 3) 65% of respondents spray volumes of ≥ 121 L/ha to apply pesticides; 4) 53% of respondents used 3 or more different nozzles on their spray booms throughout the season; 5) 65% of respondents used GPS and rate controllers on their application equipment; 6) 66% of respondents recorded their pesticide application records on a notepad or diary; and 7) 39% of respondents reported that accuracy is the biggest advantage of new spray technologies. The survey respondents also reported that weather, timing, and pesticide drift/regulations were their biggest application challenges whereas product rates, carrier volumes, pest control (weeds/insects/disease), chemicals and adjuvants (type and mixing order) were the listed in the interest areas for research. The information from this survey provided useful insights into the current application practices, technologies, and research needs of Georgia growers and will be utilized for development of appropriate research and extension programs to address the aforementioned needs as well as to improve adoption and utilization of precision application technologies among the growers.

Keywords.
Pesticides, application equipment, technology, precision agriculture, extension education

Introduction

Safe and efficient pesticide applications are important due to potential adverse human and environmental effects associated with inefficient use of pesticides. Increased concerns around off-target movement of pesticides (EPA 2017) have also prompted efforts to re-evaluate application practices (Foster et al. 2018) as well as to develop technologies to improve application accuracy and efficiency (Alves et al. 2017; Kudsk 2017). Application errors while applying pesticides common (Luck et al. 2011), which are dependent on several factors including selection of nozzle size or type, spray volume, spray pressure, ground speed, and boom height (Knoche Nuyttens et al. 2007; Meyer et al. 2016). Misapplication can further occur in various different forms including incorrect tank mix, insufficient or higher than target spray volume, physical movement of spray particles due to excessive wind or temperature inversions, application in undesired or no spray areas, and improper sprayer cleanout. Whether unintentional or not, the consequences of pesticide misapplications are very detrimental to both crops and the environment.

To improve pesticide application accuracy and efficiency, adoption and utilization of different precision application technologies has also increased considerably over the last decade. Basic spray technologies - global positioning system (GPS), rate controller and section control – have shown to significantly reduce the over-application of pesticides (Luck et al. 2010, Sharda et al. 2011; Sharda et al. 2013), and these technology benefits are maximized in large and uneven shaped fields (Edge et al. 2018). Today, new application technologies such as pulse-width modulation (PWM) and auto-boom height systems are available for spray equipment to further improve field and application efficiency. PWM equipped sprayers help to maintain a constant pressure and droplet size across a range of ground speeds (Butts and Kruger, 2018). Auto-boom height technology provides a better spray uniformity and coverage by maintaining a consistent boom height from crop/soil across a field (Sharda et al. 2016).

Agriculture in Georgia contribute billions of dollars annually to the state's economy. Georgia is a top producer of many crops including peanut (*Arachis hypogaea L.*), cotton (*Gossypium hirsutum L.*), tobacco (*Nicotiana tabacum*), blueberries (*Vaccinium sect. Cyanococcus*) and peaches (*Prunus persica*) in the United States (USDA-NASS, 2020). Peanut, cotton and field corn (*Zea mays L.*) are the major agronomic crops grown in Georgia and collectively account for 10% of the total agricultural production in the state. For growers, pesticide applications are important for sustaining the production of these agricultural crops. According to a recent chemical use surveys, pesticides were applied to more than 93% of the total planted acres in peanut, cotton and field corn in the United States (USDA-NASS, 2020). In all these row-crops, herbicides were the most extensively used pesticides (applied to more than 90% of the planted acres) followed by fungicides and insecticides. Pesticide applications also represent a major portion of farm production costs where agricultural chemicals accounts for 4.5% ($16.5 billion) of the total farm production expenditures in the United States (USDA-NASS, 2021).

Pesticide application practices and technology adoption can vary considerably among the growers from one state to the other, depending on the demographics and agronomic crops grown in each state. Recently, several consultant and pesticide applicator surveys have been conducted in few different states (Missouri – Bish and Bradley, 2017; Arkansas – Butts et al. 2021) which highlighted the need for more research on pesticide application practices and techniques as well as to better understand the local/regional needs in order to develop and implement appropriate educational programs for effective and precise pesticide applications. Currently, the baseline knowledge on prevalent pesticide application practices and technology adoption among the growers in Georgia is limited. Therefore, the objective of this survey was to determine the common pesticide application practices and technologies used in Georgia agricultural crops. A thorough understanding of common practices, equipment and technologies used by growers would help in provide recommendations specific to the pesticide application practices, conduct applicable application research to address grower needs, and develop necessary extension efforts to educate growers on using management practices and technologies for making more efficient pesticide applications.

