VARIOUS WEED CONTROL TECHNIQUES IN CONTAINER NURSERY PRODUCTION

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VARIOUS WEED CONTROL TECHNIQUES IN CONTAINER NURSERY PRODUCTION

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VARIOUS WEED CONTROL TECHNIQUES IN CONTAINER NURSERY PRODUCTION

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VITA

Diana Renae Cochran was born in Mobile, Alabama on July 15, 1981. She is the daughter of Mr. and Mrs. Dale Hopper and Mr. and Mrs. Herbert L. Cochran. She has two sisters, Helen and Margaret. In 1999 she graduated from Baldwin County High School where she went to Faulkner State Community College for a year before enrolling at Auburn University. In the spring of 2005 she graduated with a B.S. in Landscape Design where she went on to pursue a Master of Science degree in horticulture. She received her Master's Saturday, August 4, 2007.

THESIS ABSTRACT

VARIOUS WEED CONTROL TECHNIQUES IN CONTAINER NURSERY PRODUCTION

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Studies were conducted evaluating selected herbicides during propagation of *Loropetalum chinense* 'Ruby' to determine effects on rooting and subsequent plant growth. Herbicides evaluated were: Gallery, Ronstar, and Regal O-O. Herbicides were applied in single applications during the propagation process: before sticking, lightly rooted cuttings, or fully rooted cuttings. Before sticking treatments were applied to flats filled with standard medium before cuttings were stuck. Once cuttings had 3 to 5 cm roots, the lightly rooted herbicide treatment was applied. The final herbicide treatment occurred when the cuttings were fully rooted. One year after sticking, growth indices of 'Ruby' Loropetalum were similar regardless of herbicide treatment. Ronstar applied before sticking and at lightly rooted suppressed root growth, while Regal O-O suppressed root coverage on all dates of application.

Additional studies were conducted to evaluate the influence of alternative substrates on herbicide efficacy in container grown nursery crops. Substrates evaluated were either pine wood chips hammer-milled, whole pine trees chipped or hammer-milled, or the previously mentioned combined with pinebark. Rout and Ronstar were applied at recommended label rate. After herbicides were applied and irrigated, containers were overseeded with 25 spotted spurge (*Euphorbia maculata*) seed per container. With all of the substrates except whole pine tree chipped-hammer-milled to pass a 0.48 cm screen, the addition of commercially used pine bark resulted in less weed control (more weeds). Rout provided superior control followed by Ronstar and the non-treated control. These data show that control of prostrate spurge with commonly used pre-emergent applied herbicides may actually be improved with some of the alternative substrates currently being evaluated.

Final experiments were conducted to evaluate non-chemical weed control options in containers. Pine bark mini-nuggets were evaluated as a non-chemical weed control technique for two weed species, *Chamaesyce maculata* (Spotted Spurge) and *Eclipta alba* (Eclipta). Seed (25/container) were directly placed on the potting substrate surface before mulching with pine bark mini-nugget mulch at 0, 0.5 in., or 1.0 in. Remaining treatments consisted of hand applying the pine bark mini-nugget mulch at 0.5 in. 1.0 in. on the potting substrate then overseeding spurge or eclipta. Results showed eclipta number per container were 87 % (1.0 in.) less 60 days after seeding and spurge fresh weight was reduced by 87 % (1.0 in.) compared to the non-mulched containers. These results, suggest that pine bark mini-nuggets can be used effectively for weed control in container nurseries with proper application.

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CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

As of 1997 there were approximately 250,000 species of plants in the world and of these less than 250 were weeds (about 0.1%) (51). The term "weed" can be defined in many ways; Emerson in 1878, "a plant whose virtues have not been discovered", Gray 1879, "persistence and resistance to control", Brenchly, 1920, "a plant that grows so luxuriantly or plentiful that it chokes all other plants that posses more valuable properties", Bailey and Bailey, 1941, "a plant not wanted and therefore destroyed", and Weed Science Society of America, 1994, "any plant that is objectionable or interferes with the activities or welfare of man". Regardless of the definition, weeds have been with humankind since the beginning of agriculture; however the history of weed science is largely the history of chemical weed control (51).

In the 1900s, inorganic salts were the first herbicides used to control weeds in cereals (68). During the 1940s, 2, 4-dichlorophenoxyacetic acid (2,4-D) was introduced as the first widely used herbicide and since then chemical weed control has become standard practice for container nursery production (64).

Weeds in container-grown nursery crops are primarily managed by pre-emergent herbicides, sanitation, hand weeding, and/or non-chemical control. However, cost of weed management was estimated at 20% of the total cost of production in the 1970's

(64). Furthermore, hand weeding alone, in Alabama (1990) ranged from \$608 - \$1401/ha (\$246-567/acre) annually with the lower cost occurring in nurseries from 4.4-9.7 ha (11 – 50 acres) in size and the higher cost associated with nurseries under 4.0 ha (10 acres) and over 20.2 ha (50 acres +) (24). Based on more current research by Judge et al (35) hand weeding cost ranged from \$2,389 to \$5,506/ha (\$967 to \$2,228 per acre) in North Carolina.

Weed management is not only expensive but can be detrimental to the crop. Due to limited availability of nutrients, air, and water in containers (44) weeds become heavy competitors. Depending on the size of the container, weeds can prevail over the crop being produced; weeds in smaller containers were superior in uptake of nutrients, water, and light compared to weeds in larger containers (8). As a result weeds also reduced the growth of container-grown nursery crops (35). In any case, container plants infested with weeds are aesthetically un-appealing and subsequently less marketable than weed-free containers (16, 47).

Chemical Weed Control

Generally, pre-emergent herbicides are the most common chemical control in container nurseries (22) due to increasing labor costs (20). Hayes et al. (29) reported that most herbicides used in nursery and landscape crop production either contain components of or are dinitroaline (DNA) herbicides. The primary mode of action of DNA herbicides is mitotic inhibition which limits the production of the protein tuberin resulting in lack of separation among chromosomes during cell division (5) resulting in root suppression. To avoid root suppression, nursery crops should be planted at a depth where the roots can avoid the chemical barrier at the surface of the container because DNA herbicides have a low solubility reducing their movement in the root zone (6).

Weed Control in Propagation

Weeds are a major issue in production of nursery crops and even more so in propagation as a result of propagating in small containers and herbicide restrictions (61). Herbicide restrictions in propagation are a result of apprehension with volatilization and co-distillation of the herbicide (3). With these herbicide restrictions; hand weeding is the major form of weed control in propagation but can suppress growth of cuttings through mechanical disruption (34). Additionally, relying merely on hand weeding is time-consuming and subjects nurserymen to lower profits due to labor cost (65, 15, 50).

Pre-emergence Applied Herbicides for Post-emergent Control

Altland et. al. (1) showed that Gallery provided excellent post-emergence bittercress control when applied to small non-flowering bittercress, and caused no injury to 10.2 cm (4 in.) pots of crapemyrtles. In one study Gallery was applied only to potted bittercress and in the second study Gallery was applied at three rates .56 kg ai/ha (0.5 lb ai/A), 1.12 kg ai/ha (1.0 lb ai/A) or 2.24 kg ai/ha (2.0lb ai/A), to different bittercress sizes, small 0.5 to 3 cm (0.2 to 1.2 in) , intermediate 4 to 6 cm (1.6 to 2.4 in) and large 10 to 15 cm (3.9 to 5.9 in). The 1.12 kg ai/ha (1.0 lb ai/A) rate of Gallery applied to small, non-flowering bittercress provided excellent post-emergence control. Experiment two was similar to experiment one, bittercress control was influenced by bittercress size and Gallery rate. The greatest control of bittercress occurred among smaller, non-flowering bittercress. There were no signs of injury or growth reduction in ‘Natchez’ crapemyrtle from any treatment.

