Mechanized Spot Application of Granular Agrochemical: An Evaluation of a Novel Precision Spot Applicator

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ABSTRACT

To date, the development of spot-application technology in precision agriculture has primarily focused on liquid applications, with granular spot applicators remaining largely underexplored. This study presents one of the first field-validated precision spot applicators designed for granular agrochemical application. Specifically, the system was tested for its ability to apply dichlobenil to patches of hair fescue (Festuca filiformis) in wild blueberry (*Vaccinium angustifolium* Ait.) fields based on prescription maps. Field trials demonstrated exceptional system performance, with accuracy, precision, sensitivity, and specificity values of 95%, 91%, 99%, and 91%, respectively. Furthermore, spot-applied dichlobenil achieved equivalent levels of hair fescue control compared to conventional broadcast applications ($p > 0.05$), while reducing herbicide use by approximately 66%. This marks a significant advancement in precision weed management, offering substantial cost savings and environmental benefits. Beyond wild blueberry, the system's adaptable design suggests potential applications in other cropping systems reliant on granular agrochemicals. This research represents a critical advancement in precision spot application technology. It addresses a key gap in granular agrochemical management by reducing inputs while maintaining treatment efficacy through a first-of-its-kind approach to granular application.

KEYWORDS

Pesticide, prescription mapping, rate control, smart machinery, weeds

RÉSUMÉ

À ce jour, le développement des techniques d'application localisée en agriculture de précision s'est principalement concentré sur les applications liquides; les applicateurs localisés de granulés restent largement sous-exploités. Cette étude présente l'un des premiers applicateurs localisés de précision validés sur le terrain, conçu pour l'application de produits agrochimiques granulaires. Plus précisément, le système a été testé pour son aptitude à appliquer du dichlobénil sur des zones infestées de fétuque filiforme (*Festuca filiformis*) dans des champs de bleuet sauvage (*Vaccinium angustifolium* Ait.) sur la base de cartes d'application. Les essais en champ ont démontré des performances exceptionnelles du système, avec des valeurs d'exactitude, de précision, de sensibilité et de spécificité de 95 %, 91 %, 99 % et 91 %, respectivement. De plus, l'application localisée de dichlobénil a permis d'obtenir des niveaux de contrôle de la fétuque filiforme équivalents à ceux des applications conventionnelles à la volée ($p > 0,05$), tout en réduisant l'utilisation d'herbicides d'environ 66 %. Ceci représente une avancée significative dans la gestion précise des mauvaises herbes, offrant des économies substantielles et des avantages environnementaux. Au-delà du bleuet sauvage, la conception adaptable de ce système laisse entrevoir des applications potentielles dans d'autres systèmes de culture recourant à des produits agrochimiques granulaires. Cette recherche représente une avancée majeure dans le domaine des applications localisées de précision. Elle comble un gap important dans la gestion des produits agrochimiques granulaires en réduisant les intrants tout en maintenant l'efficacité du traitement grâce à une approche inédite d'application de granulés.

MOTS CLÉS

Pesticide, cartographie d'application, contrôle des doses, machines agricoles intelligentes, mauvaises herbes

CITATION

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INTRODUCTION

Wild blueberry (*Vaccinium angustifolium* Ait.) is a perennial crop typically produced on a biennial basis. After harvesting, fields are mowed back to near ground level, and the plants will enter a dormant phase in preparation for overwintering. It is at this point in late fall when preemergence herbicides are typically applied, especially those targeting hair fescue (*Festuca filiformis*). Hair fescue is an invasive and densely tufted perennial grass which has quickly become the pest of greatest concern for the Nova Scotian wild blueberry industry (Laforest et al. 2022; Porter et al. 2020; Wild Blueberry Producer's Association of Nova Scotia 2019, 2022). In 2001, hair fescue was found in only 7% of Nova Scotian wild blueberry fields and by 2019, it was found in over 75% (Lyu et al. 2021). The rapid spread is attributable to the over 3000 seeds which a single hair fescue tuft can produce (White & Kumar 2017). These seeds readily break from the panicle, lack primary dormancy, and spread easily through both primary and secondary dispersal (Amen 1966; Boyd & White 2009; White 2018, 2020; White & Kumar 2017). Wild blueberry is a no-tillage crop, so herbicides are the only effective means of controlling this economically destructive weed.