Materials and Methods

A survey to assess the common pesticide application practices and technologies was created in spring 2021 using the Qualtrics survey platforms (Qualtrics, Provo, UT). The survey included a total of 22 questions and was divided into five different sections with each section consisting of several single- and multiple-choice questions. The first section included demographic and other basic information while the second section was focused on information specific to the prevalent (regular or specialty) spray equipment used by the growers. The third section was intended to gather information on common application parameters including ground speed, boom height, spray pressure and droplet size used by the growers for applying pesticides. The fourth section was aimed at determining the use of spray technology such as GPS and rate controller, pulse width modulation (PWM), direct injection, auto-boom height, and the preferred method for logging pesticide records by the growers. The final section consisted of two open-ended questions to identify the respondent views on the benefits of application technologies, pesticide application challenges, and research needs in pesticide applications in the future. Surveys were distributed among the growers by county agents by sending a direct survey link to the growers via email and/or text message, and also at various face-to-face grower meetings in their respective counties. All survey data collected in both online and printed survey were recorded into the online Qualtrics platform and was imported into Microsoft Excel (Microsoft Office 2019, Redmond, WA) for further analysis.

Results

A total of 186 survey responses were recorded where approximately half of these surveys were completed directly in the online Qualtrics platform by the respondents and the other half represented the printed surveys filled out by the growers at various face-to-face county meetings. These growers represented 65 different counties in Georgia and represented counties in the southeast, southcentral and southwest region of the state representing most of the primary agricultural crops (corn, cotton, peanut, soybean, pecan, blueberries) grown in the state. One of the survey questions asked about the preferred means of receiving latest information on pesticide application practices and technologies. Respondents were allowed to select all applicable choices as listed in Table 1 below. A total of 514 observations were recorded for this question and results indicated that university Extension was the most preferred way (29%) of receiving new information related to pesticide application and technology followed by agriculture industry and consultant/salesperson (24% and 23%, respectively).

Table 1. Preferred method of receiving pesticide application and technology information as reported by growers in Georgia.

Preferred method of receiving information	% of respondents
Agriculture Industry	24
Consultant/Salesperson	23
University Extension	29
Internet/Digital Media	12
Printed Material	11
Other	2

Application Equipment and Parameters

Due to diverse agricultural crops grown in Georgia, many different types of spray equipment for applying pesticides are common in the state. As application practices can differ among the sprayer types, growers were asked about the number and the type of sprayers used on the farm each year for pesticide applications. Of the 185 responses received for this question, approximately 44% of the respondents indicated using two sprayers for pesticide applications on the farm while the 22% indicated using three or more sprayers for pesticide applications on their farm (Fig. 1a). Further, self-propelled and three-point hitch sprayers were selected as the most common sprayer types (45% and 38%, respectively) used by the respondents for pesticide applications on their farms (Fig. 1b). These results were somewhat expected as these are the two most common sprayer types used for pesticide applications in row-crops.

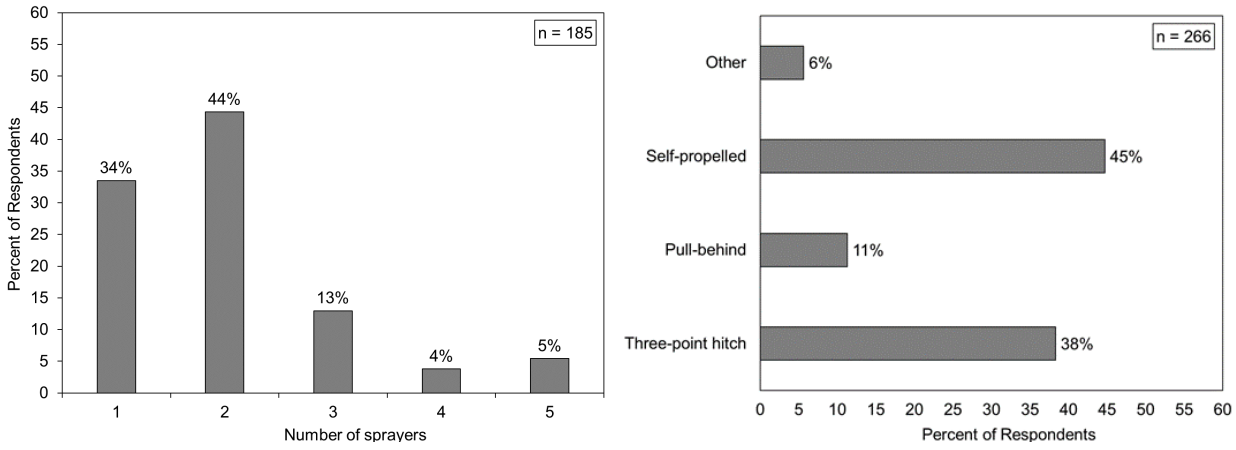

Fig. 1 (a) Number of sprayers, and (b) sprayer type used on the farm by the survey respondents in Georgia. Multiple responses were allowed for the information presented in Fig. 3(b).

