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# In-field and Greenhouse Assessments of a Selection of Preemergent Herbicides on Newly Planted Blackberries

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In-field and Greenhouse Assessments of a Selection of Preemergence Herbicides on Newly Planted Blackberries

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## Abstract

This field trial assesses some of the preemergence herbicide options available to growers and their effect on newly transplanted blackberries (*Rubus* L. subgenus *Rubus* Watson). Weed control has recently been surveyed as a top priority for blackberry growers; however, limited preemergence herbicides are registered for new blackberry plantings. Weed control is an ongoing component of blackberry production and with few in-season postemergence herbicide options available, growers rely on preemergence herbicides to maintain clean fields. The preemergent herbicides assessed in this trial were chosen with the intention to broaden the chemical control options available to growers in new plantings. A two-year field trial was initiated in 2021 and conducted at two locations: Milo J. Shult Research and Extension Center in Fayetteville, AR (36.09 ºN, 94.17 ºW) and the University of Arkansas Fruit Research Station in Clarksville, AR (35.53 ºN, 93.40 ºW). Seven treatments consisting of six preemergence herbicides (mesotrione, flumioxazin, oryzalin, *S*-metolachlor, pendimethalin, and napropamide) and one hand-weeded check were applied to field plots of newly transplanted tissue culture propagated blackberry plugs (var. 'Ouachita'). Preemergence herbicide treatments were reapplied to the same plots in 2022. Data were collected on visual injury, plant height, leaf chlorophyll content, and green coverage of blackberry canopies and of bare ground portions of each plot. Yield data were collected in the second year, and fruit were analyzed for soluble solids content (°Brix), pH, and average berry weight. In the first year mesotrione and flumioxazin treatments caused the most injury to the primocanes. Injury by flumioxazin was not detectable at the final rating of the first year, but injury by mesotrione was high 84 days after treatment (DAT). Napropamide, *S*-metolachlor, oryzalin, and pendimethalin did not cause injury over 6% throughout the 2021 season. In the second year (2022) no damage was incurred by any treatments, from the treated or

the non-chemical weed-free (NCWF) check. The mesotrione treatment affected plant height the most in 2021 at the end of the season compared to the NCWF check. In 2022 plant height was not assessed. Yield measurements taken in 2022 exhibited no significant differences in response to preemergence herbicide treatments.

A greenhouse experiment was conducted to investigate the effects of a broad selection of preemergence herbicides at two rates. This screening was initiated August 2021 and repeated March 2022 in Fayetteville, AR in a horticultural greenhouse at the Milo J. Shult Research and Extension Center. Tissue cultured ‘Ouachita’ blackberry plugs were transplanted into utility pots that were treated with a preemergence herbicide treatment. Twenty-five treatments in total consisted of twelve preemergence herbicides at 1× and 2× rates and one untreated control. Data were collected on plant height, visual injury ratings, internode length, leaf chlorophyll content, and destructive harvest including leaf count, leaf dry biomass, specific leaf area (SLA), and leaf area to dry matter ratio (LADMR). Halosulfuron, rimsulfuron, and mesotrione treatments showed progressively increasing visual injury from 7 days after treatment (DAT) until 42 DAT. Flumioxazin, napropamide, *S*-metolachlor, and pendimethalin treatments exhibited similar responses to the untreated control regarding height and visual injury and may be acceptable for use in young blackberry weed management programs. Data obtained from this screening characterized the physiological response of new blackberries treated with these preemergence herbicides. Both trials demonstrated the deleterious effects of mesotrione on young plants and why it is not recommended for use in first year plantings. Both trials demonstrated the validity of the 24(c) labeling of *S*-metolachlor. These findings validate many of the regional recommendations and provide new evidence to consider expanding registration and labeled usage requirements for select preemergence herbicides. This knowledge and further field investigation have the potential to lead to more informed IPM strategies.

## Dedication

To my parents Dan and Lolita Knepp who took up the difficult task of managing my expectations and who have supported me in countless endeavors.

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# Chapter 1. Literature Review

## The Blackberry

Blackberries (*Rubus* L. subgenus *Rubus* Watson) are enjoyed as fresh and processed fruit. They adorn desserts and salads as fresh additions while serving as the main ingredient in processed pies, canned goods, and other fruity treats. Sold fresh in markets globally and locally as well as in pick-your-own establishments, blackberries have economic value and are expected to gain more value in the market due to better understanding of their high nutritional importance (Sobekova 2012). Acreage devoted to blackberry production in the southern US has increased since the 1990's (Fernandez et al. 2016)

The genus *Rubus* is thought to have origins in China, but there is some evidence for North America and Africa due to the wide genetic diversity found among blackberry and raspberry populations in those regions (Gu et al. 1993; Hummer 1996). Commercial blackberries are grown in the United States (US) with Oregon as the lead producer followed by California (USDA-NASS 2021). Approximately 27,000 hectares (ha) of commercial blackberries are cultivated worldwide (Strik et al. 2008).

Blackberries are available in trailing, erect, and semi-erect growing habits. To optimize plant canopy development, most commercial growing operations use trellising systems. First year blackberry plants will grow large canes that require trellising for optimized production. Cane production occurs in a biennial rotation. The new or first year growth is termed a primocane while the second-year growth is termed a floricane. Both types of canes, or ages, can occupy the same plant in the same season. Trellising systems facilitate upright growth of the canes for ease of harvest and create a structured canopy for ideal flowering and berry formation. While vertical trellising using the T-trellis or V-trellis methods are common, some growers have adopted the rotating cross arm (RCA) trellis which can adjust the orientation of primocanes and floricanes throughout the season (Henderson 2020; Hall & Funt 2017). While more expensive to install, the RCA can protect canes during winter by laying them down for cover and can facilitate harvest by manipulating the plant canopy to induce flowering and fruit set to occur only on one side of each row (Henderson 2020). Trellising enhances fruit yield, fruit quality, and economic viability. Supporting the upright branching and lateral growth of the canes, trellising allows for improved air circulation throughout the canopy. This facilitates drying after rain and prevents extended periods of high humidity in the plant canopy that could contribute to disease. While trellising technique can enhance some fruit characteristics, fruit qualities such as firmness and soluble solids are often most closely related to the cultivar selection or nutrient management (Fernandez-Salvador et al. 2015; Nelson & Martin 1986). Newer dwarf varieties with shortened internodes are marketed as patio container specimen plants. The Baby Cakes® blackberry with primocane, thornlessness, and dwarf tendencies is an example of the touted patio orchard and landscape plant (Clark & Boches 2016). These dwarf varieties are an attractive option for homeowners because they can grow without the support of a trellis system, which may be inconvenient for a hobby grower. Genetic control of plant height through dwarfing characteristics has been established (Johns 2022; Clark 2021).

Blackberries have perfect flowers with both male and female reproductive structures and do not require cross pollination for berry production. While blackberries are capable of self-pollination, they still require wind or pollinator activity for fertilization. Uniform fertilization ensures proper drupelet formation for optimum berry quality. Pruning out dead canes and canopy maintenance in the dormant season allows for air circulation and light penetration creating a better environment for fruit development and ripening while helping to deter disease and pest loads. A planting site on a north slope or with afternoon shade with well-drained soil and a soil pH of 5.5 to 7.0 will yield healthy productive plants (Kaiser & Ernst 2016; Burgos et al. 2014).

Significant contributions of the University of Arkansas System Division of Agriculture Fruit Breeding Program include the introgression of thornlessness and the discovery of primocane-fruiting tetraploid blackberries. These two important traits have been united to make a desirable combination for use in both commercial production and home gardening. Primocane fruiting was developed in 2005 with 'Prime-Jan®' and 'Prime-Jim®' (Clark et al. 2005). Prior to the development of primocane-fruiting varieties, fruit were only produced on second-year growth referred to as floricanes. The primocane fruiting trait can provide a secondary harvest so producers have two production periods per year. The thornlessness characteristic has contributed to marketability of blackberries for commercial production. All fresh market blackberries are picked by hand, and the thornlessness trait allows laborers to be more efficient in harvesting berries and maintaining plants. Due to the high cost of labor, this increase in harvesting and plant maintenance efficiency creates an economic incentive for producers to plant thornless varieties in favor over thorny varieties. Additionally, thornless varieties are considered preferable in U-pick operations to prevent minor injuries to customers. "Production practices and cultivars that bring a higher quality, year-round product to the consumer, and that are profitable for growers, packers, and processors have been an integral part of this fresh market expansion" (Clark & Finn 2014). The first primocane fruiting thornless blackberry to be released to the market was 'Prime-Ark® Freedom' in 2014 followed by 'Prime-Ark® Traveler' in 2016 which is more suitable for shipping (Clark & Salgado 2016; Clark 2014). Both primocane-fruiting and thornlessness traits are recessive traits, which require additional crosses for new releases to express both traits. These desirable traits plus the stability in shipping of ‘Prime-Ark® Traveler’ created a distinguished trifecta not available to the market previously (Clark & Salgado 2016).

**Impact of Weeds**

Stakeholders within the United States blackberry industry have indicated the need to see more research for weed management strategies (Worthington et al. 2020). Left uncontrolled, weeds can overrun a blackberry planting, competing directly with the crop for light, water, and nutrients. Dense weed populations also create environments that favor disease and insect pests or environments that are unsuitable for flowering and fruit development (Herrera 2017; Agustí-Brisach et al. 2011). Insects such as spotted wing drosophila (SWD) (*Drosophila suzukii*), green stink bug (*Chinavia hilaris*) and brown stink bug (*Halyomorpha halys*) are pests commonly associated with blackberry canopy management and the presence of weeds (Diepenbrock & Burrack 2017; Rolston & Kendrick 1961). But weed pressures are especially difficult to manage because they benefit from the same fertility and management utilized for growing blackberries. Thus, weed control must be prioritized to maintain a healthy and high-yielding blackberry planting throughout its productive years. Best management practices would be to scout regularly and to identify weeds before they have become unmanageable or limited control methods are available. It is also important to implement weed management soon after problematic weed species are detected. An unfortunate mistake for many growers is to wait until the last minute to initiate a weed management strategy, which contradicts the ‘start clean, end clean’ framework recommended for blackberry weed management (Burgos et al. 2014). Keeping records from regular scouting year-round can potentially inform what is to come the following year and forecast some of the necessary weed management activities.

Developed by entomologists, integrated pest management (IPM) employs an understanding of an insect pest's life cycle and then uses a multifaceted approach to manage pests when they break out of equilibrium and threaten damage, based on researched economic injury levels and thresholds (Stern et al. 1959). Stern et al.'s paper titled, "The Integration of Chemical and Biological Control of the Spotted Alfalfa Aphid" published in 1959 is one of the first published uses of the "IPM" term, though others were practicing ecology-based pest management prior to the 60's. IPM is a multi-faceted pest management strategy that combines physical (mechanical), cultural, biological, and chemical controls into a dynamic management strategy. Strategies may include crop rotation, delayed sowing, and use of pesticides as appropriate to prevent economic losses. Rather than relying on a single method of control, IPM implements complimentary control methods, based on cropping systems, management costs, and knowledge of pest phenology and biology. Thus, IPM is dependent on knowledge of the phenology and biology of pests, as well as researched integrated responses to specific pests. When applied to weeds, IPM can be more specifically termed "integrated weed management" (IWM) and can serve as the basis for an effective weed management plan.

Mechanical control of weeds is achieved through physical destruction, by uprooting, burying, burning, and other physical processes. The most familiar and iconic form of mechanical control may be the hand-hoe, a toiling effort that is reliable and effective, particularly for removing maturing weeds, which can produce tens or hundreds of thousands of seeds (Monaco 2002). More advanced mechanical control may rely on specialized implements such as a flame weeder, basket weeder, and even robotic and electric weeders (Fennimore & Cutulle 2019; Fennimore et al. 2016; Reiser et al. 2017). Integrated tillage and integrated mowing have also been shown to be effective in perennial specialty crops to increase diversity in biomass coverage and species in maintained green areas for intra-row management (Mia et al. 2020).

Cultural controls create an environment that favors the crop over problematic weed species. Examples may be starting with healthy disease-free plants, amending soils to optimize fertility, or pruning or trellising plants properly, specifically in a perennial system. Use of white plastic as a weed barrier has been shown in caneberries to improve overall yield and yield qualities including soluble solids which may be partially attributed to light reflection and the consequential increase of light penetration into the canopy (Makus 2010, 2011). Polyethylene and biodegradable plastic mulches have been found to be effective components in weed control strategies for caneberries (Zhang et al. 2019).

Biological controls are often dependent on the relationships between living organisms and weeds. Goats (*Capra hircus*) and a rust pathogen (*Phragmidium violaceum*) have been utilized as a biological control method in cases where wild type blackberries have become weedy and are considered invasive (Chalak & Pannell 2015). The same study investigated different chemical controls and one mechanical control in an effort to determine the efficacy of utilizing IWM strategies on weedy blackberries (Chalak & Pannell 2015). A concern for using livestock to graze on cropped land would be potential impacts of soil damage. Bell et al. (2011) found that the long-term effects of hoof traffic are minimal.

Chemical control involves the use of herbicides to kill weeds with either preemergence or postemergence herbicides. Preemergence herbicides are applied prior to weed emergence and are active on weeds at specific growth stages following germination. The term can sometimes cause confusion because preemergence herbicides may be applied either before or after the emergence of the crop. Direct-seeded crops may be sensitive to preemergence herbicides applications, and preemergence herbicide applications may need to be banded between rows or be delayed until crops have established to a particular growth stage. In contrast, transplanted crops and perennial crops are less sensitive to the preemergence herbicides, and a wider selection of chemistries and application methods are typically available. Because some preemergence herbicide products will only be effective on specific weed species, good record keeping is vital to the selection of the proper preemergence herbicides. In contrast, postemergence herbicides are applied to weeds that have already emerged. Due to crop sensitivity, a limited selection of postemergence herbicides are registered for use in specialty crops, relative to field crops such as corn or soybean. Though chemical control is widely used it should be supplementary to other methods (Harker & O'Donovan 2013). Chemical control of weeds in a blackberry crop is useful in reducing weed presence within a vegetation-free strip (VFS) (Meyers et al. 2015).