Pronamide (group 3) is the most widely used herbicide for controlling hair fescue in wild blueberry and has demonstrated over 90% reduction in hair fescue vegetative tuft density (White 2019; Zhang et al. 2018). Other herbicides such as terbacil, hexazinone, foramsulfuron, flazasulfuron and clethodim have demonstrated an ability to reduce inflorescence numbers; however, they are not as effective as pronamide in terms of reducing vegetative tufts (White 2019, 2022; White & Graham 2021; White & Zhang 2020, 2021). As of now, hair fescue resistance to pronamide in wild blueberry fields has yet to be documented; however, the industry's nearly complete reliance on the product makes it an excellent candidate. Alternative products with similar reductions in vegetative tuft counts are needed to prolong the lifespan of pronamide and continue to ensure that the industry has options for managing hair fescue.

Dichlobenil is a group 29 herbicide sold under the trade name Casoron® G4. It is a granular formulation, which, like pronamide, should be applied in wild blueberry during late fall for controlling hair fescue. The findings MacEachern et al. (2024) have demonstrated dichlobenil's similar effectiveness to pronamide in terms of reduction in vegetative tuft density, flowering tuft density and reduction in inflorescence number. Despite the benefits, the significant product costs (over \$1800 ha^{-1} at 175 kg ha^{-1}) of dichlobenil have limited its implementation in the wild blueberry cropping system. That said, precision agriculture and spot application solutions could serve to make this product more appealing to growers.

While spot sprayers are becoming more prevalent in agriculture for a variety of applications, granular spot applicators have seen very little development. The majority of research into granular applicators has been done on variable rate applications (Alameen et al. 2019; Chandel et al. 2016; Fulton et al. 2001; Iida et al. 1998; Ishola et al. 2014; Kim et al. 2008; Mirzakhaninafchi et al. 2021; Tola et al. 2008; Yinyan et al. 2018) however, these developments do not allow for sectional control within the application width. If an applicator is to perform similarly to a spot sprayer, it needs to offer this sectional control. One such device was developed by Chattha et al. (2014), who demonstrated the potential of an individually orifice-controlled applicator. Their applicator was designed to avoid applying fertilizer in bare spots within wild blueberry fields. While the design was accurate in isolated trials, the applicator did not see any uptake from the industry due to technical limitations, including inconsistent delay timings and granule degradation resulting from the product return auger. The design of the applicator under evaluation in this study built off many of the concepts proposed by Chattha et al. (2014).

MacEachern et al. (2024b) developed a novel precision spot applicator (Fig. 1) which is capable of spot applying granular agrochemical. The applicator reads a predeveloped prescription map and can individually control the application of product across 12 orifices. The potential to spot apply agrochemical on hair fescue is particularly appealing given that primary seed dispersal causes patches of hair fescue to form within fields. By mapping these patches against wild blueberry plants and applying herbicide only to the patches, there is significant potential for cost mitigation.

Given the wild blueberry industry's overreliance on pronamide and the potential of dichlobenil to manage hair fescue, the need for a cost effective means of applying dichlobenil, and the recent development of a novel spot applicator for spot applying granular agrochemical, the goal of this study was to field evaluate the spot applicator by determining its application accuracy and precision while assessing the potential of dichlobenil applied via the novel applicator for controlling hair fescue.