Georgia growers rely extensively on use of auxin herbicides such as dicamba and 2,4-D for weed control in cotton production systems. Additionally, peanut is grown as an important rotational crop with cotton in Georgi and to avoid any potential tank contamination issues, some growers prefer to use a separate sprayer – one for cotton and another for peanut – for all pesticide applications throughout the season. Forty two percent of the respondents suggested that they use a separate sprayer for applying dicamba, 2,4-D or 2,4-DB on their farm (Table 2). To mitigate spray drift concerns from auxin herbicides, use of in-row or broadcast hooded sprayers during pesticide applications is recommended as one of the application practices that can considerably reduce the drift of spray particles to short distances downwind. In response to a question about use of a hooded sprayer, only 16% of the survey respondents indicated using a hooded sprayer for restrictive pesticide applications on their farm.

Table 2. Use of a separate or hooded sprayer for restrictive pesticide applications as reported by the respondents in Georgia in a 2021 survey.

Survey Question	% of respondents	
	Yes	No
Do you use a separate sprayer for applying dicamba, 2,4-D or 2,4-DB?	42	58
Do you use a hooded sprayer for any restrictive pesticide applications? (e.g. for applying dicamba or 2,4-D)	16	84

Nozzle selection is considered an important parameter for pesticide application as it can influence both spray coverage and product efficacy. A survey question asked growers about the number of nozzles typically used in a growing season and the type of nozzles used on the spray equipment. Out of the 181 growers who answered this question, nearly 74% of the respondents indicated using two or three different nozzle types in a growing season for pesticide applications (Fig. 2a). Sixteen percent of the respondents suggested using only one nozzle while 10% of the respondents indicated using four or more nozzles for pesticide applications within a single growing season. These results suggested that most growers are aware about the importance of correct nozzle selection to maximize the pesticide efficacy, and either spend time changing nozzles or utilize multi-nozzle bodies that can make switching between nozzles relatively easier and quicker during the season. For nozzle types used by the growers, nozzles manufactured by TeeJet® Technologies (TeeJet Technologies, Springfield, IL) were most commonly used followed by Hypro (Pentair, Minneapolis, MN), GreenLeaf (Greenleaf Technologies, Covington, LA) and Wilger (Wilger Industries Ltd, Saskatoon, SK, Canada) (Fig. 2b).

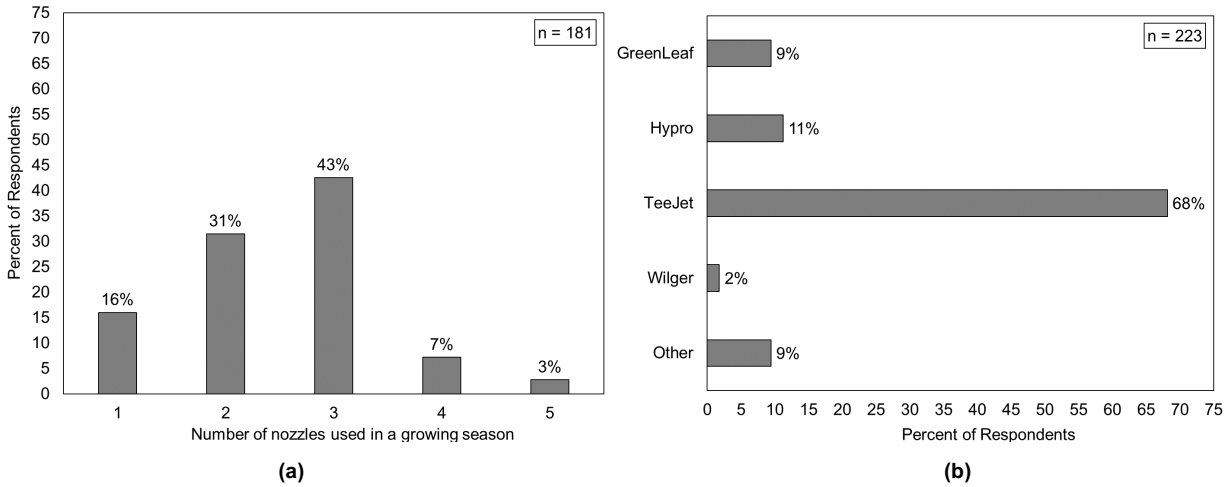

Fig. 2 (a) Number of nozzles used in a growing season, and (b) nozzle type/manufacturer used by the survey respondents in Georgia. Percentages may not total 100% due to rounding.

With the availability of larger spray equipment, there is also an increasing trend towards higher application speeds to cover more hectares quickly. While a higher application speed does improve field efficiency, it could also decrease application efficiency by reducing coverage and by increasing the potential for off-target movement of spray particles. Survey results indicated that 85% of the respondents apply pesticides at ground speeds of ≤16.1 kph while only 1% of the survey respondents indicated making pesticide applications above 24.1 kph (Fig. 3a). Height of the spray boom is another application parameter which can affect both application uniformity and spray drift. Thirty percent of the respondents suggested using a boom height of less than or equal to 50.8 cm while 56% of the respondents indicated using a boom height between 50.9 and 76.2 cm for pesticide applications (Fig. 3b). Only 15% of the survey respondents suggested using boom heights greater than 76.2 cm from the crop or soil surface.