Thresholds play a major role in weed control. Harkening back to the entomology based IPM, thresholds such as the economic threshold (ET) and economic injury level (EIL) work by evaluating the economic loss in comparison to the economic cost of using a management strategy for control (Pedigo et al. 1986). Other terms and definitions headlining "thresholds" and "levels" have been proposed and some even used for a time, but they have all been derivatives of the ET and EIL terms. IWM works similarly but rather than evaluating insect populations, weed population densities and critical periods for weed control are determined, based on crop yield responses. The critical period for weed control (CPWC) is the period of time during which weed species need to be managed to prevent interference from weeds which will ultimately reduce crop yields. Deciphering how much yield loss is acceptable is the first step in determining a CPWC. A 5% yield loss is a generally acceptable level of loss for determining CPWC; though, that can vary based on crop value and costs of weed control (Bertucci et al. 2019; Charles et al.

2019; Seyyedi et al. 2016). A major short-coming of the CPWC model is that CPWC only addresses yield thresholds, ignoring contributions to the weed seed bank from weed escapes. Further, mid- or late-season weed control timings advised by the CPWC may not be realistic if there are limited postemergence herbicide options. Unlike row crops which have genetically engineered trait technology and or selective breeding that has provided options for postemergence applications, blackberries have few postemergence herbicide options.

Maintaining a weed-free strip width (WFSW) of 1.2 m has been demonstrated and as a best management practice for blackberry production (Meyers et al. 2014; Meyers et al. 2015; Childers et al. 1995; Fernandez & Ballington 1999). A WFSW that is wider will increase herbicide costs while a WFSW that is narrower may delay growth and development of the blackberry plants (Meyers et al. 2014). Considering the perennial life cycle of a floricane-bearing blackberry plant with biennial fruiting, the care and attention that is provided the primocanes will greatly affect the next year's fruit production and overall vegetation growth (Lawson & Wiseman 1975). Maintaining a WFSW will alleviate any weed interference and allow the blackberry plants to be more easily harvested, especially considering that blackberries are hand harvested.

Because of the physiological and morphological differences that distinguish broadleaf weeds and grasses, the two categories can dictate the type of chemical control used for weed control. Broadleaf weeds have aboveground growing points which are usually positioned at the top of the plant. Grasses maintain a growing point below the soil surface. Both have different vascular system structures as well. Due to the locations of the growing point and the difference in vascular systems in broadleaves and grasses, there are herbicides that are effective on one, the other, or both. Cool season and warm season are terms that differentiate when the weed is growing and producing reproductive structures. By combining two broad categories, management techniques can then be specified further. There can be cool season broadleaves, cool season grasses, warm season broadleaves, and warm season grasses. Broadleaf weed species should be targeted when the blackberry, being broadleaf as well, is dormant. Knowing when a weed and or the crop is active allows for correctly timed and more effective herbicide applications.

Weeds consume nutrients and water from the soil profile and can keep crop plants from attaining those resources. Some weeds are considered luxury feeders of certain nutrients, specifically nitrogen, and may use fertilizer resources as well as resources already present in the soil. It has been shown that nutrient availability limits plant growth (Burnett et al. 2018). Removal of soil nutrients may not always be problematic; in fact, phytoremediation is a plant's ability to remove harmful soil components. Though this term is often in conjunction with environmental restoration practices and possesses positive connotations (Ali et al. 2013). Competition, allelopathy, and harvest impediment are causes of lower crop yield loss and quality (Dixon et al. 2016; Egushova & Anokhina 2022; Li et al. 2016). "A cleaner vegetation-free strip (VFS) is beneficial, in that it allows berry picking laborers to harvest the crops more efficiently" (Meyers et al. 2015). Weed pressures on blackberry crops have little impact on "shiny black blackberry fruit soluble solid content (SSC), nor titratable acidity, sugar-to-acid ratio, or pH of shiny or dull black blackberry fruit or primocane number, length, and stem caliper" (Meyers et al. 2014). Basinger et al. (2017) found that berry weight and cumulative yield increased with the increase in width of the VFS. Keeping a clean area around the blackberry plants holds particular value for U-pick operations, creating an area free of unruly obstructions and providing good access to harvest.

**Current and Potential Preemergence Herbicides for Use in Blackberry**

At this time in commercial blackberry cropping systems, plasticulture or landscape fabric is widely utilized during the first two years of establishment to keep chemical control methods to a minimum and maintain the best practices recommendations of a 1.2 m WFSW (Meyers et al. 2015; Fernandez & Ballington 1999; Basinger et al. 2017). Though commonly considered the optimal operating procedure to use landscape fabric, this does not usually span far enough to maintain the required WFSW. Plastics are used to facilitate fumigation for nematodes though little is known about caneberry nematode problems in the southeast (Mitchem & Jennings 2022). Plastics do not last as long and disposing of plastics is difficult and harmful to the environment. Another consideration is that the augmented soil biome under plastic has a deleterious effect on the soil organic matter content. Rysin et al. (2015) investigated the idea of a changed soil biome under plastic in strawberries. Using organic matter for mulching could be considered for weed management because a full site renovation is not anticipated annually the residual mulch may not be problematic. Hand weeding is laborious and intensive making it expensive (Monaco 2002; Harkins et al. 2013; Olmstead et al. 2012). Anywhere from 38-90 h/ha of hand weeding may be required depending on the cultural practices used.

Preemergence herbicides are used before weeds are expected to emerge and become problematic. Though at the time of application, the weed seed may not be active, preemergence herbicides only work on active physiological processes. Preemergence herbicides may be applied as a preemergence but after a crop is planted. The application may only be “pre” in relation to the target weeds or target species not necessarily the crop. Options for postemergence herbicides are even more limited than preemergence herbicides in specialty crops due to crop sensitivity. In a trellised blackberry system either shield or hood sprayers may be employed to keep unwanted herbicide application or drift down by as much as 80% depending on the droplet size (Foster et al. 2018). Hooded or shielded systems may eliminate undesired off-target movement of herbicides. There are a variety of application systems that have been or are being developed including the automated devices and precision application systems (Warneke et al. 2020; Hunter et al. 2019; Fennimore et al. 2016; Fennimore & Cutulle 2019).

Due to the perennial nature of blackberries, there are no opportunities for complete site renovation nor indiscriminate weed control following planting. This is a divergence from annual cropping systems where the full arsenal of weed control strategies are available between crops, and crop succession can be adjusted based on weed pressures. Instead, blackberry producers must enact weed management strategies in ways that are effective in killing weeds but do not harm the blackberry plants. Thus, it is highly encouraged for producers to "start clean, end clean" (Burgos et al. 2014). Research specifically investigating preemergence herbicides in new blackberry plantings is limited.

**Chemical Materials for Investigation**

The Weed Science Society of America (WSSA) in coordination with the Herbicide Resistant Action Committee (HRAC) has created an ordinal grouping system for herbicides based on their mode of action (MOA) of which there are currently 29 groups (WSSA-Mechanism-of-Action, n.d.; Herbicide Resistant Action Committee, n.d.). Within a group there may be different chemical compounds, but they all have the same mode of action within the plant. The mode of action is the physiological process through which herbicide acts on a plant. Having multiple MOAs provides options to control weeds and prevent resistant individuals from proliferating, allowing for diversification of weed control (Norsworthy et al. 2012; Mitchem &

Jennings 2022). To address the needs of specialty crops sometimes opening up or widening label uses would benefit specialty crop weed management options (Gast 2008).

**Oryzalin "Surflan"**

Oryzalin is a WSSA designated group 3 herbicide, making it a microtubule assembly inhibitor. Cell inhibitors affect mitosis which is exemplified in stunted roots. Usually formulated as an aqueous suspension (AS) or granular (G) and used in nonbearing fruit and nut trees which does include nonbearing blackberries, ornamentals, noncropland, and industrial sites, and established warm season turf. Oryzalin is applied to the soil surface and irrigation or rainfall is required for activation. For control of many annual grasses and broadleaf weeds oryzalin is to be applied at 4.48 kg ai $ha^{-1}$ (Monaco 2002; Anonymous 2011).

**Pendimethalin "Prowl H2O/Satellite Hydrocap"**

Pendimethalin is a WSSA designated group 3 herbicide. Formulated as an emulsifiable concentrate (EC), water dispersible granular (WG or DG), wettable powder (WP) or G and used in many capacities including preemergence, postemergence, and preplant. Pendimethalin is to be used in grasses, many fruit bearing and nonfruit bearing trees, several specialty crops, row crops, and blackberries. Most annual grasses and certain broadleaf weeds can be controlled during germination. Irrigation or rainfall is required for activation. Pendimethalin applied in a preemergence herbicide capacity should be applied no more than two days post planting and 3.36 kg ai $ha^{-1}$ is the rate (Monaco 2002; Anonymous 2020; Anonymous 2017b).

**Flumioxazin "Chateau"**

Flumioxazin is a WSSA group 14 herbicides and is generally formulated as a granular. Group 14 indicates flumioxazin is a protoporphyinogen oxidase (PPO) inhibitor. Flumioxazin is used as a preemergence herbicide and a component in burndown applications targeting broadleaf weeds. Flumioxazin should be applied at 210.16 g ai $ha^{-1}$. This chemical is currently labeled in many row crops and specialty crops including blackberries (Monaco 2002; Anonymous 2021).

**Napropamide "Devrinol"**

Napropamide is a WSSA group 15 herbicide and formulated as a WP, EC, dry flowable (DF), and G. It inhibits very long chain fatty acids, affecting shoot growth. Used as a preplant or preplant incorporated, napropamide can be used in many vegetable crops, oilseed rape, tobacco, sunflowers, safflowers, olives, figs, mint, turf, strawberries, grapes, many fruit and nut trees, and woody ornamentals and blackberries. Though some broadleaves are sensitive, most annual grasses are controlled. Napropamide should be applied at 4.48 kg ai $ha^{-1}$ (Monaco 2002; Anonymous 2017a).

***S*-metolachlor "Dual Magnum"**

*S*-metolachlor like napropamide is a WSSA group 15 herbicide. *S*-metolachlor is formulated as an EC, DF, WG, and G. It may be used as a preplant or a preemergence application. *S*-metolachlor is used for weed control in beans, peas, lentils, corn, cotton, grasses grown from seed, horseradish, peanuts, potatoes, pumpkin, rhubarb, safflowers, sweet grain, forage sorghum, soybeans, immature seed, sugar beets, sunflowers, and tomatoes and blackberries. *S*-metolachlor controls both grasses and broadleaf weeds and should be applied at 1.6 kg ai $ha^{-1}$ (Monaco 2002; Anonymous 2020).

**Mesotrione "Callisto"**

Designated as a WSSA group 27 herbicide mesotrione is generally formulated as a soluble concentrate (SC). Inhibiting *p*-hydroxyphenyl pyruvate dioxygenase (HPPD) results in altering carotenoid synthase which manifests as tissue bleaching. Mesotrione is used as a preemergence and postemergence herbicide and is labeled for use in field corn, seed corn, yellow popcorn, sweet corn and other listed crops including blackberries. Mesotrione is used for control of annual broadleaf weeds with an application rate of 157.62 g ai $ha^{-1}$ (Monaco 2002; Anonymous 2018).

**Conclusion**

Weed pressures in new blackberry plantings require attention and continued research. Investigation into chemical control options has value for the industry especially knowing that chemical control has proven to be an effective asset within an IPM approach to weed management (Meyers et al. 2015). The opportunity to validate regional recommendations and labeling while providing evidence to consider expanding registration and labeled use requirements for materials would allow more options for growers to maintain fields and potentially lead to more informed IPM strategies.

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## Chapter 2. Herbicide Screen of Young Blackberries with a Selection of Preemergence Herbicides and Rates


### Abstract

Weed control has recently been surveyed as a top priority for blackberry growers; however, limited preemergence herbicides are registered for new blackberry plantings. This greenhouse experiment was designed to investigate the effects of a broad selection of preemergence herbicides at multiple rates on blackberry transplants. Screening was initiated August 2021 and repeated March 2022 in Fayetteville, AR in a greenhouse at the Milo J. Shult Research and Extension Center. Tissue cultured 'Ouachita' blackberry plugs were transplanted into utility pots that contained soil and growth media treated with a preemergence herbicides. A total of twenty-five treatments consisted of twelve preemergence herbicides at 1× and 2× field rates and one untreated control. Herbicide treatments included diuron, flumioxazin, halosulfuron, indaziflam, mesotrione, napropamide, oryzalin, pendimethalin, rimsulfuron, *S*-metolachlor, simazine, and sulfentrazone, applied to substrate in containers at their respective 1× or 2× field rates. Data were collected on plant height, visual injury ratings, internode length, leaf chlorophyll content, and destructive harvest including leaf count, leaf dry biomass, total dry biomass, specific leaf area (SLA), and leaf area to dry mater ratio (LADMR). Halosulfuron, rimsulfuron, and mesotrione treatments showed progressively increasing visual injury from 7 days after treatment (DAT) until 42 DAT. Oryzalin and simazine appeared to have a rate dependent injury response, with the 1× rate causing minimal injury (<5%) and the 2× rate causing higher injury levels, though these differences were not statistically different. At both 1× and 2× rates, flumioxazin, indaziflam, napropamide, *S*-metolachlor, and pendimethalin treatments exhibited similar responses to the untreated control regarding plant height and visual injury. This screening

characterized the morphological response of new blackberries treated with these preemergence herbicides and may be useful to guide future field research and targeted rates for assessing herbicide tolerance and safety.

## Introduction

Weeds are an ever-present competitor for crop resources. Significant amounts of nutrients, light, and water can be taken from a crop when weed pressures exceed acceptable thresholds. Within perennial peach orchards, lower weed pressure through chemical control produced higher yields (Mia et al. 2020). Blackberry growers deal with weeds year-round and unlike annual specialty crops, do not have the opportunity to cultivate an entire field to start with a clean site annually. Young blackberry plants (*Rubus* L. subgenus *Rubus* Watson) are smaller than established plants and less competitive with weed species, making them more sensitive to weed interference.