MATERIALS AND METHODS

Equipment Description

The applicator was based on a modified Valmar 1255 Twin Roller equipped with 12 individually controlled orifices across a 7.31 m boom. Product flow at each orifice was directed by electrically actuated diversion valves, allowing granules to be either applied or recirculated. Control signals were generated from prescription maps using a John Deere RC2000 controller with StarFire 6000 GNSS and SF3 correction, which has previously demonstrated positional accuracy of ±73.8 mm in wild blueberry fields (Esau et al. 2021). Valve actuation was achieved using bistable rotary solenoids with a rated switching time of <10 ms, controlled through a custom signal-processing system. The base metering system remained that of the stock applicator and was calibrated to the target rate of 175 kg ha^{-1}; in companion testing, the modified system achieved a mean application rate of 182 ± 8.31 kg ha^{-1}, which was not significantly different from the target rate. Full engineering details are provided in MacEachern et al. (2024b). Prescription maps were developed using the technique described in Bilodeau et al. (2023).

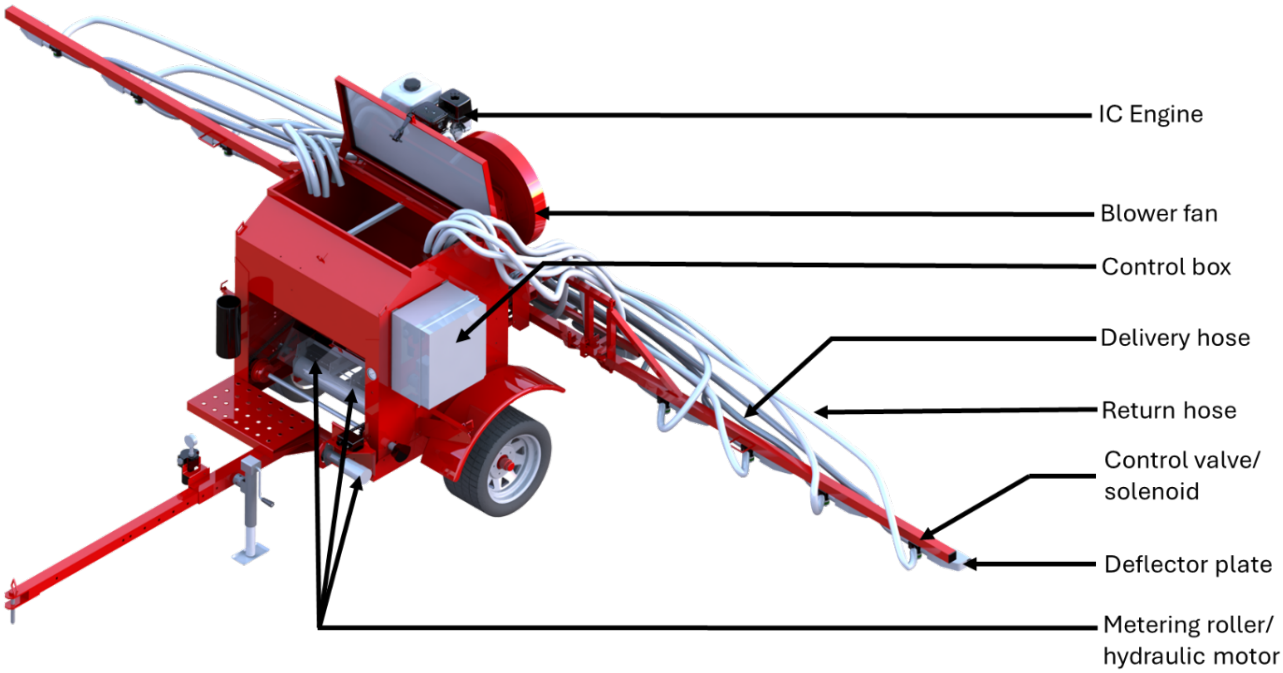


Fig. 1. Computer-aided design drawing of novel spot applicator.