Pre-emergence applied herbicides in propagation

Langmaid (39) reported the use of Ronstar G (2 % oxadiazon) in broadleaf stem propagation at a rate of 90.7 kg/ha (200 lb/A). After rooting Scott's Ornamental Herbicide 2, (OH-2) (2 % oxyfluorfen and 1 % pendimethalin) was applied at a rate of 45.3 kg/ha (100 lb/A). Due to plant damage caused through volatilization of herbicides in covered areas most nurseries don't treat cuttings until greenhouses are uncovered. After the greenhouses were uncovered Ronstar G (2 % oxadiazon) was applied at the same rate (2 lb aia/acre) to the floor of the greenhouse and to the medium filled liners before cuttings were stuck. Herbicide treatments were successful.

Johnson and Meade (34) conducted a study using four species: *Rhododendron obtusum* Planch.'Hino Crimson', *Euonymus fortunei* Hand.-Mazz. 'Emerald Gaiety,' *Ilex crenata* Thunb. 'Helleri', and *Cotoneaster horizontalis* Decne. Each holly cutting was dipped into 10:1, all others into 20:1 (Dip 'n' Grow). Dual (metolachlor) at 4lb/aia, Devrinol (napropamide) at 3lb/aia, Ronstar (oxadiazon) at 4 lb/aia, Surflan (oryzalin) at 3 lb/aia, and Rout (oxyfluorfen + oryzalin) at 3 lb/aia were applied. In azalea and cotoneaster, Surflan reduced rooting percentage. There was no reduction of rooting percentage with any treatment for either Ilex or Euonymus. However herbicide treatment decreased root percentage on cotoneaster, the only deciduous shrub. Ronstar and Rout can possibly be used on certain species. In an experiment done by Thetford and Gilliam (61), Rout (oxyfluorfen 2G + oryzalin 1G), OH-2 (oxyfluorfen 2G + pendimethalin 1G), Surflan (oryzalin), Prowl 4L (pendimethalin), and Ronstar 2G (oxadiazon), were applied to the medium prior to dipping cuttings of *Ilex* × *attenuata* Ashe. 'Fosteri' and *Juniperus horizontalis* Moench. 'Wiltonii' in a 5000 ppm K-IBA solution. Surflan suppressed rooting percentage and reduced rooting quality for Foster Holly. In a second experiment, *Abelia x grandiflora* Rehd 'Sherwoodii,' *Buxus sempervirens* Sieb. and Zucc *var. koreana*, and *Ilex crenata* Thunb. 'Compacta,' were evaluated. Surflan affected the root percentage and quality. Thirteen months after potting, Rout, OH-2, and Prowl resulted in lower root densities. This demonstrates that herbicide application may have varying effects on root inhibition depending on plant species and herbicide. In every case Surflan and Prowl had negative effects on plants root systems. In 1993, a study was conducted by Gilliam et al. (23) evaluating commonly used granular pre-emergent herbicides and their influence on root initiation and growth of stem cuttings of selected woody ornamental species. In this experiment cuttings of *Rhododendron obtusum* Planch. 'Hino Crimson', *Rhododendron* × 'Trouper' (Glenn Dale Hybrid USDA), and *Gardenia jasminoides* Ellis. 'August Beauty' gardenia, were dipped into a 2000 ppm K-IBA solution for five seconds. Prior to sticking cuttings, Rout 3G (oxyfluorfen + oryzalin), OH-2 3G (oxyfluorfen + pendimethalin), Ronstar 2G (oxadiazon), Southern Weed Grass control 2.68G (pendimethalin), or Snapshot 2.5TG (isoxaben + trifluralin), was applied to the substrate. Rout 3G and Snapshot 2.5TG tended to cause the greatest suppression of root growth in all three cultivars; on average by 63 % ('Hino Crimson' azalea), 61 % ('Trouper' azalea), and 34 % ('August Beauty' gardenia). In a second experiment 'August Beauty' gardenia cuttings were stuck at, 1.3 cm or 2.5 cm in the media filled containers. They concluded that both Rout 3G and Snapshot 2.5TG improved root quality ratings with a deeper sticking depth. These studies suggest DNA herbicides can suppress rooting yet by sticking the cuttings deeper (2.5 cm) root development improves. Gallery applied to *Liriope muscari* 'Big Blue' two days after division resulted in similar root growth to the non-treated (29). Cook and Neal (17) tested the effects of herbicides and times of application (at sticking, five weeks after sticking and at eight weeks after sticking) on rooting of *Rhododendron* × 'Girard Rose' and *Ilex crenata* Thunb. 'Hetzii.' Pre-emergence herbicides used were Ronstar 2G (oxadiazon) at 3 lb/aia, Regal 0-0 (oxadiazon + oxyfluorfen) at 3 lb/aia, RegalKade (prodiamine) at 1 lb/aia, or BroadStar (flumioxazin) at 0.25 lb/aia. Of the herbicides tested Ronstar, Regal 0-0, or BroadStar caused no reduction in root quality regardless of the date of application. When RegalKade G was applied before sticking, it significantly reduced azalea and holly rooting percentages, azalea being affected the most. When herbicides were applied to the azaleas five-weeks after sticking, root quality was significantly reduced, but application after eight weeks had no effect on root quality. It can be concluded that the use of pre-emergent herbicides in propagation depends on the herbicide, the timing of application, and species of plants.

Herbicide Efficacy in Alternative Substrates for Container Grown Nursery Crops

In the past few years, the supply of pinebark for use in container nursery crop production has declined (42). Several factors have contributed to this decline including: use of pine bark for fuel, a trend towards in-field harvesting of pine trees which leaves the pine bark in the forest, and increased foreign importation of logs (no bark) (42). With limited supply and increasing prices, there is greater interest in the use of alternative substrates in container nursery crop production.

Many alternative substrates have been evaluated for container grown crops including: biosolids (25, 32, 27, 30), wood waste (43), coco fibers (40), pine chips (67, 12, 21). In recent research *Cypress sempervirens* and *C. arizonica* were grown effectively in pinebark or coconut fiber mixed with 30 % sewage sludge (biosolid compost) (30). Compost-based media derived from biosolids and yard trimmings showed *Justica carnea* had similar growth compared to a peat-based media grown *J. carnea* (66). Although there has been success with several alternative substrates the most common alternative substrates being evaluated are by-products from the forestry industry (48). In 2004, Gruda and Schnitzler (26) had success in growing vegetable transplants in non-treated spruce wood chips. Wright and Browder (67) demonstrated that *Ilex crenata* 'Chesapeake' could be grown effectively in ground loblolly pine (*Pinus taeda*) logs. Boyer et al. (12) reported that perennials grown in clean chip residual (forestry by-product of in-field harvesting) were similar to plants grown in pinebark. Fain et al. (21) evaluated a substrate made from all above ground portions of loblolly pine (*WholeTree*) with plants being similar to those grown in traditional pinebark substrates.

While these substrates have been evaluated for container-grown crops, limited research has been done with alternative substrates to determine if herbicide efficacy is affected. Pre-emergent herbicides are the most common chemical control in container nurseries (22). Herbicides are applied to and adsorbed by the substrate and it must be desorbed into solution for uptake by the weed (14). Degradation is dependent on temperature, pH, and moisture content of the soil (33). While some of the by-products such as *Quercus suber* L. (cork oak) had an optimum pH value of 6.1 and a low electrical conductivity of 0.35 mS cm^{-1} (48) others have shown an increase in pH values in composted material (biosolids and yard trimmings) (66). Subsequently, many of the alternative substrates being researched contain organic material, which has previously been shown to affect the mobility of pesticides (60). Herbicide efficacy in organic matter depends upon crop species and herbicide (52). Warren (62) reported propachlor leached out rapidly in soil with 0.7 % organic matter, whereas soil with 3 % organic matter improved the adsorptive capacity reducing the amount of propachlor leaching. The impact of high wood content substrates on herbicide adsorption is unknown; however, other cultural practices have been impacted by these substrates. For example, Wright and Browder (67) demonstrated Electrical Conductivity (EC) was lower in crops grown in pine wood chips and additional fertilizer was required in order to have similar growth to crops grown in pine bark.