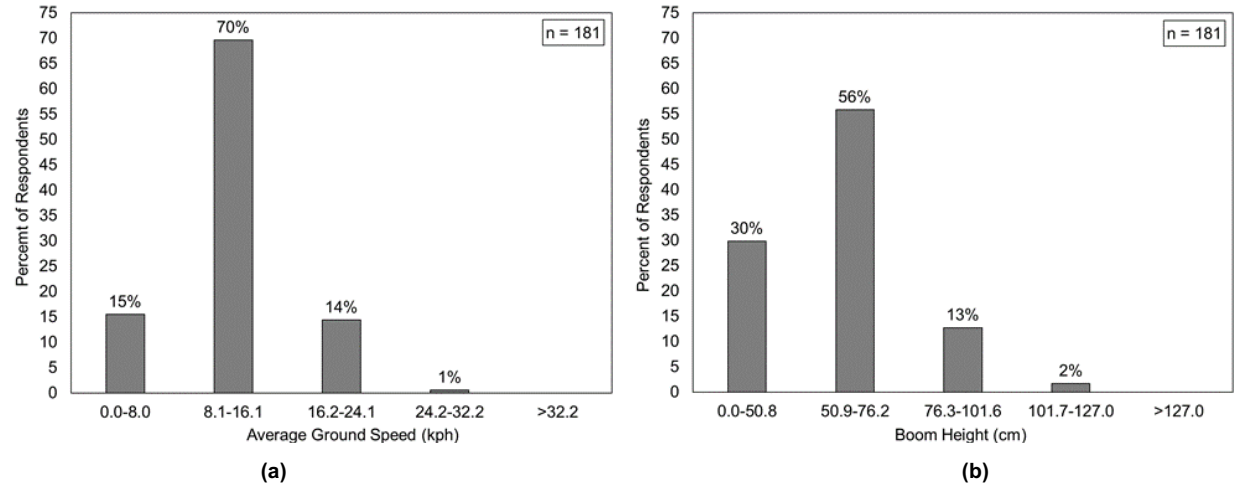

Fig. 3 (a) Average ground speed and (b) boom height for pesticide applications in Georgia as reported by the survey respondents. Percentages may not total 100% due to rounding.

Since general application practices or selection of spray parameters can differ between the type of pesticides, questions about the other application parameters (spray volume, nozzle size, spray pressure and droplet size) were asked specifically for herbicides, fungicides and insecticides used by the respondents. Survey results indicated that spray volumes between 95 and 140 L ha^{-1} were commonly used by the growers for most of the pesticides (Fig. 4a). Approximately 40-45% of the respondents indicated using spray volumes of 113 to 140 L ha^{-1} for applying herbicides and fungicides, while the spray volumes of 95 to 114 L ha^{-1} was more common for insecticide applications. For nozzle size/color, majority of the respondents indicated using a size 03 (blue) or 04 (red) nozzles regardless of the pesticide type (Fig. 4b). An interesting observation regarding nozzle size was that nearly 10 to 15% of the respondents were unsure about the size/color of the

nozzle they typically use for pesticide applications on their farm. This was concerning as information on nozzle type and size is considered critical for making accurate and efficient pesticide applications

Another important application parameter is spray pressure as it affects volume and droplet size. Approximately 32-35% of the growers reported using higher pressures (>277 kPa) when applying these pesticides (Fig. 4c). Droplet size is another important spray parameter as smaller droplets can provide better coverage and efficacy but are more susceptible to spray drift. When asked about the droplet size, nearly 50-54% of the respondents indicated using fine or medium droplets for applying fungicides and insecticides, and around 28% respondents indicated using them for applying herbicides (Fig. 4d). Similarly, larger droplets (coarse to ultra coarse) were more commonly used (about 51%) by the respondents for applying herbicides mostly to reduce the potential of spray drift. As noted with the nozzle size/color results, about 12-16% of the respondents again were unsure about the droplet size used for pesticide applications on their farm. Overall, these results imply that most growers in Georgia are aware about the importance of selecting correct application parameters – spray volume, nozzle size and type, spray pressure, and droplet size – specific to the type of pesticide for maximizing product efficiency and efficacy while also understanding the implications of off-target applications on crops and environment. However, the lack of knowledge on nozzle type and/or droplet size among some respondents, regardless of the sprayer type and crop, also suggests the need to continue educational efforts to increase the awareness about selection and utilization of optimal application parameters for making safe and effective herbicide applications.