Experimental Sites and Design

The field evaluation trial of the applicator was set up to compare spot application to broadcast application and the effect of applicator-applied dichlobenil on hair fescue vegetative tuft density. The experiment was a randomized complete block design across three commercially managed fields, with three blocks and three treatments per block (spot application, broadcast application, and no application) in each field. The three selected sites were all located in Nova Scotia's Colchester County. Site 1 is a 1.96 ha field section located in Murray Siding (45.369061, -63.206695), site 2 is a 1.33 ha field section located in Murray Siding (45.364875, -63.213123), and site 3 is a 3.00 ha field located in Kemptown (45.500496, -63.102192). Developed prescription maps for each site are shown in Figure 2.

Dichlobenil was applied at site 1 on December 3, 2022, at site 2 on December 15, 2022, and at site 3 on December 16, 2022. Average wind speeds during application were 5.81, 5.36 and 3.13 m s^{-1} at each of sites 1, 2 and 3, respectively. Dichlobenil was applied at 7000 g a.i. ha^{-1}. Each plot was 35 m by 7.31 m with a 15 m buffer between adjacent plots. The novel applicator was used in both the spot and broadcast applications as it still maintains its stock broadcast functionality. Within each test plot, 20 Catchmaster glue traps (134 mm × 288 mm; AP&G Co., Inc., Bayonne, USA) were placed to assess application accuracy. Ten traps were positioned in target locations where hair fescue was present, and 10 were positioned in non-target locations where hair fescue was absent. We hypothesized that, when the prescription track was driven, applied product would be detected on traps in target locations but not on traps in non-target locations.

Applicator Performance Analysis

Following application, all traps were collected and labelled as either hit or missed in terms of product application. These labels were then compared against their placement (target or non-target locations) to determine the precision, accuracy, sensitivity, and specificity of the novel applicator. Precision considers when the applicator is applying product and how often that is in the correct location. It is determined using Eq. 1

$$\text{Precision} = \frac{\text{TP}}{(\text{TP}+\text{FP})} \quad (1)$$

where, TP is the number of true positives and FP is the number of false positives. Accuracy considers how often the applicator is applying product in target areas as well as how often it is not applying product in non-target areas. It is determined using Eq. 2.

$$\text{Accuracy} = \frac{\text{TP}+\text{TN}}{(\text{TP}+\text{TN}+\text{FN}+\text{FP})} \quad (2)$$

where, TN is the number of true negatives and FN is the number of false negatives. Sensitivity considers how often the applicator applies product in target areas. It is determined using Eq. 3.

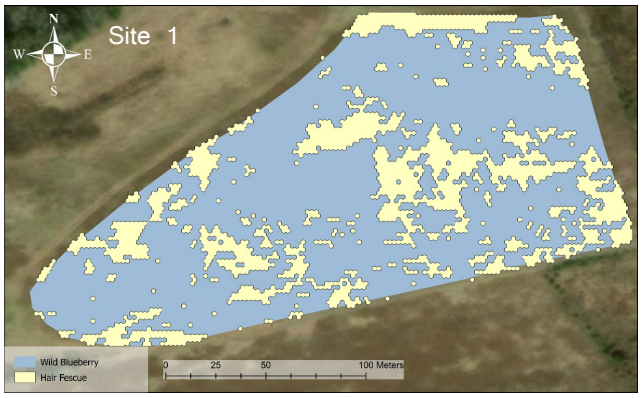
$$\text{Sensitivity} = \frac{\text{TP}}{(\text{TP}+\text{FN})} \quad (3)$$

Specificity considers how often the applicator is not applying product in non-target areas. It is determined using Eq. 4.

$$\text{Specificity} = \frac{\text{TN}}{(\text{TN}+\text{FP})} \quad (4)$$

Vegetative Tuft Analysis

Hair fescue vegetative tuft data was likewise collected from each plot before and after application. To do this, a tape measure was laid between both sets of diagonal