Effects of Mulch Depth on Weed Control in Nursery Containers

One key to a successful weed control program is to prevent suitable habitats conducive for weed growth; particularly in container-grown crops where water and light requirements are favorable. Once weeds infest container-grown crops, they become competitors with the marketable crop for water, light and nutrients (8) and can reduce the growth of container-grown nursery crops (35). Furthermore, container plants infested with weeds are less marketable than weed-free containers (47).

Environmental concerns from chemical control have focused the nursery industry to evaluate alternative weed control options (44). Controlling unwanted plants, as well as preventing weed growth with the use of non-chemical control methods has been steadily on the increase since the early 1990s in European countries (45). In the United States, non-chemical control methods were re-addressed in 1984 after herbicide resistance became an issue (4). Ryan (57) first reported herbicide resistance in common groundsel (*Senecio vulgaris*) to atrazine and simazine. Warwick (63) stressed the importance of non-chemical weed control after discovering more than 100 herbicide resistant species.

Rao (52) reported an increase of herbicide resistance in a 10 year span equal to that reported by Holt (31) of insecticide resistant biotypes over a 50 year span. Relying merely on herbicides as a form of weed control can lead to herbicide resistant weeds (38) and a decrease in density and diversity of the weed flora (58). Once the diversity of weed flora has been altered, no one herbicide can be used exclusively and hence the significance behind choosing the right herbicide rotation program (55). Since then recommendations have been made to rotate herbicides with different mode of actions (MOAs) (30, 28), by using several MOAs, herbicide resistant weeds are less likely to pose a threat. Furthermore, herbicide resistance if not controlled can lead to an increase in herbicide use as a result of inadequate weed control with current herbicides (30).

Incorporating a non-chemical weed control program can help reduce the use of herbicides (37). Applying mulch over a soil surface or substrate in theory is preventing the passage of light to the existing seed bank (36), which can prevent some weed species from germinating (9). Billeaud and Zajicek (11) used pinebark nuggets as a form of weed control in a field study and results indicated less weed number compared to the control (no mulch). Additionally, the suppression of weed growth reduced transpiration and allowed the soil surface layer to stay moist longer (55). Duryea et al. (19) analyzed the chemical make up of several mulches including pinebark and concluded that pinebark based on subsidence, decomposition, allelopathy, soil pH and color change ranked in the top three landscape mulches. More recently pinebark used as mulch in a field study had no affect on soil pH or N concentrations (13). Additionally, large particle size and hydrophobic properties of fresh pine bark are not conducive for weed germination (54).

Recently Richardson et al. (53) reported reduced spurge number in large containers (# 7) by 100 % when pine bark mini-nuggets were applied to a depth of either 1.5 or 3 inches.

Literature Cited:

1. Altland, J. E., C. H. Gilliam, J. H. Edwards, G. J. Keever, J. R. Kessler, Jr., and D. J. Eakes. 2000. Effect of bittercress size and Gallery rate on postemergence bittercress control. J. Environ. Hort 18(3):128-132.

2. Altland, J. 2006. Research examines a new tool for control of creeping wood sorrel. Digger. 50:24-28.

3. Altland, J., R. Regan, and A. Newby. 2003. Liverwort control in propagation: Challenges and opportunities©. Comb. Proc. Intl. Plant Prop. Soc. 53:383-386.

4. Appleby, A.P. 2005. A history of weed control in the United States and Canada—a sequel. Weed Sci. 53:762-768.

5. Ashton, F.M. and A. S. Crafts. 1973. Chapter 14. Dinitroanilines in Mode of Action of Herbicides. Pg. 221-235.

6. Ashton, F.M. and A.S. Crafts. 1981. Dinitroanalines. pp. 201-223. *In:* Mode of Action of Herbicides. 2nd Ed. John Wiley & Sons, Inc., New York. Bul. AG-427. North Carolina State University, Raleigh, NC, pp. 104.

7. Bachman, G. and T. Whitwell. 1995. Hairy bittercress seed production, dispersal, and control. Proc. South. Nurs. Assoc. Res. Conf. 40:288-290.

8. Berchielli-Robertson, D.L. C.H. Gilliam, and D.C. Fare. 1990. Competitive effects of weeds on the growth of container-grown plants. HortScience. 25:77-79.

9. Bewley, J.D. and M. Black. 1994. Seeds – Physiology of Development and Germination, 2nd edn. Plenum Press, New York.

10. Bilderback, T.E., W.C. Fonteno, and D.R. Johnson. 1982. Physical properties of media composed of peanut hulls, pinebark, and peatmoss and their effects on azalea growth. J. Amer. Soc. Hort. Sci. 107:522-525.

11. Billeaud, L.A. and J.M. Zajicek. 1989. Influence of mulches on weed control, soil pH, soil nitrogen content, and growth of *Ligustrum japonicum*. J. Environ. Hort. 7:155-157.

12. Boyer, C.R., G.B. Fain, C.H. Gilliam, T.V. Gallagher, H.A. Torbert, and J.L. Sibley. 2006. Clean chip residual: A new substrate component for container-grown plants. Proc. SNA Res. Conf. 51:22-25.

13. Broschat, T.K. 2007. Effects of mulch type and fertilizer placement on weed growth and soil pH and nutrient cover. HortTech. 17:174-177.

14. Caberera, A., L. Cox., and W.C. Koskinen. 2006. Soil organic amendment as affecting herbicide fate. American Chemical Society Abstracts. p. 99.

15. Carpenter, P.L. 1973. Chemical weed control in container-grown nursery stock. HortScience 8:385-386.

16. Case, LT., H.M. Mathers, and A.F. Senesac. 2005. A review of weed control practices in container nurseries. HortTech. 15:535-545.

17. Cook, J.C. and J.C. Neal. 2001. Effects of herbicides and application timing on rooting of azalea and japanese holly cuttings. Proc. SNA Res. Conf. 46:422-424.

18. Davies, F.T. and S.A. Duray. 1992. Effect of preemergent herbicide application on rooting and subsequent liner growth of selected nursery crops. J. Environ. Hort. 10:181-186.

19. Duryea, M.L., R.J. English, and L.A. Hermansen. 1999. A comparison of landscape mulches: Chemical, allelopathic, and decomposition properties. J. Arboriculture. 25:88-97.

20. Everest, J.W., C.H. Gilliam and K. Tilt. 1998. Weed control for commercial nurseries. Al. Coop. Ext. Sys. Auburn University. Oct. ANR-465.

21. Fain, G.B., C.H. Gilliam, and J.L. Sibley. 2006. Processed whole pine trees as a substrate for container-grown plants. Proc. SNA Res. Conf. 51:59-61.

22. Gilliam, C.H., D.C. Fare, and A. Beasley. 1992. Nontarget herbicide losses from application of granular Ronstar to container nurseries. J. Environ. Hort. 10(3)175-176.

23. Gilliam, C.H., D.J. Eakes, and J.W. Olive. 1993. Herbicide use during propagation affects root initiation and development. J. Environ. Hort. 11:157-159.

24. Gilliam, C.H., W.J. Foster, J.L. Adrain, and R.L. Shumack. 1990. A survey of weed control costs and strategies in container production nurseries. J. Environ. Hort. 8:133-135.

25. Gouin, F.R. 1993. Utilization of sewage sludge compost in horticulture. HortTech. 3:161-163.

26. Gruda, N. and W.H. Schnitzler. 2004. Suitability of wood fiber substrate for production of vegetable transplants I. Physical properties of wood fiber substrates. Sci. Hortic-Amsterdam 100:309-322.

27. Guerrero, F., J.M. Gascó, and L. Hernandez-Apaoloaza. 2002. Use of pine bark and sewage sludge compost as components of substrates for *Pinus pinea* and *Cupressus arizonica* production. J. Plant Nutr. 25:129-141.