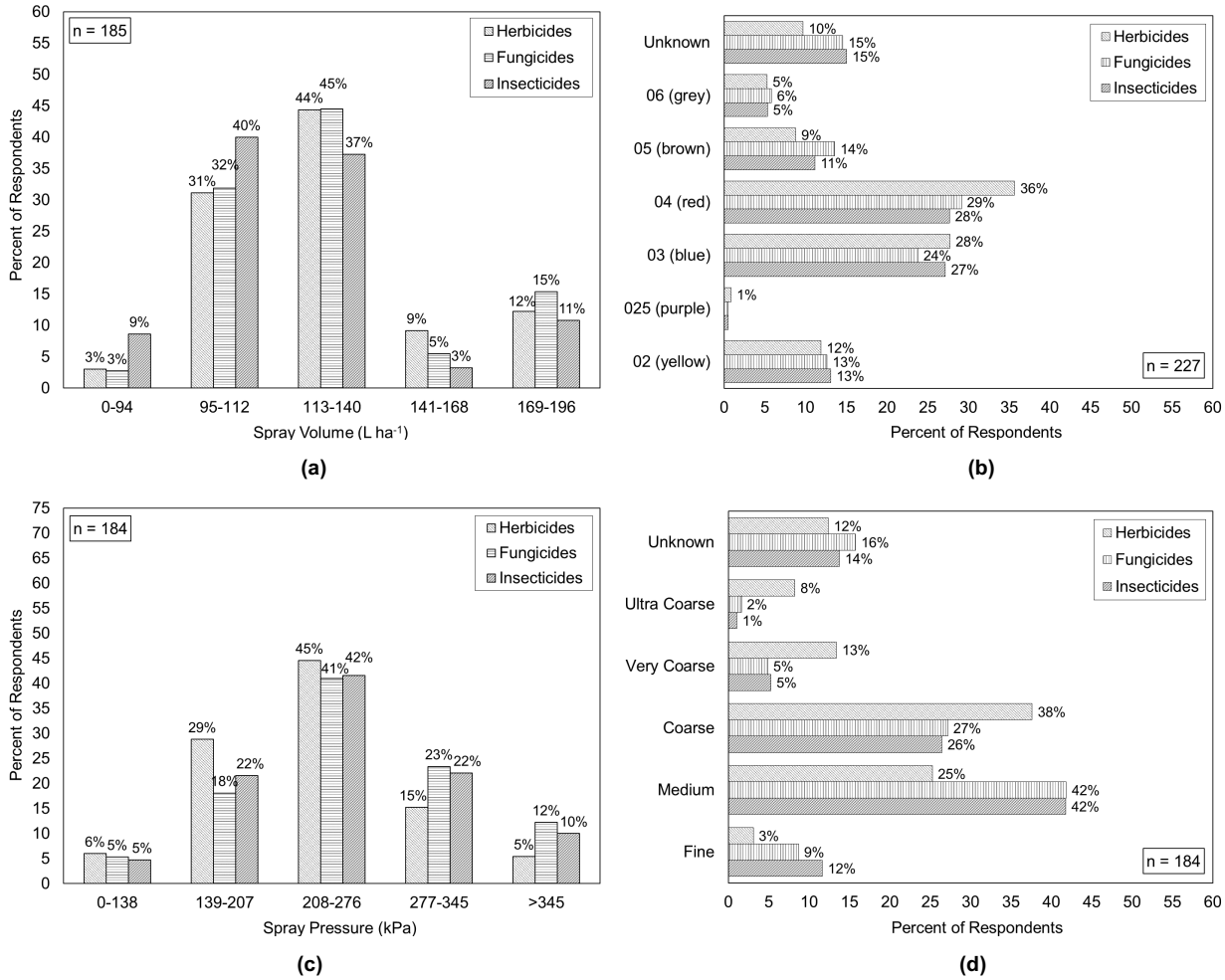

Fig. 4 (a) Spray volume, (b) nozzle size/color, (c) spray pressure and (d) droplet size used for pesticide applications in Georgia as reported by the survey respondents.

Application Technology and Benefits

Application technologies are becoming more common on commercial sprayers as the interest in improving application accuracy and efficiency continues to rise among the industry and growers. One of the questions asked survey respondents about use of GPS and rate controller on their sprayers when making pesticide applications. Of the total 169 responses received, 65% of the respondents indicated using both GPS and rate controller on their sprayers while 9% of the respondents reported using a GPS but no rate controller on the sprayer for pesticide applications (Fig. 5a). Beside demonstrated benefits of these basic technologies, it was an interesting find that 25% of the respondents indicated not using any of these technologies on their farm for pesticide applications. Advanced spray technologies such as PWM and direct injection systems are also now being offered on new or as a retrofit option for pesticide application equipment and has seen increased adoption among the growers, especially in the mid-western US. In response to a question regarding the use of new application technologies, 23% of the total respondents (n = 183) indicated using auto-boom height technology, 13% reported using PWM technology and 9% reported using a direct injection system on their sprayers (Fig. 5b). Use of electrostatic boom/sprayer was not very common with only 3% of the respondents indicating using it for pesticide applications. Fifty two percent of the respondents indicated that they do not use any advanced spray technologies for pesticide applications on their farm. These results suggested the adoption and utilization of both basic and advanced spray technologies can be improved among Georgia growers by increasing the knowledge on different available technologies and by demonstrating technology benefits through hands-on trainings and workshops.