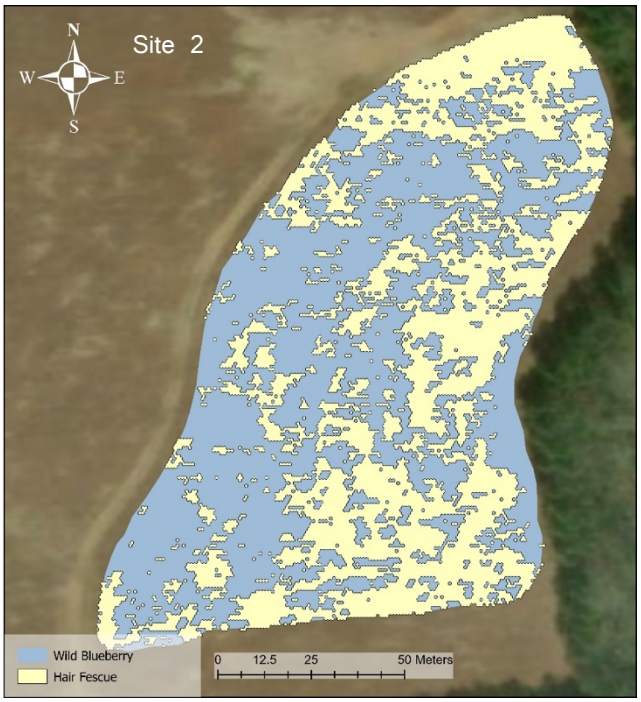
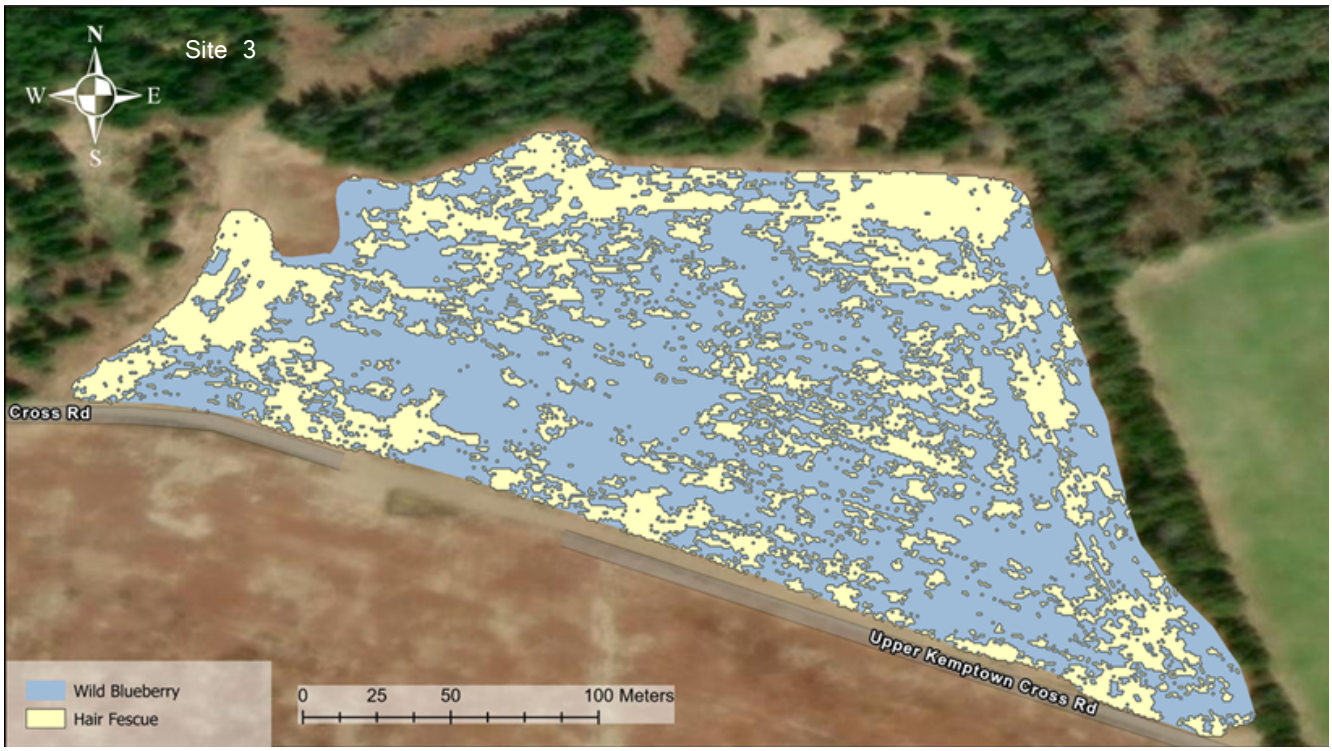