Best management practices recommend keeping a clean weed-free growing space for optimal plant growth and fruit yield (Meyers et el. 2014; Burgos et al. 2014; Norsworthy et al. 2012). To effectively maintain weed-free growing sites, it is necessary to understand and implement integrated weed management (IWM) techniques. Current options for weed management in blackberries include cultural and chemical controls (Makus 2010, 2011a; Zhang et al. 2019). Biological controls such as grazing animals are not considered broadly viable for perennial blackberries. In fact, goats (*Capra hircus*) have been used to control invasive wild type blackberries (Chalak & Pannell 2015). Crown and root disturbance inflicted from trampling and hoof traffic is also a possibility though detrimental long-term effects are unlikely (Bell et al. 2001). Mechanical controls, such as hand hoeing or mowing, are still used, though hand-weeding is expensive and labor intensive (Monaco 2002; Harkins et al. 2013; Olmstead et al. 2012). Robotic and automated weeders are being actively developed and integrated for specialty crops, these methods may provide weed management options that are effective and available for growers moving toward IWM approaches (Fennimore & Cutulle 2019; Fennimore et al. 2016;

Reiser et al. 2017). Cultural controls include use of plastics, landscape fabric, or other mulch barriers for weed suppression. In raspberry (*Rubus idaeus* L.*)* plots covered with polyethylene mulch or biodegradable mulch, weed populations were reduced by more than 95% relative to bare ground plots (Zhang et al. 2019). However, plastic mulch or landscape fabric is not usually reapplied after it has broken down, and the persistence of biodegradable mulches may not be sufficient to offer more than one season of weed control (Zhang et al. 2019). Though it is common practice to utilize landscape fabric, and this can last upwards of seven years, this does not usually span the needed distance to maintain the required WFSW. Chemical controls are widely used due to being cost effective and time efficient (Meyers et al. 2015). Chemical controls have versatile application methods, which allow growers to select suitable herbicides based on their production system (Warneke et al. 2020; Hunter et al. 2019; Fennimore et al. 2016).

Pesticide registrants often see negligible value in registering pesticides for use in specialty crops due to low return on investment and liability risk (Gast 2008; Fennimore & Cutulle 2019). This disinterest is largely due to the low acreage and limited market opportunity these crops offer compared to agronomic crops. Herbicide discovery for specialty crops is often the byproduct of investigation of chemical use for agronomic crops (Gast 2008). Chemical company consolidations have also resulted in reduced investigation into new chemical development (Gast 2008). Within specialty crops, there are relatively few in-season options for postemergence herbicide use, thus preemergence herbicides are critical for weed suppression. Annual applications of registered preemergence herbicides are necessary to suppress weed populations in blackberry production (Mitchem & Jennings 2022). Standard recommendations to maximize yields and profitability are to maintain a weed-free strip width (WFSW) of 0.9 meters for early plantings and 1.2 meters for mature plantings (Meyers et al. 2014; Meyers et al. 2015; Childers et al. 1995; Fernandez & Ballington 1999; Basinger et al. 2017). Further, to reduce risk of herbicide resistance, growers should rotate which active ingredients are used for weed management (Norsworthy et al. 2012; Mitchem & Jennings 2022).

A further limitation on preemergence herbicides used in blackberries is the age of the crop and fruit-bearing status. Some herbicides are labeled for use in "established" plantings while others are not. Established plantings must be a minimum of one year in the ground but the term can also refer to two or three years, with this determination being specifically stated within herbicide labels (Anonymous 2017a; Anonymous 2021c). Additionally, some herbicides are restricted to use only in non-fruit-bearing plantings (Anonymous 2011).

The objective of this trial was to assess the response of newly planted blackberries to a broad selection of soil-applied preemergent herbicides at two rates using greenhouse trials. This data should be used to inform field research and not necessarily be used to immediately claim field application usage in new blackberry plantings.

**Materials and Methods**

A greenhouse trial was initiated August 31, 2021, and repeated March 3, 2022, in Fayetteville, AR at the Milo J. Shult Research and Extension Center (36.09 ºN, 94.17 ºW). The trial was arranged as a randomized complete block design with 12 preemergence herbicides applied at both 1× and 2× of recommended field rates (Table 2-1). All treatment combinations were replicated five times in each trial run, and an untreated check receiving no herbicide was included in each replication. Some of the selected herbicides for investigation are currently labeled for use in newly planted blackberry plantings (mesotrione, flumioxazin, sulfentrazone, and napropamide); however, oryzalin is labeled for use in non-fruit-bearing plantings

(Anonymous 2011; Anonymous 2012a; Anonymous 2012b; Anonymous 2018; Anonymous 2021c). Diuron is not labeled for use in blackberries at all (Anonymous 2019b). The formulation of pendimethalin used in this trial, Prowl®, is not labeled for use in blackberries but Satellite HydroCap®, which also utilizes pendimethalin as an active ingredient, is labeled for blackberries rendering the pendimethalin data still valuable (Anonymous 2017b; Anonymous 2021a). *S*-metolachlor is not labeled for use in blackberries under a Section 3 label; however, section 24(c) special local need (SLN) labels have been registered in Oregon and North Carolina (Anonymous 2020; Anonymous 2022). Arkansas acquired the same SLN label for *S*-metolachlor in 2022. Further, three of the herbicides (indaziflam, halosulfuron, and rimsulfuron) are only registered for use in blackberries established for one or more years (Anonymous 2017a; Anonymous 2019a; Anonymous 2021b). Simazine is labeled for use in blackberries but includes two restrictions: do not apply when fruit is present and cut the application rate by half if the plants are six months of age or younger (Anonymous 2013). Of these labeled products, napropamide, simazine, and oryzalin are recommended for use in blackberries of all growth stages (Burgos et al. 2014, Mitchem & Jennings 2022). Flumioxazin, indaziflam, mesotrione, and rimsulfuron are labeled for use and recommended for use in established plantings by the caneberry spray guide (Mitchem & Jennings 2022).

Plastic containers (3.8 L) were filled with a prepared substrate using a 1:1 v/v ratio of herbicide-free field soil (sourced from University of Arkansas Vegetable Research Station, Kibler, AR (35.37 ºN, 94.23 ºW) and general use potting soil (PRO-MIX BX Mycorrhizae, Pro-Mix, 200 Kelly Rd. Unit E-1, Quakertown, PA 18951 USA). The field soil was Roxana silt loam and had not been sprayed with herbicide for over twenty years and was herbicide-free at the time it was sourced.

Prior to treatment, filled containers were thoroughly watered, allowed to settle and drain to field capacity. Herbicide treatments were applied to prepared containers using a compressed air powered spray chamber calibrated to deliver 187 L/ha at 1.6 kph and fitted with two flat fan 1100067 nozzles placed 50 cm apart. Twenty-four hours after application, 'Ouachita' blackberry tissue cultured plugs were transplanted into the 3.8 L plastic black utility pots. Plant plugs were ordered from Agri-Starts (Agri-Starts, 1728 Kelly Park Rd., Apopka, FL 32712) and were planted to a depth sufficient to cover the root-ball (~6 cm). Care was taken to displace as little substrate as possible to allow for a more accurate representation of root uptake of the soil-applied herbicides.

Potted plants were then placed in the greenhouse on tables and randomized within each replication. Plants were watered and fertilized (Sta-Green® Water-soluble All-purpose Plant Food, Gro Tec, Inc., P.O. Box 290, Madison, GA) as needed. Visual injury was rated at 7, 14, 21, 28, 35, and 42 days after treatment (DAT). Injury ratings were recorded on a 0 to 100 scale, with 0 indicating no injury and 100 indicating complete plant death. Visual injury symptoms were not uniform across herbicide treatments, thus total canopy reduction (i.e., stunting, reduced leaf size) were accommodated in visual injury ratings in addition to necrotic or chlorotic leaf surfaces. A soil plant analysis development (SPAD) meter (SPAD-502Plus, Konica Minolta, 101 Williams Drive, Ramsey, NE 07446) was used to measure chlorophyll content of the youngest fully expanded leaves at 14 and 42 DAT. Internode length at the second node from the meristem was measured with an electronic digital caliper (CID Bio-Science Inc., 1554 NE 3rd AVE, Camas, WA 98607) at 14 and 42 DAT. Plant height was measured to the highest apical meristem at 14 and 42 DAT. Destructive harvest was conducted at 42 DAT, and data were collected on leaf area and leaf count. Leaf area was determined using a leaf area scanner (LI-3100C Area

Meter, LI-COR® Biosciences, 4647 Superior Street, P.O. Box 4425, Lincoln, NE 68504). Biomass was recorded by harvesting detached leaves and remaining aboveground biomass (stems) separately for each sample then oven drying (Laboratory Oven, Blue M Electric Company, New Columbia, PA) for 4 d at 63°C. Dried biomass was weighed for data collection with a laboratory balance (BP61S – Sartorius, Goettingen, Germany). Total aboveground biomass was recorded as the sum of the detached leaf biomass and the remaining aboveground biomass from each container. Specific leaf area (SLA) was calculated as the ratio of leaf area to leaf biomass, and leaf area to dry mater ratio (LADMR) was calculated as the leaf area to total aboveground biomass ratio.

All data were subjected to ANOVA as a randomized complete block design using the GLIMMIX procedure in SAS, version 9.4 (SAS Institute Inc., Cary, NC). Main effects of herbicide, rate, and herbicide by rate interaction were treated as fixed effects, while block (nested in trial) and trial were treated as random effects. Data were checked for heteroscedasticity by reviewing residual plots from SAS, and means were separated using Tukey's Honest Significant Difference multiple comparisons adjustment ($\alpha = 0.05$) (Tukey 1973). Data for untreated plots were excluded from the initial means separation analyses. Instead, untreated plots were only included when the Dunnett's procedure (Dunnett 1955) was utilized for analysis to detect whether each treatment combination was significantly different from the untreated check.

**Results and Discussion**

*Injury.* Plant visual injury was assessed weekly for the duration of the trial. Depending on herbicide active ingredients, plant visual injury symptoms manifested as chlorosis, bleaching, necrosis, leaf deformation, or general stunting. There was no statistical need to present the different rates separately until the 28 DAT rating because no statistical separation was found

(Table 2-2). At 28, 35, and 42 DAT there was a rate dependent interaction. Mesotrione and halosulfuron treatments exhibited injury from 7 DAT and increased injury levels by termination (42 DAT) when compared to the untreated control. Indaziflam, napropamide, *S*-metolachlor, and pendimethalin treatments exhibited injury levels under 5% throughout the trial and spanning both rates. The observed lack of injury in response to pendimethalin and *S*-metolachlor is consistent with field trials of established ‘Marion’ blackberries, where no injury or yield reduction was observed in response to the 1× and 2× rates of pendimethalin and an *S*-metolachlor rate (1.41 kg ai $ha^{-1}$) similar to the current 1× rate (Peachey 2012). Indaziflam has also previously been shown to inflict no injury to blackberries (Grey et al. 2021). When injury occurred, most herbicides exhibited increased injury over time; but in the last two weeks simazine injury levels did improve and injury was reduced by 2% and 3% for 1× and 2× rates, respectively (Table 2-2).

Treatments that resulted in stunting may not have caused dramatic visual symptoms initially, but later visual ratings detected higher injury levels due to contrast in growth from the untreated control. This contrast was particularly apparent in mesotrione, halosulfuron, and rimsulfuron treatments where initial injury ratings (7 DAT) were mild but were among the most injurious by 42 DAT when compared to the untreated control (Table 2-2). In field studies on established blackberries flumioxazin, simazine, oryzalin plus simazine, and *S*-metolachlor plus simazine resulted in no injury to the blackberry plants (Meyers et al. 2015). Thus, it may be justified that some of these preemergence herbicides are only registered for established blackberries, rather than new blackberry plantings. Despite a lack of significance according to statistical comparisons, there were observed differences between the 1× and 2× rates or oryzalin and simazine treatments and to a lesser extent flumioxazin and indaziflam treatments.

*Plant Height.* At 14 DAT plant height did not exhibit any significant differences between treatments or between treatments and the untreated control, when adjusted according to Tukey's honest significant difference (Table 2-3). However, differences in height were observed at 42 DAT. Mesotrione and halosulfuron treatments severely stunted plants, reducing heights by 70% and 67%, respectively; but they were found to not be significantly different from diuron, rimsulfuron, and sulfentrazone treatments which stunted the plants 40%, 46% and 38% respectively. Mesotrione, halosulfuron, diuron, rimsulfuron, and sulfentrazone treatments were also found to be significantly different from the untreated control at 42 DAT according to a Dunnett's test (Table 2-3). Reduced height likely resulted from combinations of leaf bleaching, chlorosis, and necrosis which all could impact energy production and thus growth. All other treatments resulted in acceptable blackberry plant growth and were found to be similar including oryzalin, simazine, flumioxazin, indaziflam, napropamide, *S*-metolachlor, and pendimethalin (Table 2-3).

*Internode Length.* At 14 DAT plant internode length did not display any significant differences between treatments, and none of the treatments differed from the untreated control (Table 2-3). At 42 DAT shortened internode length was evident in the mesotrione treatment which was found to be similar to the halosulfuron and sulfentrazone treatments. Diuron (20.59 mm) and rimsulfuron (17.08 mm) treatments also exhibited reduced internode length according to Tukey's Honest Significant Difference. Relative to the untreated control, mesotrione, halosulfuron, and sulfentrazone showed reduced internode length 96%, 85%, and 57%, respectively. At 42 DAT mesotrione, diuron, rimsulfuron, halosulfuron, and sulfentrazone treatments were significantly different from the untreated control according to Dunnett's procedure. The same selection of herbicides with reduced internode length exhibited reduced plant heights (Table 2-3), indicating that heights were reduced as a result of shortening of internodes (“stacking”) rather than fewer nodes per plant, though data were not collected on nodes per plant. Pedroso & Moretti (2022) found that *S*-metolachlor applied at three rates (Dual Magnum;1×=1.39 kg ai $ha^{-1}$), 1×, 2×, and 4×, to newly planted hazelnuts exhibited no effect on internode length which is congruent with the findings of this trial. The internode length of blackberries has been shown to vary by cultivar and in response to prohexidione-Ca, a plant growth regulator (Clark 2021; Johns 2022). Results from this trial indicate that preemergence herbicides can alter internode length and thus the stature and architecture of the plant and its canopy may also be affected; however, the majority of selected herbicides were not distinguishable from the untreated control regarding internode length (Table 2-3).