28. Hamill, A.S., J.S. Holt, and C.A. Mallory-Smith. 2004. Symposium. Contributions of weed science to weed control and management. Weed Tech. 18:1563-1565.

29. Hayes, C.K., C.H. Gilliam, J.W. Olive, G.J. Keever, and D.J. Eakes. 1999. Pre-emergence applied herbicides for container-grown liriope after division. J. Environ. Hort. 17:31-35.

30. Hernández-Apaolaza, L., A.M. Gascó, J.M. Gascó, and F. Guerrero. 2005. Reuse of waste materials as growing media for ornamental plants. Bioresour. Technol. 96:125-131.

31. Holt, J.S. and H.M. LeBaron. 1990. Significance and distribution of herbicide resistance. Weed Technol. 4:141-149.

32. Ingelmo, F., R. Canet, M.A. Ibañez, F. Pomares, and J. García. 1998. Use of MSW compost, dried sewage sludge and other wastes as partial substitutes for peat and soil. Bioresour. Technol. 63:123-129.

33. James, T.K., P.T. Holland, A. Rahman, and Y.R. Lu. 1999. Degradation of the sulfonylurea herbicides chlorsulfuron and triasulfuron in a high-organic-matter volcanic soil. Weed Research 39:137-147.

34. Johnson, J.R. and J.A. Meade. 1987. Pre-emergent herbicide effect on the rooting of cuttings. Comb. Proc. Intl. Plant Prop. Soc. 36:567-570.

35. Judge, C.A., J.C. Neal, and J.B. Weber. 2004. Dose and concentration responses of common nursery weeds to Gallery, Surflan and Treflan. J. Environ. Hort. 22:106-112.

36. Juroszek, P. and R. Gerhards. 2004. Photocontrol of weeds. J. Agron. Crop Sci. 190:402-415.

37. Kempenaar, C. and L.A.P. Lotz. 2004. Reduction of herbicide use and emission by new weed control methods and strategies. Water Sci. Technol. 49:135-138.

38. Kudsk, P and J.C. Streibig. 2003. Herbicides – a two edged sword. EWRS Weed Research 43:90-102.

39. Langmaid, M. 1987. Herbicides used in propagation at Wight Nurseries. Proc. Intern. Plant. Prop. Soc. 37:539-540

40. Lennartsson, M. 1997. The peat conservation issue and the need for alternatives. In: Proceedings of the IPS International Peat Conference on Peat in Horticulture. Schmilewski, Amsterdam, 112-121.

41. Lohr, V.I. and C.H. Pearson-Mims. 2001. Mulching reduces water use of containerized plants. HortTech. 11:277-278.

42. Lu, W., J.L. Sibley, C.H. Gilliam, J.S. Bannon, and Y. Zhang. 2006. Estimation of U.S. bark generation and implications for horticultural industries. J. Environ. Hort. 24:29-34.

43. Lumis, G.P. 1976. Using wood waste compost in container production. Am. Nurseryman 163:10-11, 58-59.

44. Mathers, H.M. 2003. Novel methods of weed control in containers. HortTech. 13:28-34.

45. Melander, B., I.A. Rasmussen, and P. Bàrberi. 2005. Symposium. Integrating physical and cultural methods of weed control—examples from European research. 53:369-381.

46. Neal, J.C. and J.F. Derr. 2005. Weeds of container nurseries in the United States. North Carolina Association of Nurserymen, Inc. ISBN: 0-89892-312-3.

47. Norcini, J.G. and R.H. Stamps. 1994. Container nursery weed control. Florida Coop. Ext. Serv., Inst. Food and Agr. Serv., Univ. of Florida. Circa 678.

48. Ortega, M.C., M.T. Moreno, J. Ordovás, and M.T. Aguado. 1996. Behaviour of different horticultural species in phytotoxicity bioassays of bark substrates. Sci. Hortic-Amsterdam 66:125-132.

49. Ozores-Hampton, M. 1998. Compost as an alternative weed control method. HortScience 33:938-940.

50. Pradgett, J.H. and T.L. Frazier. 1962. The relationship between costs and pruning of woody ornamentals. Ga. Agr. Expt. Sta. Bul. (N.S.) 100.

51. Radosevich, S., J. Holt, and C. Ghersa. 1997. Weed Ecology, 2nd Edition: Implications for Management. John Wiley & Sons, Inc. New York, NY Pg 4-5, 7.

52. Rao, V.S. 2000. Principles of Weed Science; Herbicide resistance and genetic engineering. 2nd edition science publishers Inc., Enfield NH, USA printed in India Pg 305.

53. Richardson, B. 2006. Effective non-traditional weed control in container-grown nursery production, MS Thesis. Auburn University, Auburn, AL.

54. Richardson, B.M., C.H. Gilliam, G.R. Wehtje, and G.B. Fain. 2005. A non-chemical alternative for weed control in container nursery crops. Proc. SNA Res. Conf. 50:446-449.

55. Robinson, D.W. 1988. Mulches and herbicides in ornamental plantings. HortScience 23:547-552.

56. Ruter, J.M. and N.C. Glaze. 1992. Herbicide combinations for control of prostrate spurge in container-grown landscape plants. J. Environ. Hort. 10:19-22.

57. Ryan, G.F. 1970. Resistance of common groundsel to simazine and atrazine. Weed Sci. 18:614-616.

58. Schütte, G. 2002. Herbicide resistance: Promises and prospects of biodiversity for European agriculture. Agr. Hum. Values 20:217-230.

59. Simpson, C. V., C. H. Gilliam, J. E. Altland, G. R. Wehtje, and J. L. Sibley. 2004 Diuron: Postemergence Oxalis Control in Container-grown Plants. J. Environ. Hort. 22:45-49

60. Spark, K.M. and R.S. Swift. 2002. Effect of soil composition and dissolved organic matter on pesticide sorption. Sci. Total Environ. 298:147-161.

61. Thetford, M. and C.H. Gilliam. 1991. Herbicide use in propagation: Effects on rooting and root growth of stem cuttings. J. Environ. Hort. 9:21-23.

62. Warren, G.F. 1973. Action of herbicides in soilà. Affected by organic matter. Weeds Today 4:10-11.

63. Warwick, S.I. 1991. Herbicide resistance in weedy plants: Physiology and population biology. Annu. Rev. Ecol. Systems 22:95-114.

64. Weatherspoon, D.M. and W.L. Currey. 1975. Evaluation of Treflan, Lasso and Ronstar herbicides for use in woody ornamental nurseries. Proc. FL. State Hort. Soc. 88:535-540.

65. Weller, S.C., J.B. Masiunas, and P.L. Carpenter. 1984. Evaluation of Oxyfluorfen formulations in container nursery crops. HortScience 19:222-224.

66. Wilson, S.B., P.J. Stofella, and D.A. Graetz. 2002. Development of compost-based media for containerized perennials. Sci. Hortic-Amsterdam 93:311-320.

67. Wright, R.D. and J.F. Browder. 2005. Chipped pine logs: A potential substrate for greenhouse and nursery crops. HortScience 40:1513-1515.

68. Zimdahl, R.L. 1991. Weed Science: A plea for thought. Colorado State University, Fort Collins, CO.

CHAPTER II

HERBICIDE USE IN PROPAGATION OF *LOROPETALUM CHINENSE* 'RUBY'

Abstract

Selected herbicides were evaluated during propagation of *Loropetalum chinense* 'Ruby' to determine herbicide effects on rooting and subsequent plant growth. Herbicides evaluated were: Gallery (isoxaben), Ronstar (oxadiazon), or Regal O-O (oxyfluorfen + oxadiazon). Herbicides were applied as a single application during the propagation process: before sticking (BS), lightly rooted (LR), or fully rooted (FR). Before sticking treatments were applied to flats filled with standard medium prior to the cuttings being stuck. Once cuttings had roots 3 to 5 cm (1-2 inches long) the lightly rooted treatment was applied. Third stage of application (fully rooted) was applied once the cuttings were fully rooted. One year after sticking, growth indices of 'Ruby' Loropetalum were similar regardless of when Gallery was applied. With Ronstar and Regal O-O shoot growth was similar about one year later; however, root coverage was suppressed with Ronstar applied before sticking or lightly rooted, while Regal O-O suppressed root coverage for all dates of application (Exp. 1 and 2).