Fig. 2. Prescription maps for Sites 1 (top), 2 (side) and 3 (bottom) showing wild blueberry non-target areas (blue) and hair fescue target areas (yellow).



corners of each plot. After selecting a random starting point using a random number table, 10 samples were taken at equal distances from one another along each line. At each sampling point, a 0.5 m x 0.5 m quadrat was placed, and all living and non-living tufts were counted, producing 20 samples per plot. Tufts were considered living if even a single green leaf was found on the plant. Living tuft counts before application were collected on December 1, 2022, in sites 1 and 2 and on December 2, 2022, in site 3. Living tufts after application were counted on May 26, 2023, in site 2 and on May 24, 2023, in site 3. Data for site 1 were not reliable after application, as the field owner sprayed the contact herbicide glufosinate ammonium (Ignite® SN) in the spring prior to counting. Glufosinate ammonium causes necrosis of green plant tissue and thus made living (i.e., green) tuft counts impossible. For this reason, living tuft data from site 1 was omitted from the analysis. Mean separation on both pre- and post-application vegetative tuft density was performed using Fisher's LSD on Minitab (v. 21.2; Minitab LLC, State College, PA).

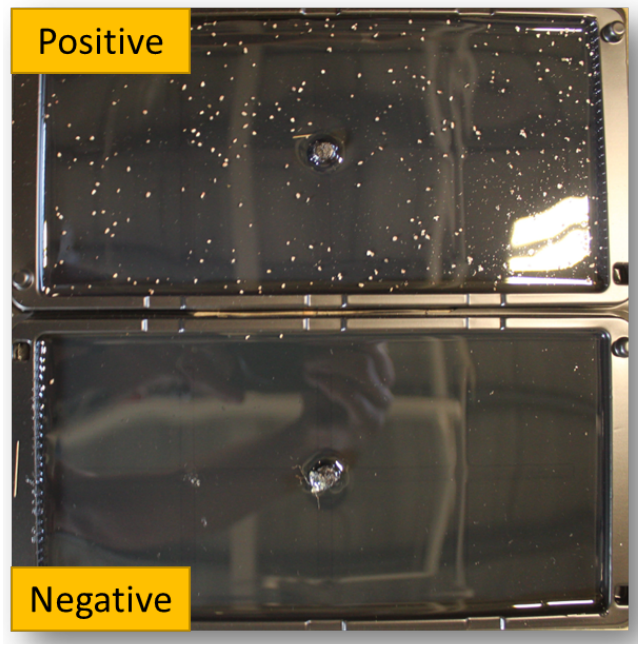


Fig. 3. Example of glue traps with applied dichlobenil (top) and glue traps which did not have dichlobenil applied (bottom)

RESULTS AND DISCUSSION

Applicator Performance Analysis

Performance data from the in-field evaluation of all three sites are presented in Table 1. These data were calculated based on positive and negative glue trap targets (Fig. 3). Across all sites, glue trap outcomes included 86 true positives, 1 false negative, 79 true negatives, and 8 false positives. Six traps were omitted from the calculation because they were driven over by the tractor during application.

Accuracy, precision, sensitivity, and specificity were all > 90% (Table 1). The applicator's measured accuracy of 95% is quite encouraging, as this metric best encapsulates the overall system performance. While 95% is encouraging, it is important to consider the other calculated metrics as they lend a better understanding of where the system's shortcomings are and how it might be further improved.