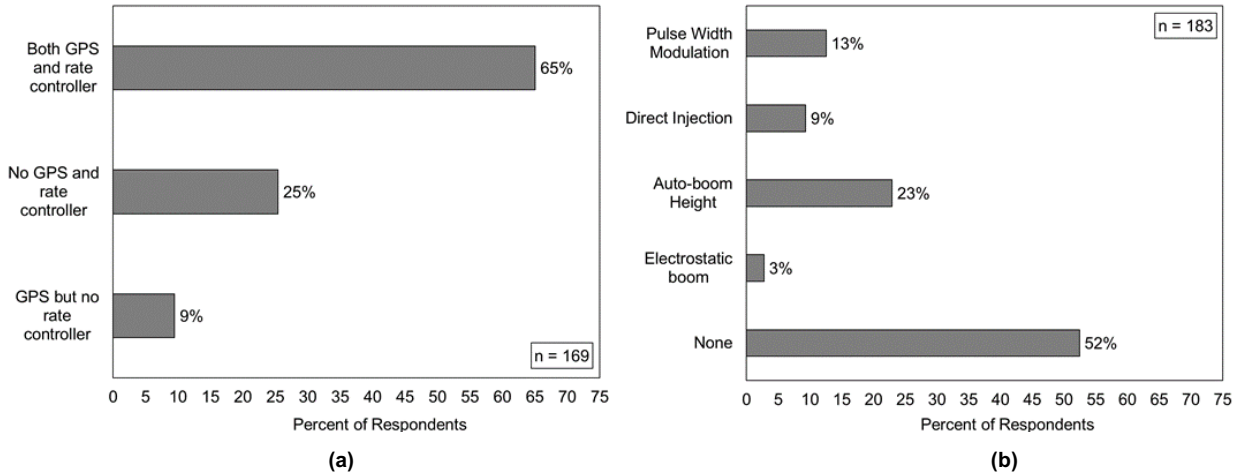

Fig. 5 Use of (a) GPS and rate controller, and (b) other precision spray technologies by Georgia growers as reported in a 2021 survey. Percentages may not total 100% due to rounding.

To ensure proper and safe use of pesticides on agricultural farms, all private pesticide applicators including growers are required by law to keep record(s) of their federally restricted use pesticide applications for a period of 2 years. Survey participants were asked to indicate their preferred methods of recording pesticide application records. Results indicated most growers (66%) utilize a traditional method of writing records on a notepad or diary to log pesticide applications while very few growers (15% total) indicated using a smartphone app (application) or a computer program (e.g. Microsoft Excel) to log pesticide records (Table 3). These smartphone or computer applications ranged anywhere from using a simple note-keeping app such as Evernote or Google Sheets to using a dedicated farm data management apps such as Farm Logs or Climate FieldView to record pesticide logs. These results were surprising as smartphones or tablets are becoming more common among growers today and there are also numerous apps available for free or at low-cost to record farm logs including pesticide applications. Using sprayer display/computer to log pesticide records was only selected by 16% of the respondents. Few survey participants (3%) also indicated using other methods such as writing on a calendar when an application was made or “home-made” charts on paper.

Table 3. Method of recording pesticide application records as reported by Georgia growers in a 2021 survey (n = 196).

Method of recording pesticide applications	% of respondents
I write all my spray records on a notepad or diary	66
I use an app on my Smartphone or Tablet	9
I use a program (e.g. MS Excel) on my computer	6
My Sprayer display/computer saves it and I can access them later	16
Other (please specify)	3

The last question related to application technologies was an open-ended opinion question about what growers perceive as the biggest benefit/advantage of using application technologies for making pesticide applications. A total of 105 responses were received, which were summarized into seven distinct one or two-word descriptors as listed in Fig. 6. According to the respondents, the three biggest benefits of using application technologies were accurate application (39%), reduced/no overlap (30%), and cost savings (14%). It is interesting to note that these three benefits are all related to each other as accurate applications help in reducing overlap or over-application which further results in cost savings. Better coverage (7%), safer application (5%), on-target application (5%) and easier data logging (2%) were also among the other technology benefits indicated by the survey respondents. While spray technology adoption is moderately low to average across Georgia, growers who utilize these technologies understand their benefits in making efficient pesticide applications. However, to encourage more adoption and effective utilization among the growers, it is important for industry to make these technologies simple, affordable and easy to use, and for educators to develop programs and modules to effectively train and educate growers on operation and benefit of these technologies.

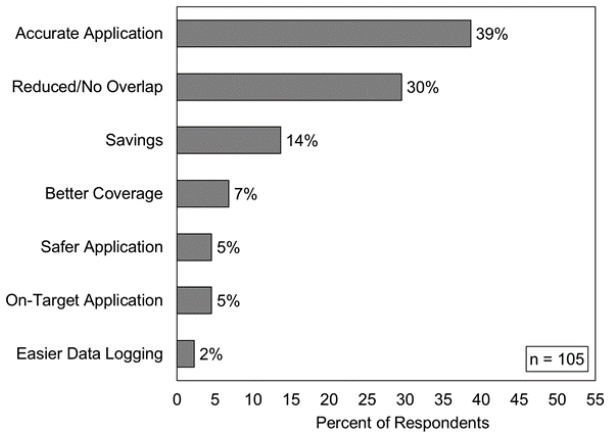

Fig. 6 Benefits of spray technologies as reported by Georgia growers in a 2021 survey. Results reported here are based on a word frequency analysis of responses. Percentages may not total 100% due to rounding.