Index Words: Preemergence herbicides, isoxaben, oxadiazon, oxyfluorfen + oxadiazon

Herbicides used in this study: Gallery (isoxaben), N-[3-(1-ethyl-1methylpropyl)-5-isoxazolyl}-2,6-dimethoxybenzamide; Ronstar (oxadiazon), {3-[2,4-dichloro-5-(1-

methylethoxy)phenyl]-5-1(1,1-dimethylethyl)-1,3,4-oxadiazol-2-(3H)-one}; Regal 0-0 (oxyfluorfen + oryzalin), 2-chloro-1-(3-ethoxy-4-nitrophenoxy)-4-(trifluoromethyl) benzene, 2-tert-butyl-4-2(2,4-dichloro-5-isopropoxyphenyl)-delta^2-1,3,4-oxadiazolin-5-one

Species used in this study: *Loropetalum chinense* 'Ruby' (R. Br.)

Significance to the Nursery Industry

Loropetalum chinense is an evergreen nursery crop propagated in outside beds during the summer. These conditions are ideal for weed germination and growth. A successful weed control program in the field is in part dependent upon starting with a weed free liner. In this study three pre-emergence herbicides were evaluated for potential use in propagation. These results showed timing of herbicide application and herbicides applied have varied responses. Gallery applied to 'Ruby' loropetalum when LR or FR had no negative impact on rooting. These data suggest that Gallery could be used in 'Ruby' Loropetalum propagation for post-emergence control of bittercress.

Introduction

Weeds are a major issue in production of nursery crops even more so in propagation as a result of propagating in small containers and herbicide restrictions (15). Herbicide restrictions in propagation are a result of apprehension with volatilization and co-distillation of the herbicide (2). With these herbicide restrictions hand weeding is the major form of weed control in propagation but can suppress growth of cuttings through mechanical disruption (11). Additionally, relying merely on hand weeding is time-consuming and reduces profits due to increased labor costs (16, 6, 14). In 2004, North Carolina's annual weeding labor costs ranged from $967-$2,228/acre based on an hourly wage of $14.75/hr (12). Weeds not controlled in propagation may become serious problems when liners are potted up for production.

In 2001 no pre-emergence applied herbicides were labeled for use on non-rooted cuttings and few herbicides were labeled for use on liners (7, 12). One reason for lack of herbicide use in propagation is because of safety issues with herbicide use in enclosed areas. However, in the Southern United States, many evergreen nursery crops are frequently propagated in outside beds during the summer, which reduces the risk of herbicide use in enclosed areas. Additionally, most herbicides available for the nursery industry contain dinitroaline (DNA) herbicides, which are root inhibiting (2, 15). Mode of Action (MOA) of DNA herbicides is mitotic inhibition which limits the production of the protein tuberin resulting in failed separation among chromosomes during cell division (4) resulting in root suppression.

Previous research suggests selected pre-emergent herbicides can be used in propagation with minimal impact on root growth. Johnson and Meade (11) reported similar root growth compared to the non-treated when Ronstar was applied to *Rhododendron obtusum* 'Hino Crimson', *Ilex crenata* 'Helleri' or *Euonymus fortunei* 'Emerald Gaiety' cuttings at sticking. Thetford and Gilliam (15) reported Ronstar caused no reduction in root growth or quality when applied during propagation of *Buxus microphylla* var. *koreana* Nakai (Korean boxwood). Application of Ronstar (label rate) to cuttings of Lantana camara L. 'New Gold', Hibiscus rosa-sinensis 'White Leprechaun', *Trachelospermum asiaticum* and *Ilex cornuta* Lindl & Paxt 'Burfodii' showed no reduction in root growth compared to the non-treated (8). Gilliam et al. (9) reported Ronstar 2G applied prior to sticking *Rhododendron* × 'Trouper' (Trouper azalea) cuttings resulted in similar root growth compared to the non-treated. Gallery applied to *Liriope muscari* 'Big Blue' two days after division resulted in similar root growth to the non-treated (10). Additionally, Ronstar and Regal 0-0 were reported to cause no reduction in root quality of *Rhododendron* × 'Girard Rose', *Ilex crenata* var. Hetzii, and *Ilex crenata* var. Compacta during propagation (7).

Altland et al (1) showed that Gallery [1.12 kg ai/ha (1.0 lb ai/A)] provided excellent post-emergence bittercress (*Cardamine hirsuta* L.) control when applied to small non-flowering bittercress, and had no signs of injury to 10.2 cm (4 in) pots of crapemyrtles. Bittercress has been reported as a major concern in container-grown crops in the southeastern United States (12). Bittercress is a common cool-season weed that germinates year round in shaded moist areas (13) and a major problem in propagation (5). Furthermore, bittercress is a highly competitive weed species in the southeast (12) due to rapid seed germination as a result of having no dormancy (13).

Once weeds have infested liners, they become a problem throughout the life of the crop (3). Altland (3) planted liners (received from multiple nurseries) and sent them to participating nurseries. He concluded that creeping wood sorrel quickly invaded Euonymus but no other crop (at every nursery), suggesting the rootball of Euonymus liners were infested with creeping wood sorrel.

Based on previous work with Gallery showing post-emergence control of bittercress (1), Gallery may provide an effective post-emergence option for bittercress control in propagation. Our objective was to compare Ronstar and Regal 0-0 with Gallery for effects on rooting of 'Ruby' Loropetalum when applied at different times during propagation.

Material and Methods:

Experiment 1

Study was initiated August 2, 2005 at Paterson Greenhouse Complex, Auburn University, Auburn, AL (32° 36' N × 85° 20' W, USDA Hardiness Zone 8a). Three preemergence herbicides were applied to cuttings of *Loropetalum chinense* 'Ruby' at three different times in the rooting process. Gallery (1 lb/aia), Ronstar (4 lb/aia), and Regal 0-0 (3 lb/aia) were applied either before sticking (August 2, 2005), when cuttings were lightly rooted (September 18, 2005), or when cuttings were fully rooted (November 4, 2005). Terminal cuttings 7 to 9 cm (2.8 to 3.5 in.) were stuck on August 2, 2005, in 3.5 inch (8.89 cm) containers utilizing a pinebark:sand 6:1 (v:v) medium amended with Polyon 17-6-12 @ 9.0 lbs/yd^3, Micromax @ 1.5 lbs/yd^3, and dolomitic lime @ 5.0 lbs/yd^3. Each cutting was dipped in 1 part Dip 'n' Grow: 5 parts water (2000 ppm IBA) for 4 seconds prior to sticking. Extra (non-treated) cuttings were stuck to monitor the rooting process. The experimental design was a 3×3 factorial with 9 replications of 9 containers per replication in a completely randomized design. All treatments were hand weeded throughout the study to eliminate weed competition effects.

With the before sticking (BS) treatment, propagation flats were treated 1 h before cuttings were stuck and watered in with 0.6 cm (0.25 inch) of water. Climate for the day of treatment was partly cloudy, 85° F. All pots were placed in outdoor cold frames under 47 % shade with overhead mist every five minutes for five seconds from 8:00 AM to 7:00 PM. Thirty-eight days after sticking (DAS), September 8, 2005, a separate group of lightly rooted (LR) cuttings not previously treated were pulled from the mist beds prior to mist starting at 8:00 AM to allow treatment to dry foliage. Immediately after herbicide application the foliage was lightly brushed off and plants were watered in [0.6 cm (0.25 inch)] and returned to mist. On November 4 (94 DAS), the final treatment [fully rooted (FR)] was applied the same as the second treatment and plants were left under mist for one additional week before being moved to a retractable shade house for overwintering.