Table 1. Performance data from field evaluation of applicator based on the collection of applied granules in both target and non-target locations.

Metric	Percentage (%)
Accuracy	95
Precision	91
Sensitivity	99
Specificity	91

The calculated sensitivity of 99% suggests that the system was highly adept at applying product in target locations. Comparatively, the specificity of 91% suggests that the system has a slight tendency to overapply product in non-target areas. That said, for the application of herbicides, high sensitivity is more important than high specificity as the main goal is ensuring that all weeds are targeted. The most likely cause for the lower specificity is the buffer zones, which were incorporated around the target areas during the generation of the prescription map. This method is described by Bilodeau et al. (2023), and was done for several reasons. First, the buffer zones ensure that weeds were targeted correctly independent of any slight GNSS inaccuracies. Second, buffer zones help to account for seeds spread via primary seed dispersal and their resultant seedlings, which were too small to be identified via the aerial imagery. Finally, the buffer zones act as a sort of blurring effect during map generation, which dramatically reduces map complexity and file size and improves in-field processing time. This results in a scenario where management zones, as defined by the prescription map, can fall between two orifices, and both orifices are therefore turned on. This meant that a small amount of product was applied outside of target areas, as the application width for a single orifice is 0.61 m. It should also be noted that the minimum polygon size used in the maps was 0.25 m^2



Fig. 4. Example of hair fescue on the day before dichlobenil application (left, December 2, 2022) and at the time of vegetative tuft analysis in spring post-application (right, May 24, 2023)

Table 2. Hair fescue living tuft density (tufts m-2) measured in Spring 2023 following dichlobenil application in Fall of 2022 in blueberry fields located in Murray Siding (Site 2) and Kemptown (Site 3) Nova Scotia.

	Site 2 (living tufts m^{-2})	Site 3 (living tufts m^{-2})
Control	25.48a	44.80a
Broadcast Application	5.32b	9.00b
Spot Application	5.28b	9.40b

*Means within a column followed by the same letter are not significantly different according to Fisher's LSD ($P \leq 0.05$).

regular hexagons. This meant that if a single hexagon was present in the map, even a single orifice would overapply on both sides of the target area due to the minimum application resolution of 0.61 m. The system's specificity could be improved by shrinking or removing these buffer zones; however, this would likely come at the cost of decreasing the sensitivity. Another way to consider the system performance is through precision. With a precision of 91%, the system performed well. As with specificity, precision could be increased in the system, though this would come at the cost of decreasing the sensitivity. Overall, the high sensitivity at the cost of slightly reduced precision and specificity is the ideal balance for targeting hairy fescue; therefore, this design was deemed successful.

Vegetative Tuft Analysis

While the potential for the system to apply product in the correct locations was encouraging, it was likewise important to assess the potential of spot-applied dichlobenil for controlling hairy fescue when applied spot-specifically using the applicator. There was a significant interaction between site and treatment ($p = 0.003$); therefore, data were analyzed separately across sites. There was no significant difference in terms of within-site initial tuft density ($p = 0.333$ for site 2 and $p = 0.689$ for site 3). Average initial tuft densities were 22.24 tufts m^{-2} and 39.00 tufts m^{-2} for sites 2 and 3, respectively. An example of hair fescue on the date before herbicide application and in the spring following application at the time of vegetative tuft analysis can be seen in Figure 4.

Broadcast and spot applications of dichlobenil gave equivalent reductions in hair fescue vegetative tuft density relative to the nontreated control at each site (Table 2). Dichlobenil was therefore effective on hair fescue, and the results demonstrate that spot applications can be made with the novel applicator without compromising weed control. This result is highly encouraging as it represents the potential for significant product and cost savings when applying dichlobenil. That said, although comparable weed control was observed at both valid sites, additional multi-site and multi-year evaluations would strengthen confidence in the broader generalizability of the applicator's agronomic potential.