Challenges and Future Research Needs

Towards the end of the survey, growers were asked two open-ended questions about the pesticide applications. The first question asked survey participants about their biggest challenge related to pesticide applications on their farm. From a total of 105 responses, spray drift and regulations (18%), application timing (16%), and weather (15%) were the top three responses listed by the survey participants (Fig. 7a). With nearly 98% of the cotton producers in Georgia utilizing auxin herbicides such as dicamba and 2,4-D for weed control (USDA-AMS, 2020), it was not surprising to see spray drift and application regulations at the top of the application challenges listed by the growers. Application timing was indicated as another big challenge possibly due to diversity of cropping systems and crop rotations utilized by the growers in Georgia. Some of the other challenges indicated by survey respondents included on-target application and coverage (9%), sprayer cleanout (7%), cost of equipment/chemicals (7%), product selection and efficacy (6%), safety (4%), nozzle selection (4%), spray records (4%) and pest control (5%). Some less common challenges mentioned only by few respondents were grouped under the category “other”

and included topics such as application knowledge, sprayer calibration, small farm size, and urban invasion. While some of the challenges listed by the survey respondents have also been reiterated by growers and Extension agents at various educational trainings and county meetings across the state, the survey also helped in bringing attention to other common but less noticeable challenges faced by the growers.

The second open-ended question asked respondents about the research that they would you like to see the University of Georgia conduct that can help address their current or any future pesticide application issues or concerns. Seventy-three survey participants answered this opinion question and individual responses were grouped and categorized into one or more of the 14 categories listed in Fig. 7b. Product and carrier rates (12%), pest control (10%) and products (10%) were the among the top three research categories based on the responses. Responses for product and carrier rates were related to both rate of the product (active ingredient; kg ai per hectare) and spray volume (liters per hectare) of the carrier while the responses related to the products included information or data on different types of chemicals, adjuvants, crop oils, and surfactants. Other frequently mentioned responses included dicamba (9%), spray drift (8%), cost effectiveness/economics (8%), spray parameters (7%) and spray technology (6%). Again, it was not surprising to note that the terms “dicamba” and “spray drift” together (total 17%) were mentioned largely in the responses and the need for more research on different ways (nozzle type, droplet size, wind effect, ground speed, boom height, etc.) to safely apply these chemicals while mitigating pesticide drift. With increasing chemical and application equipment prices, growers are also interested in information on the economic feasibility of continue using different pesticide products and the number of applications as well as learning about affordable equipment and technology options that can help in making more efficient pesticide applications.

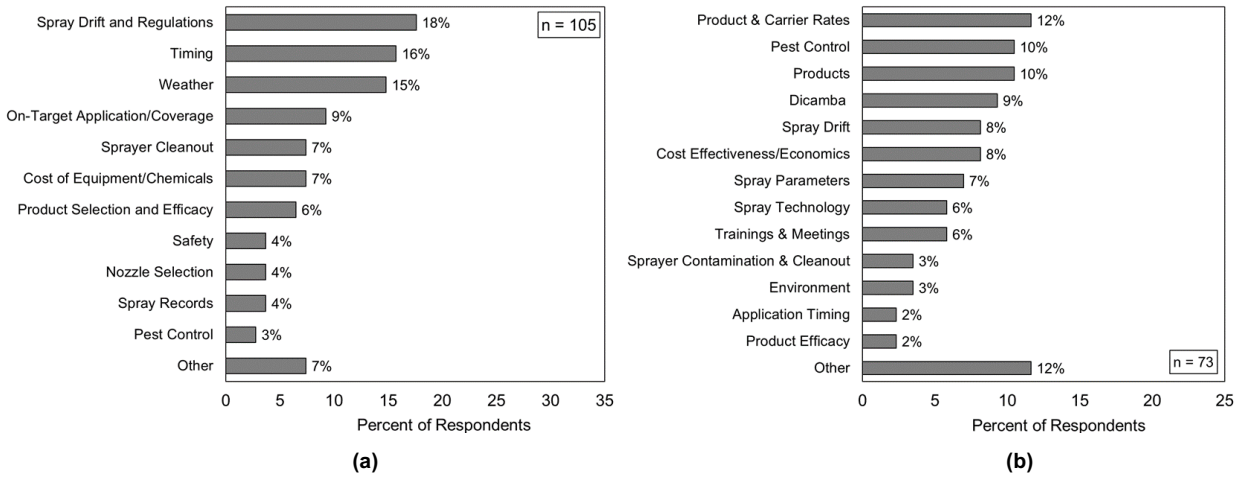

Fig. 7 (a) Pesticide application challenges and (b) areas for future research in pesticide application and technology as reported by Georgia growers in a 2021 survey.