Data collected fell into two area, 1) cutting performance and 2) overall plant performance. With cutting performance only the 1^{st} two application timings are considered. Response variable included shoot number, length, and root number, length and weight. With overall plant performance, all 3 application timings are included. Response variables are growth indices and root coverage. Cutting performance data was collected 65 DAS. At 65 DAS, shoot number per cutting and average length of the three longest shoots were recorded for cuttings treated before sticking or lightly rooted. Four plants from each replication were randomly selected to determine; 1) number of primary roots, 2) average length of the three longest roots, and 3) root fresh weight. Overall plant performance data was collected 248 and 342 DAS. After over-wintering, April 7, 2006 (248 DAS), growth indices [(height + width at widest point + width perpendicular) ÷ 3] and percent root coverage of the propagation container (0-100 scale) were taken prior to potting in full gallon (#1) containers. Growth indices and percent root coverage of containers were taken again on July 10, 2006 (342 DAS).

Experiment 2

Study initiated on September 22, 2005. Material and methods were similar to experiment 1. Lightly rooted application was applied on November 4, 2005 and fully rooted application on April 12, 2006, then placed in a retractable shade house. On June 27, 2006 growth indices and root ratings were taken and liners were potted into full gallon (#1) containers. On September 29, 2006, study was terminated and final growth indices and root ratings were recorded.

Results and Discussion:

Experiment 1

65 DAS – *Before Sticking* - Gallery had no effect on shoot growth or root growth of cuttings of 'Ruby' Loropetalum (Table 1). Ronstar and Regal 0-0 (BS) suppressed shoot and root growth: shoot number (57 and 53 %), shoot length (44 and 37 %), root number (20 and 31 %), root length (30 and 16 %), and root fresh weight (50 and 33 %) compared to the non-treated control when applied before sticking. *Lightly rooted* – Compared to the non-treated control plants there were no herbicide effects on new shoot number, shoot length, or root fresh weight with the LR application, with the exception of Regal 0-0 having greater shoot length (Table 1). Gallery and Ronstar had slightly less root numbers compared to Regal 0-0 and non-treated plants when applied to LR cuttings. There was suppression in root length (less than 10 %) with Gallery and Regal 0-0 (applied to LR cuttings) compared to the non-treated control. Our data is similar to Hayes et al. (10) showing reduced root ratings with Regal 0-0, 90 days after treatment.

248 DAS – *Before Sticking* – Gallery, Ronstar, and Regal 0-0 had less root coverage and growth indices compared to the non-treated control plants. Comparing herbicides, Gallery and Ronstar applied BS were similar (48 and 46 % root reduction and 38 and 44 % reduction in growth indices compared to the non-treated cuttings) while Regal 0-0 (BS) caused severe reduction in growth indices (73 %) and root coverage (74 %) (Table 2). *Lightly Rooted* – 'Ruby' Loropetalum stem cuttings treated when roots were 2.5 to 5 cm (1-2 in.) long were similar in growth indices regardless of herbicide

treatment (Table 2). Root ratings were less for Ronstar and Regal 0-0 (LR) compared to the non-treated control; however, Gallery (LR) had similar rootball coverage to the non-treated control plants. *Fully rooted* – Compared to the non-treated plants new shoot growth was reduced by 27 (Gallery), 29 (Ronstar), or 45 % (Regal 0-0) (Table 2). Gallery applied to FR cuttings had similar root ratings compared to the non-treated plants. However, Ronstar and Regal 0-0 (FR) suppressed root coverage by 22 and 38 %, respectively, compared to the non-treated plants.

342 DAS – *Before Sticking* – Approximately one year after application, all stem cuttings had similar growth indices regardless of herbicide treatment (Table 3). All herbicide treatments (applied BS) had less root coverage than the non-treated control plants. No difference in root coverage was observed between Gallery and Ronstar, which had 17 and 19 % less root coverage respectively, compared to the non-treated cuttings. Regal 0-0 (BS) had the greatest root suppression (33 %) compared to the non-treated plants (Table 3). *Lightly rooted* – Plants from all herbicide treatments were similar in shoot size or larger than the non-treated control plants when treated at the lightly rooted stage during propagation (Table 3). Gallery applied to LR cuttings had similar root coverage compared to the non-treated control plants. Ronstar and Regal 0-0 had less root coverage than the non-treated plants however Ronstar treated cuttings had similar root coverage to cuttings treated with Gallery. *Fully rooted* – Gallery, Ronstar, and Regal 0-0 applied to FR cuttings had similar growth indices compared to the non-treated control one year after propagation (Table 3). There was no herbicide affects in percent root coverage compared to the non-treated control with the exception of Regal 0-0 which reduced root coverage by 23 % when applied to fully rooted cuttings.

Experiment 2 ~ 65 DAS – *Before Sticking* – There was no shoot growth observed, therefore shoot growth was not recorded. Gallery (BS) had fewer root numbers compared to the non-treated cuttings which resulted in less than average root length and root fresh weight (Table 4). Ronstar and Regal 0-0 (BS) had similar root growth compared to the non-treated cuttings. *Lightly Rooted* – Compared to the non-treated plants there were no herbicide effects on root number, length, or fresh weight with the exception of root length with Gallery (Table 4). Our data concur with previous data showing Ronstar to have no effect on root quality of several other woody nursery crops (9, 7, 15, 11)

268 DAS – *Before Sticking* – Regardless of herbicide treatment, growth indices were similar compared to the non-treated plants (Table 5). However root coverage was less in all herbicide treatments (BS) compared to the non-treated plants. *Lightly Rooted* – Cuttings treated with Gallery and Ronstar had greater growth indices compared to Regal 0-0 treated cuttings and the non-treated plants (Table 5). Gallery applied to 'Ruby' loropetalum stem cuttings with 1-2 inch roots (LR) had similar root coverage compared to the non-treated. Compared to the non-treated cuttings, Ronstar and Regal 0-0 treated cuttings had a reduction in root coverage by 25 and 18 % respectfully. *Fully Rooted* – Growth indices were greater for Gallery and Ronstar treated cuttings compared to Regal 0-0 treated cuttings and the non-treated plants. Root coverage was similar among herbicide treated cuttings compared to the non-treated plants (Table 5).

362 DAS – Regardless of herbicide treatment or application time growth indices and root coverage were similar compared to the non treated plants with the exception of

Regal 0-0 (Table 6). When Regal 0-0 was applied BS and to LR cuttings there was a reduction in root coverage by 28 % compared to the non-treated plants.

These studies demonstrate varied responses in using herbicides during propagation. In Experiments 1 and 2 Gallery, Ronstar, and Regal 0-0 had similar shoot growth compared to the non-treated ‘Ruby’ Loropetalum cuttings by the end of the first year. Gallery applied to lightly or fully rooted stem cuttings of ‘Ruby’ loropetalum did not cause any suppression in shoot or root growth in either experiment. In experiment 1, Ronstar suppressed root coverage when applied BS and to LR cuttings, however in experiment 2 root coverage was similar compared to the non-treated plants. Regal 0-0 suppressed root growth regardless of application time in experiment 1 but in experiment 2 a reduction in root coverage only occurred when applied to BS and LR cuttings compared to the non-treated cuttings. From a grower’s point of view, use of herbicides in propagation which causes slight reductions in root coverage may be more acceptable than dealing with weed pressure and added labor cost throughout the life of the crop.

Literature Cited

1. Altland, J.E., C.H. Gilliam, J.H. Edwards, G.J. Keever, J.R. Kessler, Jr., and D.J. Eakes. 2000. Effect of bittercress size and Gallery rate on postemergence Bittercress Control. J. Environ. Hort 18(3):128-132.

2. Altland, J., R. Regan, and A. Newby. 2003. Liverwort control in propagation: Challenges and opportunities©. Comb. Proc. Intl. Plant Prop. Soc. 53:383-386.