*Leaf Chlorophyll Content.* Leaf chlorophyll content evinced significant separation at 14 DAT, most notably from the mesotrione treatment (Table 2-3). Napropamide, *S*-metolachlor, and oryzalin at 14 DAT maintained the smallest reduction in leaf chlorophyll content overall. Mesotrione and halosulfuron exhibited reduced leaf chlorophyll content relative to the untreated control at 14 DAT. The greatest reductions in leaf chlorophyll content at 42 DAT were in response to treatments with mesotrione at the 1× and 2× rates, and diuron at the 2× rate, which reduced leaf chlorophyll content by 52%, 42%, and 42%, respectively, and were significantly different from the untreated control (Table 2-3).Though flumioxazin did not cause significant reduction of leaf chlorophyll content in the present blackberry trial, Saladin et al. (2003) reported a negative impact on photosynthesis and a reduction in foliar chlorophyll and carotenoids content when flumioxazin was applied to young grapes (*Vitis vinifera* L.). Flumioxazin treated plants exhibited some leaf necrosis in a speckled pattern which would account for some injury and lesser leaf chlorophyll content though neither was different from the untreated control (Table 2-2

& 2-3). Leaf chlorophyll content was affected most by treatments that caused bleaching (mesotrione) and plant death. Because mesotrione is a carotenoid biosynthesis inhibitor (HPPD inhibitor), it is not surprising that this treatment is most prominent in the assay that measures chlorophyll content (Shaner 2014; Anonymous 2018).

*Leaf Biomass and Total Aboveground Biomass*. Collection of leaf biomass and total aboveground biomass took place at 42 DAT during destructive harvest. No significant interaction of herbicide × rate interaction was observed when comparing leaf biomass among treatments (Table 2-4). Thus, the main effect herbicide active ingredient was consistent when compared across rates. Mesotrione and halosulfuron treatments recorded the lowest leaf biomass, less than 1 g per plant, and diuron (1.33 g) and rimsulfuron (1.35 g) treatments exhibited statistically similar reductions in biomass (Table 2-4). The pendimethalin treatment produced the most leaf biomass with an additional 0.76 g over the untreated control, though it was not significantly different. Mesotrione (0.4 g), diuron (1.3 g), rimsulfuron (1.3 g), and halosulfuron (0.5 g) had significantly less leaf biomass compared to the untreated control (3.9 g).

For total aboveground biomass production, a significant herbicide × rate interaction was observed, requiring the means to be presented separately for rate and herbicide (Table 2-4). Mesotrione (1×=1.5 g, 2×=1.2 g), rimsulfuron (1×=3.1 g, 2×=3.0 g), and halosulfuron (1×=1.8 g, 2×= 1.4 g) treatments had very low total aboveground blackberry plant biomass in both rates (Table 2-4). Diuron (2×=1.8 g), simazine (2×=4.4 g), and sulfentrazone (2×=4.9 g) treatments also had low total aboveground blackberry plant biomass but only at the 2× rate, which indicates a rate-dependent response for total biomass for these particular herbicides. The discrepancy between the 1× and 2× rates of diuron, simazine, and sulfentrazone demonstrate the necessity for proper calibration and adherence to product labels in order to avoid exceeding the 1× field rate and incurring avoidable damage to plants. According to Dunnett's procedure 1× rates of mesotrione, rimsulfuron, halosulfuron, oryzalin, and 2× rates of mesotrione diuron, rimsulfuron, simazine, halosulfuron, oryzalin, and sulfentrazone are significantly lower than the untreated control for total aboveground biomass. When oryzalin was applied at 0.6, 1.1, 2.2, 3.4, and 4.5 kg ai $ha^{-1}$ and at different timings after transplant date to sweetpotatoes (*Ipomea batatas*), some leaf distortion was observed; but it ultimately had no significant effect on yield (Chaudhari et al. 2018).

*Leaf Number and Leaf Area.* Leaf area and leaf number characterize the ability of the plant to grow. Reductions in leaf number indicate a developmental delay while reductions in leaf area indicate reduced photosynthetic area of the plant (whether due to fewer leaves or smaller leaves). At 42 DAT, the untreated plants were observed to have 26 leaves and a 1173 $cm^2$ leaf area. Mesotrione and halosulfuron treatments reduced those to 10 and 10 leaves per plant, respectively and to 59 $cm^2$ and 125 $cm^2$ leaf areas, respectively. Mesotrione and halosulfuron treatments had the lowest leaf number while mesotrione, halosulfuron, and rimsulfuron plots were similar with the lowest leaf area (Table 2-5). Mesotrione and halosulfuron were the only herbicides to significantly reduce leaf number relative to the untreated check. Interestingly, plants treated with pendimethalin were observed to have significantly increased leaf number (37) and leaf area (1603 $cm^2$) relative to the untreated control (26 and 1173 $cm^2$). This divergence from the expected pattern may be an example of hormesis, where plants were stimulated to increase growth. Hormesis is a dose-response phenomenon where otherwise inhibitory substances can stimulate plant growth at low rates and has specifically been observed in *Alopecurus myosuroides* treated with pendimethalin (Metcalfe et al. 2017; Belz & Duke 2014; Calabrese & Blain 2009). Mesotrione (59 $cm^2$), diuron (518 $cm^2$), rimsulfuron (352 $cm^2$), halosulfuron (125 $cm^2$), and oryzalin (737 $cm^2$) exhibited significantly lower leaf areas compared to the untreated control (1173 $cm^2$) (Table 2-5).

*Specific Leaf Area.* The untreated control for SLA was 400. Mesotrione, rimsulfuron, and halosulfuron treatments incurred the lowest SLA at the 1× rate (Table 2-5). The mesotrione treatment was found to be significantly different one from the untreated control according to the Dunnett's procedure with 59% reduction in SLA compared to the untreated control. The same chemicals at the 1× rate plus diuron, oryzalin, and sulfentrazone had the lowest SLA at the 2× rate. At the 2× rate mesotrione, diuron, and halosulfuron were found to be significantly different from the untreated control. Overall, the flumioxazin and pendimethalin treatments had the highest SLA across both rates. Flumioxazin did not display any significant symptoms in this trial, but Meyers et al. (2021) did find that flumioxazin reduced vine length and normalized difference vegetation index in watermelon.

*Leaf Area to Dry Matter Ratio.* The LADMR is the ratio of leaf area to total aboveground biomass, so a reduced LADMR indicates that a plant canopy is diminished with reduced leaf number or smaller leaves while an increased LADMR would indicate an increase in leaf number or leaf size, relative to the total biomass of the plant. The LADMR of untreated blackberries was 136. Mesotrione and halosulfuron treatments had the lowest LADMR at 1× and were found to be significantly lower than the untreated control (Table 2-5). Mesotrione, diuron, and halosulfuron in the 2× rate had the lowest values for LADMR and were found to be significantly lower than the untreated control.

**Conclusion**

While weed competition is an ever-present problem for blackberry growers, it is especially disruptive in new plantings. Chemical control has proven to be an effective asset within an IPM approach to weed management (Meyers et al. 2015). This trial's purpose was to evaluate the effect of preemergence herbicide applications and rates on blackberries with the intent to screen a wide variety of chemical compounds and to assess crop response to a selection of preemergence herbicides under controlled conditions. Of the chemical compounds investigated mesotrione, halosulfuron, rimsulfuron, diuron, and sulfentrazone treatments incurred the most visual injury and reduction in plant growth. Though mesotrione is labelled for use in caneberries (raspberries and blackberries), if mesotrione is needed on young plants a directed application may be best (Peachey 2012). Indaziflam could be considered for use in young unestablished plantings if labeling could be acquired and field data corroborated observations in this greenhouse trial. The 24(c) labeling for *S*-metolachlor in several states is supported by these findings and may be worth exploring for other states where alternative herbicides are not available. Simazine and oryzalin may not damage plants and are appropriate for use with the understanding that the margin of error is considerably small, a 2× rate incurred unacceptable levels of injury. Flumioxazin, napropamide, and pendimethalin treatments sustained little or no damage and corroborated their labeling designations and field use (Burgos et al. 2014; Meyers et al. 2020). This knowledge can further recommendations and field investigation that have the potential to lead to more informed IPM strategies.

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## Tables

**Table 2-1.** Herbicides tested in the greenhouse experiment on newly planted blackberries in Fayetteville, AR from 2021-2022.

| Common Name | Trade Name | Rate | Active Ingredient | Manufacturer | Manufacturer Location | Manufacturer Website |
|---|---|---|---|---|---|---|
| | | | g ai $ha^{-1}$ | | | |
| Oryzalin | Surflan® | 1× | 4483 | United Phosphorous, Inc. | King of Prussia, PA | https://www.upl-ltd.com/us |
| Oryzalin | Surflan® | 2× | 8967 | United Phosphorous, Inc. | King of Prussia, PA | https://www.upl-ltd.com/us |
| Napropamide | Devrinol® DF-XT | 1× | 4483 | United Phosphorous, Inc. | King of Prussia, PA | https://www.upl-ltd.com/us |
| Napropamide | Devrinol® DF-XT | 2× | 8967 | United Phosphorous, Inc. | King of Prussia, PA | https://www.upl-ltd.com/us |
| Pendimethalin | Prowl® H2O | 1× | 3363 | BASF | Research Triangle Park, NC | https://www.basf.com/us/en.html |
| Pendimethalin | Prowl® H2O | 2× | 6725 | BASF | Research Triangle Park, NC | https://www.basf.com/us/en.html |
| *S*-metolachlor | Dual Magnum® | 1× | 1597 | Syngenta Crop Protection, LLC | Greensboro, NC | https://www.syngenta-us.com/home.aspx |
| *S*-metolachlor | Dual Magnum® | 2× | 3194 | Syngenta Crop Protection, LLC | Greensboro, NC | https://www.syngenta-us.com/home.aspx |
| Flumioxazin | Chateau® | 1× | 210 | Valent U.S.A., LLC | San Ramon, CA | https://www.valent.com |
| Flumioxazin | Chateau® | 2× | 420 | Valent U.S.A., LLC | San Ramon, CA | https://www.valent.com |
| Mesotrione | Callisto® | 1× | 158 | Syngenta Crop Protection, LLC | Greensboro, NC | https://www.syngenta-us.com/home.aspx |
| Mesotrione | Callisto® | 2× | 315 | Syngenta Crop Protection, LLC | Greensboro, NC | https://www.syngenta-us.com/home.aspx |
| Simazine | Princep® | 1× | 11233 | Syngenta Crop Protection, LLC | Greensboro, NC | https://www.syngenta-us.com/home.aspx |
| Simazine | Princep® | 2× | 2466 | Syngenta Crop Protection, LLC | Greensboro, NC | https://www.syngenta-us.com/home.aspx |
| Diuron | Diuron 80-DF | 1× | 1569 | Alligare, LLC | Opelika, AL | https://alligare.com |
| Diuron | Diuron 80-DF | 2× | 3138 | Alligare, LLC | Opelika, AL | https://alligare.com |
| Halosulfuron | Sandea® | 1× | 53 | Gowan Company, LLC | Yuma, AZ | https://www.gowanco.com |
| Halosulfuron | Sandea® | 2× | 105 | Gowan Company, LLC | Yuma, AZ | https://www.gowanco.com |
| Rimsulfuron | Matrix® | 1× | 70 | Corteva™ Agriscience | Indianapolis, IN | https://www.corteva.com/contact-us.html |
| Rimsulfuron | Matrix® | 2× | 140 | Corteva™ Agriscience | Indianapolis, IN | https://www.corteva.com/contact-us.html |
| Indaziflam | Alion® | 1× | 50 | Bayer | St. Louis, MO | https://www.cropscience.bayer.us |
| Indaziflam | Alion® | 2× | 101 | Bayer | St. Louis, MO | https://www.cropscience.bayer.us |
| Sulfentrazone | Zeus® XC | 1× | 211 | FMC Corporation | Philadelphia, PA | https://www.fmc.com/en |
| Sulfentrazone | Zeus® XC | 2× | 420 | FMC Corporation | Philadelphia, PA | https://www.fmc.com/en |

**Table 2-2.** Visual injury ratings of young blackberries treated with soil-applied preemergence herbicides and at various rates in 2021 and 2022 greenhouse trials.[a]

| | 7 DAT[b] | 14 DAT | 21 DAT | 28 DAT | | 35 DAT | | 42 DAT | |
|---|---|---|---|---|---|---|---|---|---|
| Herbicide | Combined[c] | Combined | Combined | 1× | 2× | 1× | 2× | 1× | 2× |
| | % | | | | | | | | |
| Mesotrione | 7 a | 16 a | 36 a | 68 ab | 73 a | 75 ab | 86 a | 78 ab | 90 a |
| Diuron | 0 b | 3 c | 14 bc | 11 de | 50 abc | 13 c | 68 ab | 19 de | 73 ab |
| Halosulfuron | 3 ab | 10 b | 22 b | 34 cd | 45 bc | 58 b | 59 a | 58 bc | 68 ab |
| Sulfentrazone | 1 b | 3 c | 7 cd | 12 de | 16 de | 17 c | 21 c | 25 de | 34 cd |
| Oryzalin | 0 b | 0 c | 1 d | 2 e | 2 e | 2 c | 12 c | 4 e | 24 de |
| Rimsulfuron | 1 b | 0 c | 2 d | 4 e | 4 e | 8 c | 10 c | 18 de | 19 de |
| Simazine | 0 b | 2 c | 6 cd | 1 e | 17 de | 2 c | 21 c | 0 e | 17 de |
| Flumioxazin | 0 b | 0 c | 2 d | 0 e | 7 e | 0 c | 5 c | 1 e | 6 de |
| Indaziflam | 0 b | 0 c | 1 d | 0 e | 1 e | 0 c | 2 c | 1 e | 4 e |
| Napropamide | 0 b | 1 c | 4 cd | 1 e | 1 e | 0 c | 0 c | 1 e | 1 e |
| *S*-metolachlor | 0 b | 0 c | 0 d | 0 e | 0 e | 0 c | 1 c | 0 e | 0 e |
| Pendimethalin | 0 b | 0 c | 0 d | 0 e | 0 e | 0 c | 0 c | 1 e | 0 e |
| P-value[c] | <.0001 | <.0001 | <.0001 | 0.0011 | | <.0001 | | <.0001 | |

[a]Means were separated using Tukey's Honest Significant Difference at a $\alpha$=0.05 significance level and means followed by the same letter are not significantly different. Means should be compared by date (DAT).