Summary

The survey data presented here provides information on the current pesticide application practices and technologies along with highlighting some common challenges and research needs of the Georgia growers. Survey findings showed that self-propelled and pull-behind sprayers with boom lengths between 13.8 and 27.4 m were the most commonly used spray equipment while some growers also utilize a separate sprayer for applying auxin herbicides. Most growers utilize two or more nozzles in a growing season indicating adequate knowledge about the importance of proper nozzle selection for maximizing pesticide performance. Survey respondents also showed good understanding of the importance of other application parameters such using correct nozzle size and adequate volume to maximize coverage, canopy penetration and efficacy, and modulating spray pressure and droplet size by pesticide type. However, few growers (15%) also indicated the lack of knowledge on nozzle type and droplet size being used for pesticide

applications on their farm. Basic spray technologies (GPS and rate controller) are more common on the application equipment while advanced technologies (PWM, direct injection, auto-boom height and electrostatic boom) are not widely as adopted and utilized by Georgia growers. Majority of the respondents prefer to manually write their pesticide records and identified accurate application, reduced overlap and cost savings as the biggest benefits of new application technologies. Spray drift and regulations, application timing, and weather were identified as the major challenges to pesticide applications by respondents whereas future research in the areas including but not limited to product rates, spray volumes, pest control, chemicals and adjuvants, spray drift, spray parameters and technology. Overall, the information gained through this survey will be very valuable for developing and implementing applied research and extension efforts to address growers' challenges and needs as well as provide latest information related to pesticide applications and technology.

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References

Sharda, A., Griffin, T., Haag, L., & Slocombe, J. (2016). Automatic Boom Height Control Technology for Agricultural Sprayers. Kansas State University Cooperative Extension. Publication# MF3299.

Bish, M.D., & Bradley K.W. (2017). Survey of Missouri pesticide applicator practices, knowledge, and perceptions. *Weed Technology*, *31*, 165–177.

Butts, T.R., & Kruger, G.R. (2018). Pulse-Width Modulation (PWM) Sprayers: Why, Why, and How? G2302 NebGuide. Lincoln: University of Nebraska-Lincoln Extension. 3 p.

Butts, T. R., Barber, L. T., Norsworthy, J. K., & Davis, J. (2021). Survey of ground and aerial herbicide application practices in Arkansas agronomic crops. *Weed Technology*, *35*(1), 1-11.

[EPA] Environmental Protection Agency. (2017). Compliance Advisory: Crop Damage Complaints Related to Dicamba Herbicides Raising Concerns. https://www.epa.gov/sites/default/files/2017-07/documents/fifra-dicambacomplianceadvisory-201708.pdf. Accessed December 1, 2021.

Edge, B., Velandia, M., Boyer, C., Larson, J., Lambert, D., Roberts, R. & Falconer, L. (2018). Automatic section control technologies and GPS auto-guidance systems adoption in cotton production. *Journal of Agricultural Science*, *10*(7), 282-294.

Kudsk, P. (2017). Optimizing herbicide performance. Weed Research: Expanding Horizons. Hoboken, NJ: John Wiley & Sons, Ltd. Pages 149–179.

Foster, H., Sperry, B., Reynolds, D., Kruger, G., Claussen, S. (2018). Reducing herbicide particle drift: effect of hooded sprayer and spray quality. *Weed Technology*, *32*(6), 714-721.

Luck, J,D, Zandonadi, R.S., Luck, B.D., & Shearer S.A. (2010). Reducing pesticide overapplication with map-based automatic boom section control on agricultural sprayers. *Trans ASABE, 53*, 685–690.

Nuyttens, D., Baetens, K., De Schampheleire, M., Sonck, B. (2007). Effect of nozzle type, size and pressure on spray droplet characteristics. *Biosystems engineering*, 97(3), 333-345.

Sharda, A., Fulton, J.P., McDonald, T.P., & Brodbeck, C.J. (2011). Real-time nozzle flow uniformity when using automatic section control on agricultural sprayers. *Computers Electronics in Agriculture,* 79, 169–179.

Sharda, A., Luck, J.D., Fulton, J.P., McDonald, T.P., & Shearer, S.A. (2013) Field application uniformity and accuracy of two rate control systems with automatic section capabilities on agricultural sprayers. *Precision Agriculture,* 14, 307–322.

[USDA-NASS] U.S. Department of Agriculture – National Agriculture Statistics Survey. 2020. 2019 Agricultural Chemical Use Survey. https://www.nass.usda.gov/Surveys/Guide_to_NASS_Surveys/Chemical_Use/2019_Field_Crops/chem-highlights-cotton-2019.pdf. Accessed November 28, 2021.

[USDA-NASS] U.S. Department of Agriculture – National Agriculture Statistics Survey. 2021. 2020 U.S. Farm Production Expenditures. https://www.nass.usda.gov/Publications/Highlights/2021/farm-expenditures.pdf. Accessed November 28, 2021.