3. Altland, J. 2006. Research examines a new tool for control of creeping wood sorrel. Digger. 50:24-28.

4. Ashton, F.M. and A. S. Crafts. 1973. Chapter 14. Dinitroanilines in Mode of Action of Herbicides. Pg. 221-235.

5. Bachman, G. and T. Whitwell. 1995. Hairy bittercress seed production, dispersal, and control. Proc. SNA Res. Conf. 40:288-290.

6. Carpenter, P.L. 1973. Chemical weed control in container-grown nursery stock. HortScience 8:385-386.

7. Cook, J.C. and J.C. Neal. 2001. Effects of herbicides and application timing on rooting of azalea and japanese holly cuttings. Proc. South. Nurs. Assoc. Res. Conf. 46:422-424.

8. Davies, F.T. and S.A. Duray. 1992. Effect of preemergent herbicide application on rooting and subsequent liner growth of selected nursery crops. J. Environ. Hort. 10:181-186.

9. Gilliam, C.H., D.J. Eakes, and J.W. Olive. 1993. Herbicide use during propagation affects root initiation and development. J. Environ. Hort. 11:157-159.

10. Hayes, C.K., C.H. Gilliam, J.W. Olive, G.J. Keever, and D.J. Eakes. 1999. Pre-emergence applied herbicides for container-grown liriope after division. J. Environ. Hort. 17:31-35.

11. Johnson, J.R. and J.A. Meade. 1987. Pre-emergent herbicide effect on the rooting of cuttings. Comb. Proc. Intl. Plant Prop. Soc. 36:567-570.

12. Judge, C.A., J.C. Neal, and J.B. Weber. 2004. Dose and concentration responses of common nursery weeds to Gallery, Surflan and Treflan. J. Environ. Hort. 22:106-112.

13. Neal, J.C. and J.F. Derr. 2005. Weeds of Container Nurseries. North Carolina Association of Nurserymen, Inc. ISBN: 0-89892-312-3.

14. Pradgett, J.H. and T.L. Frazier. 1962. The relationship between costs and pruning of woody ornamentals. Ga. Agr. Expt. Sta. Bul. (N.S.) 100.

15. Thetford, M. and C.H. Gilliam. 1991. Herbicide use in propagation: Effects on rooting and root growth of stem cuttings. J. Environ. Hort. 9:21-23.

16. Weller, S.C., J.B. Masiunas, and P.L. Carpenter. 1984. Evaluation of Oxyfluorfen formulations in container nursery crops. HortScience 19:222-224.

Table 2 - 1. Effects of selected herbicides and time of application on *Loropetalum chinense* 'Ruby' during propagation, Experiment 1.

	Before sticking[z]				**Lightly rooted**[y]			
Response Variables	Gallery	Ronstar	Regal 0-0	Control	Gallery	Ronstar	Regal 0-0	Control
Shoot Number[x]	3.6a[s]	1.3c	1.4c	3.0b	2.7a	2.7a	2.8a	3.0a
Shoot Length[w]	4.3a	2.3b	2.6b	4.1a	4.5b	3.8b	5.9a	4.1b
Root Number[v]	11.5ab	10.1bc	8.7c	12.6a	10.8b	10.5b	12.7a	12.6a
Root Length[u]	22.7a	15.4c	18.5b	22.0a	19.9b	21.4ab	19.8b	22.0a
Root Fresh Weight[t]	0.6a	0.3b	0.4b	0.6a	0.6a	0.5a	0.5a	0.6a

[z] Before Sticking - herbicide prior to sticking cuttings.

[y] After Sticking - herbicide applied to lightly rooted cuttings.

[x] Shoot Number - number of new shoots per rep.

[w] Shoot Average - length of three longest shoots ÷ 3 (cm).

[v] Root Number - number of primary roots per replication.

[u] Root Average - length of three longest roots ÷ 3 (cm).

[t] Root Weight - root fresh weight (grams).

[s] Means (across columns within application times) with different letters are significantly different, according to Duncan's Multiple Range Test (α=0.05).

Table 2 - 2. The influence of herbicide application during propagation 248 days after sticking *Loropetalum chinense* 'Ruby' stem cuttings, Experiment 1.

	GI[z]			Root Coverage[y]		
Herbicide	Before sticking	Lightly rooted[x]	Fully rooted	Before sticking	Lightly rooted	Fully rooted
Gallery	19.8b[w]	30.2a	28.0b	22.1b	29.5ab	30.7ab
Ronstar	20.5b	42.7a	27.2b	19.7b	27.8b	28.4b
Regal 0-0	10.2c	22.1a	20.9b	9.3c	24.5b	22.5c
Control	38.3a	38.3a	38.3a	35.4a	35.4a	36.2a

[z] Growth indices - Height + width at widest point + width perpendicular ÷ 3.

[y] Root coverage was an estimate of the percentage of the rootball surface covered with roots (0-100 %).

[x] Lightly Rooted - herbicide applied to lightly rooted cuttings (1-2 inches).

[w] Means (within a column for each factor) with different letters are significantly different, according to Duncan's Multiple Range Test (α=0.05).

Table 2 - 3. The influence of herbicide application during propagation 342 days after sticking *Loropetalum chinense* 'Ruby' stem cuttings, Experiment 1.

	GI[z]			**Root coverage**[y]		
Herbicide	Before sticking	Lightly rooted[x]	Fully rooted	Before sticking	Lightly rooted	Fully rooted
Gallery	44.1a[x]	47.3a	47.1a	57.5b	63.3ab	65.5a
Ronstar	41.3a	44.2b	46.5a	56.1b	61.3b	64.0a
Regal 0-0	41.1a	45.2ab	51.9a	46.2c	52.8c	53.1b
Non-treated	43.7a	43.7b	43.7a	68.9a	68.9a	68.9a

[z] Growth Indices - height + width at widest point + width perpendicular ÷ 3.

[y] Root coverage was an estimate of the percentage of the rootball surface covered with roots (0-100).

[x] Lightly Rooted - herbicide applied to lightly rooted cuttings (1-2 inches).

[w] Means (within a column for each factor) with different letters are significantly different, according to Duncan's Multiple Range Test ($\alpha = 0.05$).

Table 2 - 4. Effects of selected herbicides and time of application on 'Ruby' Loropetalum stem cuttings 68 days after sticking cuttings, Experiment 2.

		Before sticking[z]			Lightly rooted[y]		
Herbicide	**Rate**	**Number[x]**	**Average[w]**	**Weight[v]**	**Number**	**Length**	**Weight**
Gallery	1 lbs/aia	8.3b[u]	2.8b	0.12b	12.7a	3.2b	0.20a
Ronstar	4 lbs/aia	10.6a	4.1a	0.18ab	11.9a	4.3a	0.22a
Regal 0-0	3 lbs/aia	11.7a	4.0a	0.21a	11.5a	4.2a	0.19a
Non-treated	-	11.4a	4.1a	0.23a	11.4a	4.1a	0.23a

[z] Before sticking - herbicide prior to sticking cuttings.

[y] Lightly rooted - herbicide applied to lightly rooted cuttings.

[x] Number - number of primary roots per replication.

[w] Average - length of three longest roots ÷ 3 (cm).

[v] Weight - root fresh weight (grams).

[u] Means (within columns) with different letters are significantly different, according to Duncan's Multiple Range Test (α=0.05).

Table 2 - 5. The influence of herbicide application during propagation 268 days after sticking *Loropetalum chinense* 'Ruby' stem cuttings, Experiment 2.

		GI[z]			Root coverage[y]		
Herbicides	**Rate**	**Before sticking**	**Lightly rooted[x]**	**Fully rooted**	**Before sticking**	**Lightly rooted**	**Fully rooted**
Gallery	1 lbs/aia	15.2a[w]	17.8a	19.0a	22.6c	32.0ab	43.7a
Ronstar	4 lbs/aia	15.8a	17.4a	18.1a	28.4bc	29.1b	42.0a
Regal 0-0	3 lbs/aia	16.5a	16.7ab	16.3b	31.2b	27.1b	34.9a
Non-treated	-	15.0a	15.0b	15.0b	38.1a	38.1a	38.1a

[z] Growth indices - Height + width at widest point + width perpendicular ÷ 3.