[b]Abbreviation: DAT, days after treatment, 1× indicates the selected field rate for a herbicide, 2× indicates twice the field rate for a herbicide.

[c]Herbicide and rate effects were tested for any interaction effect. Where no significant herbicide × rate effect was detected, the main effect of herbicide is reported with rates combined. In cases where a significant herbicide × rate effect was detected; rates are presented as separate column

**Table 2-3.** Blackberry height, internode length, and leaf chlorophyll content response to soil-applied preemergence herbicides at two rates in 2021 and 2022 greenhouse trials.[a]

| Herbicide | Height 14 DAT[b] Combined | Height 42 DAT Combined | INL[b] 14 DAT Combined | INL[b] 42 DAT Combined | LCC[b] 14 DAT Combined | LCC[b] 42 DAT 1× | LCC[b] 42 DAT 2× |
|---|---|---|---|---|---|---|---|
| | cm | | mm | | SPAD | | |
| Mesotrione | 11.5 | 12.4 d* | 4.1 | 1.7 e* | 26.6 c* | 21.9 c* | 26.2 bc* |
| Diuron | 12.6 | 24.9 bcd* | 4.7 | 20.5 bcd* | 38.1 ab | 41.7 a | 26.5 bc* |
| Halosulfuron | 11.0 | 13.6 d* | 6.8 | 6.0 de* | 35.4 b* | 39.8 a | 41.1 a |
| Sulfentrazone | 11.2 | 25.7 bcd* | 4.1 | 17.0 cde* | 42.3 ab | 42.4 a | 44.1 a |
| Oryzalin | 11.7 | 34.0 abc | 6.6 | 23.4 abc | 44.2 a | 43.1 a | 45.6 a |
| Rimsulfuron | 10.7 | 22.3 cd* | 3.5 | 22.1 bcd* | 42.0 ab | 44.9 a | 43.9 a |
| Simazine | 12.1 | 33.0 abc | 4.5 | 29.2 abc | 40.1 ab | 40.4 a | 38.2 ab |
| Flumioxazin | 12.1 | 44.9 a | 7.9 | 35.5 ab | 38.8 ab | 43.1 a | 44.0 a |
| Indaziflam | 12.1 | 37.2 ab | 7.4 | 30.9 abc | 41.8 ab | 42.5 a | 42.0 a |
| Napropamide | 12.4 | 44.0 a | 8.7 | 35.4 ab | 43.3 a | 44.5 a | 42.5 a |
| *S*-Metolachlor | 12.4 | 42.5 a | 5.4 | 31.2 abc | 43.0 a | 41.9 a | 39.4 a |
| Pendimethalin | 12.9 | 46.7 a | 8.6 | 35.5 ab | 40.1 ab | 45.5 a | 42.9 a |
| Untreated | 11.3 | 41.6 | 5.5 | 39.2 | 42.0 | 45.3 | |
| P-value | 0.0326 | <.0001 | 0.0295 | <.0001 | <.0001 | 0.0263 | |

[a]Means were separated using Tukey's Honest Significant Difference at a α=0.05 significance level and means followed by the same letter are not significantly different. Means lacking letters were determined not to be significantly different following a Tukey's multiple comparisons adjustment. Untreated checks were excluded from analyses for which Dunnett's Procedure was used to compare each treatment combination to the untreated check. Means followed by an asterisk (*) are significantly different from the untreated according to Dunnett's procedure at an α=0.05 significance level. Means should be compared by date (DAT) by parameter.

[b]Abbreviations: INL, internode length; LCC, leaf chlorophyl content; DAT, days after treatment;

**Table 2-4.** Leaf biomass and total biomass reported from destructive harvest (42 DAT) of container-grown blackberry plants in response to preemergence herbicides.

| Herbicide | Leaf Biomass Combined | Total Aboveground Biomass 1× | 2× |
|---|---|---|---|
| | g | | |
| Mesotrione | 0.4 d* | 1.5 g* | 1.2 g* |
| Diuron | 1.3 cd* | 6.0 b-f | 1.8 g* |
| Halosulfuron | 0.5 d* | 1.8 g* | 1.4 g* |
| Sulfentrazone | 3.2 ab | 7.2 a-d | 4.9 c-g* |
| Oryzalin | 2.6 bc | 6.4 b-f* | 4.3 efg* |
| Rimsulfuron | 1.3 cd* | 3.1 fg* | 3.0 fg* |
| Simazine | 2.9 bc | 8.1 a-d | 4.4 d-g* |
| Flumioxazin | 3.7 ab | 9.1 ab | 7.9 a-e |
| Indaziflam | 3.5 ab | 7.7 a-e | 7.6 a-e |
| Napropamide | 3.8 ab | 9.3 ab | 8.2 a-d |
| *S*-Metolachlor | 3.8 ab | 8.8 ab | 8.3 abc |
| Pendimethalin | 4.6 a | 11.0 a | 10.6 a |
| Untreated | 3.9 | 8.4 | |
| P-value | <.0001 | 0.0482 | |

[a]Means were separated using Tukey's Honest Significant Difference at a $\alpha$=0.05 significance level and means followed by the same letter are not significantly different. Untreated checks were excluded from analyses for which Dunnett's Procedure was used to compare each treatment combination to the untreated check. Means followed by an asterisk (*) are significantly different from the untreated according to Dunnett's procedure at an $\alpha$=0.05 significance level.

[b]Abbreviation: DAT, days after treatment, 1× indicates the selected field rate for a herbicide, 2× indicates twice the field rate for a herbicide.

**Table 2-5.** Leaf number, leaf area, specific leaf area, and leaf area to dry matter ratio reported from destructive harvest (42 DAT) of container-grown blackberries treated with soil-applied preemergence herbicides.[a]

| Herbicide | Leaves Combined | Leaf Area Combined | SLA[a] | | LADMR[a] | |
|---|---|---|---|---|---|---|
| | | | 1× | 2× | 1× | 2× |
| | ——no.—— | ——$cm^2$—— | | | | |
| Mesotrione | 10 e* | 59 h* | 165 def* | 107 f* | 52 de* | 30 e* |
| Diuron | 20 cd | 518 efg* | 443 abc | 147 ef* | 150 a | 49 de* |
| Halosulfuron | 10 e* | 125 gh* | 303 b-f | 201 c-f* | 79 b-e* | 60 cde* |
| Sulfentrazone | 27 bcd | 966 bcd | 401 a-d | 324 a-f | 133 a | 125 ab |
| Oryzalin | 23 bcd | 737 def* | 386 a-e | 313 a-f | 140 a | 103 a-d |
| Rimsulfuron | 19 d | 352 fgh* | 306 b-f | 320 a-f | 114 abc | 107 abc |
| Simazine | 28 bc | 896 cde | 432 abc | 367 a-d | 122 ab | 140 a |
| Flumioxazin | 29 ab | 1303 abc | 491 ab | 556 a | 149 a | 144 a |
| Indaziflam | 30 ab | 1168 a-d | 438 abc | 433 abc | 144 a | 140 a |
| Napropamide | 31 ab | 1349 ab | 445 abc | 485 ab | 154 a | 146 a |
| *S*-Metolachlor | 30 ab | 1283 abc | 435 abc | 460 ab | 137 a | 152 a |
| Pendimethalin | 37 a* | 1603 a* | 498 ab | 494 ab | 146 a | 146 a |
| Untreated | 26 | 1173 | 400 | | 136 | |
| | | | | | | |
| P-value | <.0001 | <.0001 | 0.0292 | | <.0001 | |

[a]Abbreviations: DAT, days after treatment; SLA, specific leaf area; LADMR, leaf area to dry matter ratio

[b]Means were separated using Tukey's Honest Significant Difference at a $\alpha$=0.05 significance level and means followed by the same letter are not significantly different. Untreated checks were excluded from analyses for which Dunnett's Procedure was used to compare each treatment combination to the untreated check. Means followed by an asterisk (*) are significantly different from the untreated according to Dunnett's procedure at an $\alpha$=0.05 significance level.

## Chapter 3. Preemergence Herbicide Use in Newly Transplanted Blackberries

### Abstract

Weed control is an ongoing component of blackberry production and with few in-season postemergence herbicide options available, growers rely on preemergence herbicides to maintain clean fields. This trial assesses some of the preemergence herbicide options available and unavailable to growers and their effect on newly transplanted blackberries (*Rubus* L. subgenus *Rubus* Watson). This two-year field trial was initiated in 2021 and conducted at two locations: Milo J. Shult Research and Extension Center in Fayetteville, AR and the Fruit Research Station in Clarksville, AR. Seven treatments consisting of six preemergence herbicides (mesotrione, flumioxazin, oryzalin, *S*-metolachlor, pendimethalin, and napropamide) and one non-chemical weed-free (NCWF) check were applied to field plots of newly-transplanted tissue culture propagated blackberry plugs (var. 'Ouachita'). Preemergence herbicide treatments were applied with a $CO_2$ backpack sprayer at 187 L/ha covering a 1 m swath), ensuring spray pattern overlap over newly planted blackberries in 2021 and reapplied in the same manner to established blackberries of the same plots in 2022. Data was collected on visual injury, plant height, chlorophyll content, and green coverage of blackberry canopies and of bare ground portions of each plot. Yield data was collected in the second year, and fruit were analyzed for soluble solids content (°Brix), pH, and average berry weight. In the first year mesotrione and flumioxazin treatments caused significant injury to newly transplanted blackberries, and mesotrione treatments (58% - Fayetteville, 29% - Clarksville) did not fully recover by 84 days after treatment (DAT). Napropamide, *S*-metolachlor, oryzalin, and pendimethalin did not exhibit injury over 6% throughout the 2021 season. In the second year (2022) no injury was incurred by any treatments. Results from these trials verify that labeled products flumioxazin, napropamide,

oryzalin, and pendimethalin at the tested rates would be appropriate options for weed control in newly planted blackberries. These results corroborate regional recommendations against the use of mesotrione use in first year blackberry plantings. The findings from this trial indicate *S*-metolachlor would be safe for registration for use in blackberries, with regard to crop visual injury and to blackberry yield.

## Introduction

The presence of weeds is disruptive to commercial horticulture production because weeds consume nutrients, light, and water resources that would otherwise be available to the crop. Crop yield loss and lower crop quality can result from competition, allelopathy, and harvest impediment (Dixon et al. 2016; Egushova & Anokhina 2022; Li et al. 2016). Blackberries (*Rubus* L. subgenus *Rubus* Watson), like other perennial crops, increasing weed pressures that accumulate over many growing seasons. Further, weeds may cause indirect losses to blackberry production by reducing efficiency of harvest. Dixon et al. (2016) conducted a trial to investigate effects of weed control options and their effect on machine harvesting, and the non-weeded treatments required use of a string-trimmer to remove vegetation just prior to harvest for the machine harvester to access the plots. Blackberries are most commonly hand-harvested, and the presence of weeds such as poison ivy (*Toxicodendron radicans* (L.) *Kuntze*), horsenettle (*Solanum carolinense* L.), and Canada thistle (*Cirsium arvense* (L.) *Scop*.) can cause interference or harm to harvesters. Pick-your-own or agritourism operations invite the public to pick blackberries, and the presence of spiny, poisonous, or irritating plants is off-putting and potentially harmful to clientele for both utilitarian and aesthetic purposes. A survey of consumers found that over 40% of respondents had purchased blackberries at a pick-your-own operation one or more times in a year (Threlfall et al. 2021). While weeds can affect harvest, they can also provide both insect and disease pathogen pests a habitat in which to thrive (Agustí-Brisach et al. 2011; Herrera 2017). Maintaining a weed-free field is paramount to success for blackberry growers (Burgos et al. 2014). Weed control was identified as a key area for research and extension according to a national stakeholder survey of blackberry growers across the United States (Worthington et al. 2020).

Best management practices recommend a 0.9 m weed-free strip width (WFSW) for young, unestablished blackberries and a 1.2 m WFSW for older established plantings (Basinger et al. 2017; Childers et al. 1995; Fernandez & Ballington 1999; Meyers et al. 2014; Meyers et al. 2015). A WFSW pertains to weeds in-row and extends into the row middles. A combination of weed management strategies is often used in blackberries because growers must address weed pressures year-round (Mitchem & Jennings 2022). To maintain a WFSW, landscape fabric, mulches, and chemical controls are utilized in the field (Makus 2010, 2011; Zhang et al. 2019). Hand weeding is not ordinarily an economic option due to the high cost of labor and its time intensive nature (Harkins et al. 2013; Monaco 2002; Olmstead et al. 2012). Polyethylene mulch reduced weed populations in raspberries (*Rubus idaeus*) by more than 95% relative to the bare ground plots (Zhang et al. 2019). When establishing a field, it is customary to install polyethylene mulch or landscape fabric directly under and around young plants then employ a chemical control to maintain the WFSW that is not covered with landscape fabric. After two to three years polyethylene mulch will break down due to the elements and traffic while fabric generally lasts the life of the planting. Polyethylene mulch is not usually replaced, and the WFSW is then maintained with organic plant-based mulches and herbicides. Chemical controls are cost- and time-effective in mature and newly planted blackberries (Meyers et al. 2014; Meyers et al. 2015). Versatile herbicide application techniques, such as banding, directed sprays, shielded, or hooded sprayers, automated devices, and precision spray applications afford growers some flexibility in their production systems (Fennimore et al. 2016; Fennimore & Cutulle 2019; Hunter et al. 2019; Warneke et al. 2020).

In-season herbicide options for postemergence weed control in blackberry are limited. Preemergence herbicides are used to prevent weed germination and emergence as spring temperatures rise. Preemergence herbicides prevent weed encroachment at the start of the season, but breakdown will occur requiring a sequential application of a preemergence herbicide or the use of a postemergence herbicide in summer or fall (Mitchem & Jennings 2022). Herbicide modes of action (MOA) should be rotated to reduce the risk of herbicide resistance (Mitchem & Jennings 2022; Norsworthy et al. 2012). Approved herbicides often have label restrictions based on crop growth stage and establishment status. Thus, there is a need for expanded registration or registration of new products.