When mapping the sites, target areas (as denoted by the presence of hair fescue) accounted for 33.89% of the total area on average. Considering the cost of dichlobenil is \$1873.00 ha^{-1}, the reduced treated area corresponds to a theoretical gross herbicide product-cost savings of \$1238.24 ha^{-1}, before accounting for capital, maintenance, mapping, labour, or other operational costs associated with the system. It is also important to note that despite the system's accuracy of 95%, there was not a significant reduction in the degree of hairy fescue treatment.

Future Implications

This trial demonstrates one of the first field-validated precision spot applicators in any cropping system. While it was designed with wild blueberry in mind, other cropping systems could benefit from this technology. Cranberry (*Vaccinium macrocarpon*) is an excellent candidate as dichlobenil is also widely used in cranberry for controlling a variety of perennial grasses, broadleaf weeds and sedges (Demoranville & Devlin 1969; Sandler 2010; Sandler et al. 2004). It can be applied mechanically using tractor-driven drop spreaders, though; it is often applied manually and spot-specifically due to the high costs of the herbicide (Sandler 2013; Swinkels personal communication). By developing an appropriate prescription map of the target weed, similar performance to what was seen in this trial should be achievable regardless of the crop. Further, the functional components of the system are not inherent to the Valmar 1255 TR and could easily be adapted to work with any air boom spreader configuration. For this reason, implementing the system in row crops using different applicators is not beyond the realm of possibility. Future research would be needed to assess which crops specifically could benefit from spot application of granular agrochemicals and how the system could be implemented.

In addition to dichlobenil, the applicator could be used with other granular herbicides such as trifluralin (Bonanza® 10G, Rival 10G, Treflan® TR-10), a group 3 herbicide used in a variety of field crops for controlling grasses and broadleaf weeds (Loveland Products Canada 2011). Alternatively, granular insecticides such as tefluthrin (Force® 6.5G), bifenthrin (Bifen L/P) and chloropyrifos (Saurus®) could benefit from the developed technology if the appropriate use cases are identified. Further work is needed to identify these implementations.

Limitations

It should be noted that the glue trap approach for analyzing the applicator is a binary measure of product presence/absence and does not quantify local application rate, deposition uniformity, or post-deposition granule bounce and roll. Future work to address these concerns should be performed as the applicator is progressed toward commercialization. Further, the study was designed to assess practical field performance rather than to isolate individual sources of spatial error; therefore, GNSS positional uncertainty and signal-to-actuation delay were not quantified separately. Future work should consider these aspects as part of a revised design. Finally, the effects of travel speed and wind conditions, including wind speed and direction, were not evaluated in this trial.

CONCLUSION

This study presents one of the first field-validated precision spot applicators for granular agrochemical application, marking a significant advancement in precision weed management. The applicator demonstrated high accuracy (95%) and sensitivity (99%), ensuring effective herbicide placement while reducing unnecessary applications. Most importantly, spot-applied dichlobenil achieved equivalent hair fescue control to broadcast application ($p > 0.05$), but with a 66% reduction in herbicide use, offering substantial cost savings and environmental benefit. By addressing a critical gap in granular precision application technology, this system introduces a scalable solution that could benefit other cropping systems reliant on granular herbicides. For instance, cranberry production and various row crops could leverage similar prescription-based granular application approaches. Beyond this, adapting the system for other granular agrochemicals, such as insecticides and fertilizers, represents a promising direction for further research. Future studies should focus on three key areas. First, economic feasibility assessments are needed to quantify long-term cost savings and return on investment. Second, integrating the system with real-time weed detection technologies could enhance automation and improve targeting accuracy. Finally, adapting the applicator for different granular agrochemicals and cropping systems would expand its applicability beyond wild blueberry production. While these assessments were beyond the scope of this project, this research represents a major step forward in the development of precision spot application technologies, paving the way for more efficient, cost-effective, and sustainable agrochemical management solutions.

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