Young blackberry plantings are delicate and are vulnerable to outside stressors which can include the herbicides intended to prevent weeds and this concept encapsulates why finding chemical control options are so difficult. The objectives of this study were to determine the effect of preemergence herbicide applications on establishment and growth of newly transplanted blackberries in Arkansas and to generate data on weed control and crop response that can be utilized for regional recommendations and applications for supplemental labels for herbicides for blackberries grown in the southern region of the continental United States of America.

**Materials and Methods**

A two-year field trial was initiated in 2021 and conducted at two University of Arkansas System Division of Agriculture agricultural experiment stations: Milo J. Shult Research and Extension Center in Fayetteville, AR (36.09 ºN, 94.17 ºW) and the Fruit Research Station in Clarksville, AR (35.53 ºN, 93.40 ºW). The soil series in Fayetteville and Clarksville were a Capatina silt loam and Linker fine sandy loam, respectively. Tissue culture propagated blackberry plugs (var. 'Ouachita') were received on April 22, 2021, from a commercial nursery (Agri-Starts, 1728 Kelly Park Rd. Apopka, FL 32712) in 72-cell trays then repotted five days later into 0.6 L containers with general use potting soil (PRO-MIX BX Mycorrhizae, Pro-Mix, 200 Kelly Rd. Unit E-1, Quakertown, PA 18951 USA) and kept in a greenhouse until transplanting in the field. Blackberries were retained in the containers for less than one month, and plants were approximately 30 cm tall with six leaves at the time of transplanting in the field. Blackberries were transplanted on May 7 and on May 14 of 2021 at Clarksville and in Fayetteville, AR field trial locations, respectively. Plots measured 2.4 m in length and included four blackberry plants at a 0.6 m spacing with a 1.2 m in-row gap to separate each plot. A total of seven treatments were included: six preemergence herbicides and one non-chemical weed-free (NCWF) check (Table 3-1). Immediately following transplanting, preemergence herbicide treatments were applied using a $CO_2$-powered backpack sprayer (8002 VS flat fan nozzles), calibrated to deliver 187 L/ha covering a 1 m swath on each side of the planting rows. Herbicide applications were completed in two passes, one on each side of the plant row, ensuring overlap of spray coverage of the soil beneath blackberry transplants an of their canopies. Treatments were applied annually to the same plot with corresponding rates of each herbicide (Clarksville - May 7, 2021 and March 16, 2022, Fayetteville – May 14, 2021 and March 24, 2022) (Table 3-1).

At the time of this trial mesotrione, flumioxazin, and napropamide are labeled for use in blackberries (Anonymous 2012; Anonymous 2018; Anonymous 2021). Though oryzalin is labeled for use in blackberries, this labeling is specific to nonfruit bearing plantings (Anonymous 2011). The active ingredient pendimethalin is labeled for use in blackberries through the registration Satellite HydroCap® (Anonymous 2017). While Prowl® H2O was used in this trial and is not labeled for use in blackberries, the data is still applicable because the concentrations of active ingredient are identical (Anonymous 2021a). *S*-metolachlor is not labeled for use in blackberries with a section 3 label; however, a section 24(c) special local need (SLN) labels had been awarded to Oregon and North Carolina (Anonymous 2020). Arkansas acquired the same

SLN label for *S*-metolachlor in 2022. Napropamide and oryzalin are recommended for use in blackberries of all growth stages (Burgos et al. 2014, Mitchem & Jennings 2022). Flumioxazin and mesotrione are recommended for use in established plantings by the caneberry spray guide (Mitchem & Jennings 2022).

Maintenance sprays of fungicides and insecticides were applied based on scouting and in accordance with regional recommendations (UGA 2022). Dormant and in-season sprays were also applied for disease and insect management. Preplant fertilizer was applied to both locations at 325 kg/ha of 19-19-19 in 2021 and 392 kg/ha of 20-20-20 in 2022. In 2021, fertilizer was applied preplant and in 2022, fertilizer was applied thru the drip irrigation system. As blackberries grew, primocanes were trained, tipped, and secured to the trellis wire with flagging tape (Presco flagging tape) and kiwiclips (Trellis Ties – 4” – KLIP4, Orchard Valley Supply 3800 NE Three Mile Lane, McMinnville, OR 97128) to promote upright growth. End-of-season pruning to remove extraneous primocanes leaving 3 to 5 primocanes per plant and heading back cuts of the laterals were made to take the laterals back to 30 to 45 cm long. Tipping was completed on the primocanes at the end of the first season.

Non-chemical weed-free (NCWF) plots were hand-weeded at least once each week to keep weed populations from negatively affecting plant growth and yield. The NCWF plots did not receive maintenance applications of chemical for weed control other than one dormant burndown application between growing seasons that all plots received. Weed populations were monitored in other plots on a weekly basis. The emergence of annual weed species was considered an indicator that a preemergence herbicide was no longer effective. Data were collected on timing of the failure of each preemergence herbicide, based on weekly scouting to identify when grass weed species reached the target size of 5 to 20 cm tall. Once the grass species had reached that growth stage, a shielded application of fluazifop (Fusilade; 1× = 876.9 g ai $ha^{-1}$ Syngenta Crop Protection, P.O. Box 18300, LLC, Greensboro, NC 27416-8300) was applied on each side of the blackberry plots once herbicide breakdown was determined. Broadleaf weeds, sedges, and any remaining weeds were removed by hand after herbicide breakdown also. Species observed in this trial included large crabgrass (*Digitaria sanguinalis* (L.) Scop.), eclipta (*Eclipta prostrata* (L.) L.), common groundsel (*Senecio vulgaris* L.), carpetweed (*Mollugo verticillate* L.), cutleaf evening-primrose (*Oenothera laciniata* Hill), goosegrass (*Eleusine indica* (L.) Gaertn.), yellow nutsedge (*Cyperus esculentus* L.), and ladysthumb (*Persicaria maculosa* Gray) at both locations.

Data were collected on visual injury, plant height, leaf chlorophyll content, and bare ground and plant photos for Turf Analyzer (Green Research Services, 2958 S Country Club Dr, Fayetteville, AR 72701). Overhead images were captured with a handheld camera (Nikon Z50 mirrorless camera, Nikon Inc., 1300 Walt Whitman Road, Melville, NY 11747-3064) from a fixed height of 0.94 m above the ground. These photos included overhead images of the treated area alongside the plant (bare ground images) and overhead images of two blackberry plants (plant images) and were then cropped to a fixed pixel size (Photoshop, Adobe Systems Inc. 345 Park Ave., San Jose, CA 95110-2704), then analyzed for green cover to determine blackberry canopy coverage and weed coverage for plant images and bare ground images, respectively. Given the divergent symptoms from the selected herbicides, visual injury ratings were assessed based on a collection of visible plant attributes such as plant stature and height as well as leaf discoloration as bleaching, chlorosis, or necrosis. Using these parameters, plant injury was visually assessed on a 0 to 100 scale with 0 representing a plant exhibiting no symptoms distinguishable from the NCWF check and 100 representing a dead plant. Leaf chlorophyll content was measured using a SPAD meter (SPAD-502Plus, Konica Minolta, 101 Williams Drive, Ramsey, NE 07446). Height was measured from two representative plants in the plot at 7, 14, 28, 42, 56, and 84 DAT in the first year. A measuring tape was placed at the base of the plant and measured to the highest point of the plant.

Yield data was taken only in the 2022 season due to Ouachita being a floricane fruiting variety that only fruits on second-year canes. Yield data consisted of marketable, cull, and average berry weights from 25 berries. Marketable berries were designated as ripe black fruit unblemished and with no damage. Berries designated as culls were chosen due to damage by insects, birds, or other animals, disease, or malformation due to incomplete or improper fertilization or development, or environmental damage such as sun scald. Weights were measured with a scale (Model: NV3202, OHAUS Corporation, 7 Campus Dr. STE 310, Parsippany, NJ 07054) in the field. Ten representative berries from each plot were harvested, placed on ice, then frozen for analysis of pH and soluble solids content (°Brix). Frozen berries were thawed, and juice was extracted. Soluble solids were measured using a refractometer (Atago Pocket Refractometer, 14432 SE Eastgate Way Ste 450 Bellevue, WA 98007), and pH was measured using a benchtop pH meter (Fisherbrand™ accument™AE150 Benchtop pH Meter, 300 Industry Drive, Pittsburgh, PA 15275).

All data were subjected to ANOVA as a randomized complete block design using the GLIMMIX procedure in SAS, version 9.4 (SAS Institute Inc., Cary, NC). Main effects of herbicide and location as well as the interaction of herbicide × location was treated as fixed effects, while block (nested in location) was treated as a random effect. Assessments related to weed control included year as a main effect; thus, for those data, main effects of herbicide, year, and their interactions were treated as fixed effects, while block (nested in year × location) was treated as a random effect. Analysis, such as injury, height, green cover, bare ground, yield, and fruit quality, was conducted separately by year for all blackberry measurements, as plants from year 1 and year 2 represented distinct growth stages. Data were checked for heteroscedasticity by reviewing residual plots from SAS, and means were separated using Tukey's Honest Significant Difference multiple comparisons adjustment ($\alpha = 0.05$) (Tukey 1973).

**Results and Discussion**

*Visual Injury.* At 7 DAT plants in plots treated with flumioxazin in both locations had the highest visual injury at 10% in 2021 (Table 3-2). In the following weeks the flumioxazin treated plots dropped to under 5% injury by 42 DAT. Mesotrione also inflicted injury observed at 7 DAT and remained high 84 DAT, at 58% in Fayetteville and 29% in Clarksville. At the end of the 2021 season mesotrione-treated plots no longer displayed bleaching but were stunted when compared to the NCWF check. Oryzalin, *S*-metolachlor, pendimethalin, and napropamide never caused above 6% injury throughout the 2021 season. Peachey (2012) observed a similar lack of injury with pendimethalin and *S*-metolachlor (1.41 kg ai $ha^{-1}$) on 'Marion' blackberries. The visual injury of the herbicide treatments were not statistically significant at any time throughout the 2022 season (data not shown). In previous field studies, flumioxazin, oryzalin plus simazine, and *S*-metolachlor plus simazine did not injure established blackberry plantings (Meyers et al. 2015). The younger plants in the first season experienced higher levels of injury than the older plants in the second season. The levels of injury observed were anticipated because the plants in the first year were expected to be more sensitive and vulnerable to the herbicide treatments. The findings of Meyers et al. (2015) agree with the results for second year plants.

*Leaf Chlorophyll Content.* Leaf chlorophyll content was measured in 2021 and 2022. A significant reduction in leaf chlorophyll content was first observed in 2021 at 14 DAT for the mesotrione treatment and this effect carried through until 42 DAT (Table 3-3). At 42 DAT the mesotrione treatment exhibited a 14% reduction in leaf chlorophyll content relative to the NCWF check. Oryzalin, *S*-metolachlor, and napropamide were not significantly different from the NCWF check. Leaf chlorophyll content was affected in treatments that also resulted in visual injury ratings. This was expected with mesotrione, given that it is a carotenoid biosynthesis inhibitor (HPPD inhibitor) (Shaner 2014). Flumioxazin has been shown to reduce foliar chlorophyll in grapes (*Vitis vinifera* L.) (Saladin et al. 2003). Herbicide treatments had no significant effect on leaf chlorophyll content at any rating dates in 2022 which aligns with the lack of visual injury observed in the second season (Table 3-3).

*Plant Height.* Plant height was measured only in 2021 because in the 2022 growing season best practices required tip pruning that kept plants heights about 10 cm above the top trellis wire. One week after treatments (7 DAT), the plant heights did not differ (Table 3-4). By 14 DAT, some reduction in blackberry plant height was apparent in plots treated with flumioxazin relative to other herbicide treatments; however, the reduction was not distinguishable from the NCWF check. No variation of plant height was observed at 28 DAT. Mesotrione had the shortest plant heights at 42, 56, and 84 DAT. At 84 DAT, the reductions in plant height were substantial with mesotrione plants reaching only 48% and 36% of the NCWF checks in Fayetteville and Clarksville, respectively. All plants, except plants treated with mesotrione, were not statistically different from the NCWF check in both locations at 84 DAT.

*Percent Bare Ground and Percent Blackberry Green Cover*. Significant differences were detected in percent bare ground at both 14 DAT and 28 DAT in 2021, and the differences were larger numbers of green pixels detected in the NCWF check likely due to better overall coverage of the chemicals that cannot be achieved from hand weeding (Table 3-5). While statistical differences were detected in 2021, it is worth noting that all treatments-maintained percent bare ground ≥97%, indicating effective weed control and a lack of undesirable vegetation in all plots, treated and in the NCWF check. The 2022 data showed no significant effect of herbicide treatments with regard to percent bare ground (Table 3-5). Visual assessments of bare ground area were similar to image analysis, but data from visual assessments were too uniform and not suited to ANOVA (data not shown). Treatments were applied earlier in the 2022 season, according to timings for best management practices. Blackberry green cover was only recorded in 2021 due to the inability to capture overhead images that accurately reflect the vertical canopy (Table 3-5). Blackberry green cover was not different across treatments at 7 DAT, but flumioxazin and mesotrione had the lowest green cover at 14 and 28 DAT compared to all other treatments. At 42 DAT mesotrione (14.0%) had the smallest canopy cover and flumioxazin (33.1%) was still significantly reduced relative to rest of the treatments and the NCWF check. The dramatic reductions in green cover for the mesotrione treatment were likely due to both reduced leaf chlorophyll content and its effect on the ability of the plant to photosynthesize and grow and the overall smaller plants.

*Yield*. The effect of herbicide or herbicide × location was not significant on blackberry yield at any harvest timing, cumulative harvest or average berry weight (Table 3-6). This was a surprising result, considering the mesotrione treatment caused severe crop injury, reduced plant height, and reduced blackberry green cover in the 2021 season (Table 3-2, 3-3, 3-4). This finding indicates that blackberry plants recover from initial injury from mesotrione and produce similar yields to non-injured plants. A possible explanation of recovery could be that pruning activity between 2021 and 2022 brought all blackberry plots back to a similar growth status and plant stature. Then, the second-year plants were not sensitive to the mesotrione applications; however, no data was collected on pruning weights to determine this for certain. Despite consistent yields, the high levels of injury caused by mesotrione support the current commercial recommendation to apply the product only to established blackberries (Mitchem & Jennings 2022). Other studies and best practices have shown that maintaining the WFSW keeps plants healthy which in turn promotes yield (Basinger et al. 2017; Childers et al. 1995; Fernandez & Ballington 1999; Meyers et al. 2014; Meyers et al. 2015). Throughout this trial the WFSW was maintained for all plots, so any disparities in yield can be attributed to the effects of the preemergence herbicide rather than weed interference.

*Postharvest quality.* Fruit quality is important for consumers, particularly for fresh market crops, like blackberry (Threlfall et al. 2016). Thus, it is critically important to assess quantitative traits that characterize fruit quality of blackberries in response to the selected herbicides. Similar to the findings with yields, no detrimental effects of herbicides on fruit quality were observed (Table 3-6 & 3-7). Blackberry pH varied more greatly between harvests than among herbicide treatments. No substantial variation in pH or °Brix was observed among and treatments or harvests. These findings are consistent with other work which has demonstrated measures of soluble solids content or pH are generally maintained under most stressors or fertility source (Basinger et al. 2017; Meyers et al. 2014). Fruit quality such as soluble solids and firmness are often determined by cultivar selection, or the rate of fertilizers applied (Fernandez-Salvador et al. 2015; Nelson & Martin 1986). Therefore, herbicides in this trial had no negative effects on any measurable trait associated with fruit quality and would offer no cause for concern for commercial blackberry production.

**Conclusion**

Broadening chemical control options and producing data that can inform recommendations were the driving forces for investigation. Though the mesotrione treatment did inflict unacceptable levels of damage in the first year (2021) there was no statistical difference in yield the following year (2022). Flumioxazin did inflict injury at unacceptable levels but quickly grew out of the damage and was, in most cases, statistically similar to the NCWF check in 2021 and caused no injury in 2022 at all. Oryzalin, *S*-metolachlor, napropamide, and pendimethalin exhibited no detrimental effect to blackberries in our trials. No statistical evidence was found to demonstrate yield reductions or a decrease in fruit quality in response to preemergence herbicide treatments. In 2022, when plants were more established, there were no detectable effects of preemergence herbicides on leaf chlorophyll content, visual injury, yield, or fruit quality. This field trial found that damage observed in the first year (2021) did not affect fruit quality or yield in the following season. Based on results from this trial, mesotrione and flumioxazin would not be recommended for use as a broadcast application with potential foliar interception in first year blackberry plantings due to the unacceptable levels of injury observed. These findings validate many of the regional recommendations and provide new evidence to consider expanding registration and labeled usage requirements for materials such as oryzalin, *S*-metolachlor, and pendimethalin. It is important to acknowledge the inability of this research to predict the effects of the selected herbicides on first year harvests from primocane-fruiting blackberry varieties. While we observed no deleterious yield effects of selected herbicides in second year harvests, it is possible that the injury symptoms could reduce yields in first year primocane harvests. More research would need to be conducted to specifically quantify those responses, but there is evidence that unacceptable levels of injury were observed in response to mesotrione in first year plantings, regardless of yield outcomes.

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## Tables

**Table 3-1.** Herbicides tested in the field experiment on newly planted blackberries in Fayetteville, AR and Clarksville, AR from 2021-2022.

| Common Name | Trade Name | Active Ingredient | Manufacturer | Manufacturer Location | Manufacturer Website |
|---|---|---|---|---|---|
| | | g ai $ha^{-1}$ | | | |
| Mesotrione | Callisto® | 158 | Syngenta Crop Protection, LLC | Greensboro, NC | https://www.syngenta-us.com/home.aspx |
| Flumioxazin | Chateau® | 210 | Valent U.S.A., LLC | San Ramon, CA | https://www.valent.com |
| Oryzalin | Surflan® | 4483 | United Phosphorous, Inc. | King of Prussia, PA | https://www.upl-ltd.com/us |
| *S*-Metolachlor | Dual Magnum® | 1597 | Syngenta Crop Protection, LLC | Greensboro, NC | https://www.syngenta-us.com/home.aspx |
| Pendimethalin | Prowl® H2O | 3362 | BASF | Research Triangle Park, NC | https://www.basf.com/us/en.html |
| Napropamide | Devrinol® | 4483 | United Phosphorous, Inc. | King of Prussia, PA | https://www.upl-ltd.com/us |

**Table 3-2.** Visual injury ratings of blackberry plots in response to preemergence herbicide treatments at Fayetteville, AR and Clarksville, AR at 7, 14, 28, 42, 56, and 84 DAT in 2021.[a]

| | Visual Injury[b] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Herbicide | 7 DAT[c] | | 14 DAT | | 28 DAT | | 42 DAT | 56 DAT | 84 DAT | |
| | MJS | FRS | MJS | FRS | MJS | FRS | Combined | Combined | MJS | FRS |
| | % | | | | | | | | | |
| Mesotrione | 5 bc | 6 b | 10 abc | 13 ab | 31 a | 13 b | 56 a | 41 a | 58 a | 29 b |
| Flumioxazin | 10 a | 10 a | 7 bcd | 15 a | 13 b | 3 bc | 3 b | 4 b | 3 c | 0 c |
| Oryzalin | 2 cd | 0 d | 4 cde | 0 e | 5 bc | 0 c | 1 b | 1 b | 4 c | 0 c |
| *S*-Metolachlor | 5 bc | 0 d | 0 e | 0 e | 0 c | 1 c | 0 b | 1 b | 1 c | 0 c |
| Pendimethalin | 1 d | 0 d | 1 de | 1 de | 3 bc | 0 c | 0 b | 0 b | 0 c | 0 c |
| Napropamide | 0 d | 0 d | 0 e | 0 e | 0 c | 0 c | 0 b | 1 b | 1 c | 0 c |
| P-value | 0.0004 | | 0.0053 | | 0.0005 | | <.0001 | <.0001 | 0.0013 | |

[a]Means were separated using Tukey's Honest Significant Difference at a $\alpha$=0.05 significance level and means followed by the same letter are not significantly different. Means should be compared by date (DAT).

[b]Herbicide and rate effects were tested for any interaction effect. Where no significant herbicide × location effect was detected, the main effect of herbicide is reported with location combined. In cases where a significant herbicide × location effect was detected; locations are presented as separate columns.

[c]Abbreviations: DAT, days after treatment; MJS, Milo J. Shult – Fayetteville location; FRS, Fruit Research Station – Clarksville location

**Table 3-3.** Blackberry leaf chlorophyll content in response to herbicide treatments to 2021 and 2022 at similar timing intervals.[a]

| | Leaf Chlorophyll Content[b] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 2021 | | | | 2022 | | | |
| Herbicide | 7 DAT[c] | 14 DAT | 28 DAT | 42 DAT | 28 DAT | 35 DAT | 49 DAT | 63 DAT |
| | SPAD | | | | | | | |
| Mesotrione | 38.5 | 33.3 b | 34.8 b | 35.8 b | 42.6 | 41.5 | 47.1 | 45.5 |
| Flumioxazin | 39.4 | 42.2 a | 45.9 a | 39.5 ab | 41.8 | 41.7 | 47.5 | 47.9 |
| Oryzalin | 40.3 | 42.3 a | 34.8 a | 42.0 a | 41.6 | 42.8 | 47.1 | 47.5 |
| *S*-Metolachlor | 40.5 | 43.2 a | 48.0 a | 42.6 a | 39.8 | 43.7 | 46.1 | 47.2 |
| Pendimethalin | 39.5 | 42.5 a | 48.4 a | 40.4 ab | 41.8 | 43.7 | 48.9 | 47.1 |
| Napropamide | 42.2 | 42.8 a | 47.4 a | 41.0 a | 42.6 | 43.6 | 45.8 | 47.4 |
| Handweeded | 40.2 | 43.2 a | 45.8 a | 41.7 a | 40.0 | 41.4 | 47.9 | 46.4 |
| P-value | 0.1176 | <.0001 | <.0001 | 0.0017 | 0.2529 | 0.4505 | 0.2453 | 0.5945 |

[a]Means were separated using Tukey's Honest Significant Difference at a $\alpha$=0.05 significance level and means followed by the same letter are not significantly different. Means should be compared by date (DAT).

[b]Herbicide and rate effects were tested for any interaction effect. Where no significant herbicide × location effect was detected, the main effect of herbicide is reported with location combined.

[c]Abbreviation: DAT, days after treatment

**Table 3-4.** Blackberry heights in response to herbicide treatments for 2021 at Fayetteville, AR and Clarksville, AR at 7, 14, 28, 42, 56, and 84 DAT.

| | Blackberry Plant Height[b] | | | | | | |
|---|---|---|---|---|---|---|---|
| Herbicide | 7 DAT[c] | 14 DAT | 28 DAT | 42 DAT | 56 DAT | 84 DAT | |
| | Combined | Combined | Combined | Combined | Combined | MJS | FRS |
| | cm | | | | | | |
| Mesotrione | 11.3 | 11.0 a | 11.6 | 13.1 b | 20.5 b | 78.7 ef | 59.8 f |
| Flumioxazin | 10.5 | 9.3 b | 11.8 | 19.4 a | 34.3 a | 132.5 a-d | 117.8 b-e |
| Oryzalin | 11.3 | 11.1 a | 13.5 | 23.0 a | 35.4 a | 134.7 a-d | 109.1 cde |
| *S*-Metolachlor | 10.4 | 11.1 a | 19.2 | 21.2 a | 39.4 a | 141.7 a-d | 109.7 cde |
| Pendimethalin | 10.9 | 11.6 a | 13.3 | 22.3 a | 35.8 a | 147.0 abc | 105.8 de |
| Napropamide | 10.8 | 10.8 ab | 13.0 | 22.6 a | 39.1 a | 156.2 ab | 108.3 cde |
| Handweeded | 10.4 | 10.8 ab | 12.6 | 23.1 a | 35.4 a | 165.3 a | 104.1 de |
| P-value | 0.5268 | 0.0042 | 0.3748 | <.0001 | <.0001 | 0.0455 | |

[a]Means were separated using Tukey's Honest Significant Difference at a $\alpha$=0.05 significance level and means followed by the same letter are not significantly different.

[b]Herbicide and rate effects were tested for any interaction effect. Where no significant herbicide × location effect was detected, the main effect of herbicide is reported with location combined. In cases where a significant herbicide × location effect was detected; locations are presented as separate columns.

[c]Abbreviations: DAT, days after treatment; MJS, Milo J. Shult – Fayetteville location; FRS, Fruit Research Station – Clarksville location

**Table 3-5.** Bare ground percent cover for both years (2021-2022) and plant cover for 2021 Fayetteville, AR and Clarksville, AR in response to herbicide treatments.[a]

| | Percent Bare Ground[b] | | | | | Blackberry Green Cover | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2021 | | | 2022 | | 2021 | | | |
| | 14 DAT[c] | 28 DAT | | 14 DAT | 28 DAT | 7 DAT | 14 DAT | 28 DAT | 42 DAT |
| Herbicide | Combined | MJS | FRS | Combined | Combined | Combined | Combined | Combined | Combined |
| | % | | | | | | | | |
| Mesotrione | 99.95 a | 98.64 ab | 99.98 a | 99.57 | 98.12 | 3.3 | 3.0 bc | 3.7 b | 14.0 c |
| Flumioxazin | 99.98 a | 99.08 ab | 99.86 ab | 99.84 | 97.14 | 2.5 | 2.5 c | 4.0 b | 33.1 b |
| Oryzalin | 99.95 a | 98.34 ab | 99.92 ab | 99.90 | 99.38 | 3.4 | 4.0 ab | 7.7 a | 43.2 ab |
| *S*-Metolachlor | 99.90 a | 99.38 ab | 99.94 ab | 99.80 | 98.75 | 2.9 | 3.5 abc | 7.3 a | 50.3 a |
| Pendimethalin | 99.96 a | 99.14 ab | 99.89 ab | 99.93 | 99.09 | 3.2 | 3.9 ab | 7.5 a | 47.7 ab |
| Napropamide | 99.91 a | 99.69 ab | 99.78 ab | 99.71 | 98.97 | 3.1 | 3.7 ab | 8.2 a | 49.0 a |
| Handweeded | 99.65 b | 97.48 b | 99.94 ab | 99.79 | 98.52 | 3.0 | 4.2 a | 8.8 a | 40.9 a |
| P-value | <.0001 | 0.0343 | | 0.3961 | 0.1066 | 0.1145 | 0.0001 | <.0001 | <.0001 |

[a]Means were separated using Tukey's Honest Significant Difference at a $\alpha$=0.05 significance level and means followed by the same letter are not significantly different. Means should be compared by date (DAT) within the parameter measured.

[b]Herbicide and rate effects were tested for any interaction effect. Where no significant herbicide × location effect was detected, the main effect of herbicide is reported with location combined. In cases where a significant herbicide × location effect was detected; locations are presented as separate columns.

[c]Abbreviations: DAT, days after treatment; MJS, Milo J. Shult – Fayetteville location; FRS, Fruit Research Station – Clarksville location

**Table 3-6.** Blackberry yield by harvest, initiated at Fayetteville, AR June 28, 2022, and Clarksville, AR June 20, 2022. Harvested twice a week and final harvests took place in Fayetteville, AR July 29, 2022, and Clarksville, AR July 21, 2022. Cumulative marketable, cull yields, and average berry weight for 2022 blackberry harvest.[a]

| Herbicide | Blackberry Yield | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Harvest[b] 1 | Harvest 2 | Harvest 3 | Harvest 4 | Harvest 5 | Harvest 6 | Harvest 7 | Harvest 8 | Harvest 9 | Cumulative marketable[c] | Cumulative cull[d] | Avg. weight |
| | Kg/plant | | | | | | | | | | | |
| Mesotrione | 0.26 | 0.21 | 0.48 | 0.34 | 0.37 | 0.15 | 0.17 | 0.11 | 0.12 | 2.22 | 0.25 | 5.28 |
| Flumioxazin | 0.29 | 0.29 | 0.57 | 0.37 | 0.33 | 0.15 | 0.18 | 0.13 | 0.14 | 2.45 | 0.35 | 5.30 |
| Oryzalin | 0.29 | 0.27 | 0.49 | 0.36 | 0.38 | 0.15 | 0.20 | 0.15 | 0.17 | 2.47 | 0.35 | 5.21 |
| S-Metolachlor | 0.31 | 0.24 | 0.60 | 0.44 | 0.45 | 0.16 | 0.21 | 0.15 | 0.17 | 2.72 | 0.29 | 5.19 |
| Pendimethalin | 0.31 | 0.28 | 0.51 | 0.39 | 0.39 | 0.16 | 0.22 | 0.16 | 0.16 | 2.59 | 0.31 | 5.28 |
| Napropamide | 0.27 | 0.28 | 0.55 | 0.42 | 0.40 | 0.17 | 0.22 | 0.17 | 0.22 | 2.70 | 0.27 | 5.28 |
| Handweeded | 0.27 | 0.25 | 0.52 | 0.39 | 0.40 | 0.17 | 0.20 | 0.15 | 0.18 | 2.55 | 0.28 | 5.23 |
| P-value | 0.9310 | 0.1446 | 0.4356 | 0.5635 | 0.7187 | 0.9150 | 0.4806 | 0.1450 | 0.3097 | 0.6332 | 0.4494 | 0.9902 |

[a]Means were separated using Tukey's Honest Significant Difference at a $\alpha$=0.05 significance level and means followed by the same letter are not significantly different. Means should be compared by date (DAT).

[b]Harvests reflect only marketable berry yields.

[c]Marketable yields were defined as ripe berries without blemish.

[d]Cull yields were defined as berries that did not meet marketable standards through damage or malformation.

**Table 3-7.** Blackberry fruit quality data assessed on bulked samples of 10 marketable quality macerated berries from each plot in Fayetteville, AR and Clarksville, AR.[a]

| | Postharvest Fruit Quality[b] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Herbicide | Harvest 2[a] | Harvest 5 | Harvest 7 | All harvests | Harvest 2 | Harvest 5 | Harvest 7 | All harvests |
| | pH | | | | °Brix | | | |
| Mesotrione | 3.42 | 3.71 | 3.63 | 3.58 | 10.62 | 10.96 | 10.85 | 10.81 |
| Flumioxazin | 3.40 | 3.67 | 3.55 | 3.54 | 10.71 | 10.75 | 11.20 | 10.88 |
| Oryzalin | 3.42 | 3.47 | 3.53 | 3.56 | 10.82 | 10.91 | 10.81 | 10.85 |
| *S*-Metolachlor | 3.40 | 3.74 | 3.62 | 3.58 | 10.41 | 10.71 | 11.37 | 10.83 |
| Pendimethalin | 3.41 | 3.62 | 3.56 | 3.53 | 10.96 | 10.77 | 11.10 | 10.94 |
| Napropamide | 3.36 | 3.70 | 3.59 | 3.55 | 10.40 | 10.11 | 10.92 | 10.47 |
| Hand-weeded | 3.37 | 3.72 | 3.52 | 3.53 | 11.27 | 11.25 | 10.91 | 11.14 |
| | | | | | | | | |
| P-value | 0.9573 | 0.1806 | 0.1223 | 0.6606 | 0.6082 | 0.1901 | 0.7670 | 0.2985 |

[a]Means were separated using Tukey's Honest Significant Difference at a $\alpha$=0.05 significance level and means followed by the same letter are not significantly different. Means should be compared by date (DAT).

[b]Quality data were collected on a subset of harvest throughout the season. Harvests are indicated chronologically with harvests 2, 5, and 7 occurring on July 2, 12, and 19 or June 23, July 5, and 11 for Fayetteville and Clarksville, respectively

## Overall Conclusion

With weeds being a continued problem for blackberry growers, the use of integrated pest management strategies has found a place in weed management programs. Chemical control, though the last preferred option, is a staple component in controlling weed pressures for blackberry production (Meyers et al. 2015). The field trial and greenhouse trial have provided investigation of chemical controls that can inform the industry. The findings have validated many regional recommendations too. Though mesotrione is labeled for use in newly planted blackberries, regional recommendations and the results from these trials reflect why mesotrione is not actively used in young plantings. The 24(c) labeling for *S*-metolachlor in several states, now including (as of 2022) the state of Arkansas, is supported by these findings and may be worth exploring for other states where alternative herbicides are not available. Flumioxazin, napropamide, and pendimethalin treatments sustained little or no damage and corroborated their labeling designations and field use (Burgos et al. 2014; Meyers et al. 2020). These findings can inform recommendations and future field investigation that have the potential to lead to more informed IPM strategies and options for chemical control within new blackberry plantings.

## Appendix Tables

Supplementary Table 1. List of maintenance chemical applications for both locations (Fayetteville AR - MJS and Clarksville, AR - FRS) by date with description.

| Activity | Date | Location | Description |
|---|---|---|---|
| Chemical application | 3/21/2022 | MJS | Lime Sulfur – 93.5 L $ha^{-1}$ |
| Chemical application | 8/25/2021<br>9/8/2021<br>9/22/2021<br>10/6/2021<br>6/15/2022<br>7/1/2022 | MJS<br>MJS<br>MJS<br>MJS<br>MJS<br>MJS | bifenthrin (Tundra EC) – 0.38 L $ha^{-1}$<br>0.26 L $ha^{-1}$<br>0.26 L $ha^{-1}$<br>0.26 L $ha^{-1}$<br>0.47 L $ha^{-1}$<br>0.37 L $ha^{-1}$ |
| Chemical application | 7/29/2021 | FRS | myclobutanil (Rally 40WSP) – 0.22 L $ha^{-1}$<br>zeta-cypermethrin (Mustang Maxx) – 1.17 L $ha^{-1}$ |
| Chemical application | 8/6/2021 | FRS | pyraclostobin + bosclid (Pristine) – 1.06 L $ha^{-1}$<br>fenpropathrin (Danitol) – 0.29 L $ha^{-1}$ |
| Chemical application | 8/13/21 | FRS | zeta-cypermethrin (Mustang Maxx) – 0.22 L $ha^{-1}$ |
| Chemical application | 8/26/21 | FRS | captan (Captan 80WDG) - 2.24 kg $ha^{-1}$<br>pyraclostobin + bosclid (Pristine)– 1.46 L $ha^{-1}$<br>bifenthrin (Tundra EC) – 0.47 L $ha^{-1}$<br>abamectin (Agri-Mek) – 0.26 L $ha^{-1}$ |
| Chemical application | 9/15/2021 | FRS | bifenthrin (Tundra EC) – 0.47 L $ha^{-1}$ |
| Chemical application | 9/16/2021 | FRS | captan (Captan 80WDG) – 2.24 kg $ha^{-1}$<br>azoxystrobin (Abound) – 0.73 L $ha^{-1}$<br>bifenthrin (Tundra EC) – 0.47 L $ha^{-1}$<br>abamectin (Agri-Mek) – 0.26 L $ha^{-1}$ |
| Chemical application | 2/14/2022<br>3/25/2022 | FRS<br>FRS | sulforix (calcium polysulfides) – 18.71 L $ha^{-1}$<br>36.95 L $ha^{-1}$ |
| Chemical application | 4/18/2022 | FRS | azoxystrobin (Abound) – 1.10 L $ha^{-1}$<br>propiconazo (Tilt) – 0.44 L $ha^{-1}$<br>bifenthrin (Tundra EC) – 0.47 L $ha^{-1}$ |
| Chemical application | 5/7/2022 | FRS | azoxystrobin (Abound) – 0.73 L $ha^{-1}$<br>esfenvalerat (Asana XL) – 0.70 L $ha^{-1}$<br>cyprodinil/fludioxonil (Switch 62.5WG) – 0.88 L $ha^{-1}$ |
| Chemical application | 5/28/2022 | FRS | zeta-cypermethrin (Mustang Maxx) – 0.29 L $ha^{-1}$<br>pyraclostobin + bosclid (Pristine WG) – 1.46 L $ha^{-1}$ |
| Chemical application | 6/10/2022 | FRS | myclobutanil (Rally 40WSP) – 0.22 L $ha^{-1}$<br>zeta-cypermethrin (Mustang Maxx) - 1.10 L $ha^{-1}$ |
| Chemical application | 6/17/2022 | FRS | zeta-cypermethrin (Mustang Maxx) – 0.29 L $ha^{-1}$ |
| Chemical application | 6/23/2022 | FRS | acetamiprid (Azomar) – 0.39 L $ha^{-1}$<br>cyprodinil/fludioxonil (Switch 62.5WG) – 0.95 L $ha^{-1}$ |
| Chemical application | 7/1/2022 | FRS | fenpropathrin (Danitol) – 1.46 L $ha^{-1}$<br>azoxystrobin (Abound) – 1.02 L $ha^{-1}$<br>myclobutanil (Rally 40WSP) – 0.22 L $ha^{-1}$ |

| | | | |
|---|---|---|---|
| Chemical application | 7/8/2022 | FRS | azoxystrobin (Abound) – 0.73 L $ha^{-1}$<br>myclobutanil (Rally 40WSP) – 0.22 L $ha^{-1}$<br>zeta-cypermethrin (Mustang Maxx) – 0.29 L $ha^{-1}$ |
| Chemical application | 7/28/2022 | FRS | bifenthrin (Tundra EC) – 0.47 L $ha^{-1}$<br>captan (Captan Gold80) – 2.80 kg $ha^{-1}$ |
| Chemical application | 8/6/2022 | FRS | zeta-cypermethrin (Mustang Maxx) – 0.29 L $ha^{-1}$<br>cyprodinil/fludioxonil (Switch 62.5WG) – 0.80 L $ha^{-1}$<br>azoxystrobin (Abound) – 0.73 L $ha^{-1}$ |
| Chemical application | 8/19/2022 | FRS | abamectin (Agri-Mek) – 0.26 L $ha^{-1}$<br>bifenthrin (Tundra EC) – 0.47 L $ha^{-1}$ |
| Chemical application | 9/8/2022 | FRS | abamectin (Agri-Mek) - 0.26 L $ha^{-1}$<br>bifenthrin (Tundra EC) - 0.47 L $ha^{-1}$ |

Supplementary Table 2. Herbicide breakdown summary of preemergent herbicide treatments for Fayetteville, AR(MJS) and Clarksville, AR(FRS) for both years as days after treatment (DAT).

| | 2021 | | 2022 | |
|---|---|---|---|---|
| Herbicides | MJS | FRS | MJS | FRS |
| | DAT | | | |
| Mesotrione | 37 c | 28 c | 102 | 93 |
| Flumioxazin | 66 a | 57 a | 120 | 103 |
| Oryzalin | 51 abc | 42 abc | 114 | 99 |
| *S*-Metolachlor | 55 abc | 52 a | 113 | 93 |
| Pendimethalin | 40 bc | 50 ab | 118 | 98 |
| Napropamide | 57 ab | 33 bc | 116 | 95 |
| P-value | 0.0002 | <.0001 | 0.0756 | 0.4682 |

Supplementary Table 3. Average temperature and total rainfall by month for both locations (Fayetteville AR - MJS and Clarksville, AR – FRS)[a].

| Location | Month/Year | Average Temperature | Rainfall |
|---|---|---|---|
| MJS | May 2021 | 63 F° (17 C°) | 1.08 in (2.74 cm) |
| FRS | | 60 F° (16 C°) | 1.47 in (3.73 cm) |
| MJS | June 2021 | 75 F° (24 C°) | 0.82 in (2.08 cm) |
| FRS | | 78 F° (26 C°) | 0.74 in (1.88 cm) |
| MJS | July 2021 | 78 F° (26 C°) | 2.72 in (6.91 cm) |
| FRS | | 80 F° (27 C°) | 2.84 in (7.21 cm) |
| MJS | August 2021 | 79 F° (26 C°) | 1.52 in (3.86 cm) |
| FRS | | 83 F° (28 C°) | 0.39 in (0.99 cm) |
| MJS | September 2021 | 74 F° (23 C°) | 1.34 in (3.40 cm) |
| FRS | | 78 F° (26 C°) | 1.68 in (4.27 cm) |
| MJS | October 2021 | 62 F° (17 C°) | 2.78 in (7.06 cm) |
| FRS | | 66 F° (19 C°) | 5.32 in (13.51 cm) |
| MJS | November 2021 | 48 F° (9 C°) | 0.56 in (1.42 cm) |
| FRS | | 51 F° (11 C°) | 1.05 in (2.67 cm) |
| MJS | December 2021 | 51 F° (11 C°) | 3.22 in (8.18 cm) |
| FRS | | 53 F° (12 C°) | 3.24 in (8.23 cm) |
| MJS | January 2022 | 34 F° (1 C°) | 0.49 in (1.24 cm) |
| FRS | | 38 F° (3 C°) | 0.89 in (2.26 cm) |
| MJS | February 2022 | 37 F° (3 C°) | 0.44 in (1.12 cm) |
| FRS | | 41 F° (5 C°) | 2.05 in (5.21 cm) |
| MJS | March 2022 | 48 F° (9 C°) | 1.69 in (4.29 cm) |
| FRS | | 52 F° (11 C°) | 1.04 in (2.64 cm) |
| MJS | April 2022 | 58 F° (14 C°) | 3.27 in (8.31 cm) |
| FRS | | 62 F° (17 C°) | 3.45 in (8.76 cm) |
| MJS | May 2022 | 68 F° (20 C°) | 1.02 in (2.59 cm) |
| FRS | | 72 F° (22 C°) | 0.95 in (2.41 cm) |
| MJS | June 2022 | 76 F° (24 C°) | 1.24 in (3.15 cm) |
| FRS | | 80 F° (27 C°) | 4.58 in (11.63 cm) |
| MJS | July 2022 | 84 F° (29 C°) | 2.30 in (5.84 cm) |
| FRS | | 88 F° (31 C°) | 1.45 in (3.68 cm) |
| MJS | August 2022 | 78 F° (26 C°) | 0.95 in (2.41 cm) |
| FRS | | 83 F° (28 C°) | 0.59 in (1.50 cm) |
| MJS | September 2022 | 71 F° (22 C°) | 0.46 in (1.17 cm) |
| FRS | | 77 F° (25 C°) | 0.55 in (1.40 cm) |

[a]Temperature and rainfall data was sourced from wunderground.com from locations closest to the research locations.