[y] Root coverage was an estimate of the percentage of the rootball surface covered with roots (0-100 %).

[x] Lightly Rooted - herbicide applied to lightly rooted cuttings (1-2 inches).

[w] Means (within a column for each factor) with different letters are significantly different, according to Duncan's Multiple Range Test (α=0.05).

Table 2 - 6. The influence of herbicide application during propagation 362 days after sticking *Loropetalum chinense* 'Ruby' stem cuttings, Experiment 2.

		GI[z]			Root coverage[y]		
Herbicides	**Rate**	**Before sticking**	**Lightly rooted[x]**	**Fully rooted**	**Before sticking**	**Lightly rooted**	**Fully rooted**
Gallery	1 lbs/aia	39.8a[w]	46.9a	43.5ab	49.5a	50.6a	49.2a
Ronstar	4 lbs/aia	40.2a	44.9ab	47.9a	47.1a	50.7a	53.7a
Regal 0-0	3 lbs/aia	37.1a	41.1b	47.0a	39.4b	40.5b	53.0a
Non-treated	-	40.3a	40.3b	40.3b	51.0a	51.0a	51.0a

[z] Growth indices - Height + width at widest point + width perpendicular ÷ 3.

[y] Root coverage was an estimate of the percentage of the rootball surface covered with roots (0-100 %).

[x] Lightly Rooted - herbicide applied to lightly rooted cuttings (1-2 inches).

[w] Means (within a column for each factor) with different letters are significantly different, according to Duncan's Multiple Range Test (α=0.05).

CHAPTER III

HERBICIDE EFFICACY IN ALTERNATIVE SUBSTRATES FOR CONTAINER GROWN NURSERY CROPS

Abstract

This study evaluated the influence of alternative substrates on herbicide efficacy in container grown nursery crops. Alternative substrates evaluated were either hammer-milled pine wood chips, chipped or hammer-milled whole pine trees, or the previously mentioned substrates combined with pinebark. Rout (oxyfluorfen + oryzalin at 2.24 + 1.12 $kg \cdot ha^{-1}$) or Ronstar (oxadiazon at 4.48 $kg \cdot ha^{-1}$) were applied at recommended label rate. After herbicides were applied and irrigated, containers were overseeded with 25 spotted spurge (*Euphorbia maculata*) seed per container. In general, weed control in alternative substrates was superior to that obtained in commercially used pinebark. Rout provided superior spurge control compared to Ronstar.

Index words: growing media, soilless media

Herbicides used in this study: Rout (oxyfluorfen + oryzalin) 3,5-dinitro-N^4,N^4-dipropylsulfanilamide; Ronstar 2G (oxadiazon), {3-[2,4-dichloro-5-(1-methylethoxy)phenyl]-5-1(1,1-dimethylethyl)-1,3,4-oxadiazol-2-(3H)-one}

Species evaluated in this study: spotted spurge (*Euphorbia maculata*)

Significance to the Nursery Industry

Recent research has focused on alternative substrates derived from forest products. While these substrates have been successfully used to produce a wide range of crops, no research has been conducted to evaluate the efficacy of herbicides used with these substrates. The objective of this study was to evaluate the efficacy of herbicides on prostrate spurge which will allow growers to keep their current weed control practices and save money with alternative substrates. These data show that control of prostrate spurge with commonly used pre-emergent applied herbicides may actually be improved with some of the alternative substrates currently being evaluated.

Introduction

In the past few years the supply of pinebark for use in container nursery crop production has declined (14). Several factors have contributed to this decline including: use of pine bark for fuel, a trend towards in-field harvesting of pine trees which leaves the pine bark in the forest, and increased foreign importation of logs (no bark) (14). With limited supply and increasing prices, there is greater interest in the use of alternative substrates in container nursery crop production.

Many alternative substrates have been evaluated for container grown crops including: biosolids (8, 10, 11, 12), wood waste (15), coco fibers (16), and pine chips (2, 5, 26). In recent research *Cypress sempervirens* and *C. arizonica* were grown effectively in pine bark or coconut fiber mixed with 30% sewage sludge (biosolid compost) (11). Compost-based media derived from biosolids and yard trimmings showed *Justica carnea* had similar growth compared to a peat-based media grown *J. carnea* (25). Although there has been success in several alternative substrates the most common alternative substrates being evaluated are by-products from the forestry industry (18).   In 2004, Gruda and Schnitzler (9) had success growing vegetable transplants in non-treated spruce wood chips. Wright and Browder (26) demonstrated that *Ilex crenata* 'Chesapeake' could be grown effectively in ground loblolly pine (*Pinus taeda*) logs. Boyer et al. (2) reported that perennials grown in clean chip residual (forestry by-product of in-field harvesting) were similar to plants grown in pinebark. Fain et al. (5) evaluated a substrate made from all above ground portions of loblolly pine (*Whole tree*) with plants being similar to those grown in traditional pinebark substrates.

While these substrates have been evaluated for container-grown crops, limited research has been done with alternative substrates to determine if herbicide efficacy is affected. Pre-emergent herbicides are the most common chemical control in container nurseries (7). Herbicides are applied to and adsorbed by the substrate. It must be desorbed into soil solution for uptake by the weed (3). Degradation is dependent on temperature, pH, and moisture content of the soil (13). While some of the by-products such as *Quercus suber* L. (cork oak) had an optimum pH value of 6.1 and a low electrical conductivity of 0.35 mS cm^{-1} (18) others have shown an increase in pH values in composted material (biosolids and yard trimmings) (25). Subsequently, many of the alternative substrates being researched contain organic material, which has previously been shown to affect the mobility of pesticides (23). Herbicide efficacy in organic matter depends upon crop species and herbicide (19). Warren (24) reported propachlor leached out rapidly in soil with 0.7 % organic matter, whereas soil with 3 % organic matter improved the adsorptive capacity reducing the amount of propachlor leaching. The impact of high wood content substrates on herbicide adsorption is unknown; however, other cultural practices have been impacted by these substrates. For example, Wright and Browder (26) demonstrated Electrical Conductivity (EC) was lower in crops grown in pine wood chips and additional fertilizer was required in order to have similar growth to crops grown in pine bark.

Euphorbia maculata (spotted spurge) was selected as weed species to use in comparing herbicide efficacy in several alternative substrates. Spurge is a common summer annual weed that germinates quickly (21) resulting in it being a major weed problem throughout the U.S. The objective of this study was to compare herbicide efficacy on control of spotted spurge grown in alternative substrates compared to a traditional pine bark substrate.

Materials and Methods

Experiment One

Nine alternative substrates were evaluated for herbicide efficacy in container grown nursery crops: pine wood chips (100 % wood) hammer-milled to pass a 0.4 cm (0.16 in) screen (PWCH1), pine wood chips hammer-milled to pass a 0.64 cm (0.25 in) screen (PWCH2), whole pine tree chipped (WTC) [particle size distribution: 4 % was above 5.1 cm (2.0 in.), 9 % between 2.5 and 5.1 cm (1.0 - 2.0 in.), 26% between 1.3 and 2.5 cm (0.5 and 1.0 in.), and 61 % was less than 1.3 cm (0.5 in.)], WTC-hammer-milled to pass a 0.48 cm (0.19in) screen (WTCH) (Hammer-mill, Model10HMBLPK, C.S. Bell Co., Tiffin, Ohio), PWCH1:pinebark (PB) (1:1 v:v), PWCH2:PB (1:1 v:v), WTC:PB (1:1 v:v), WTCH:PB (1:1 v:v), and PB:sand (6:1 v:v) (PBS). In addition, substrates were amended with 5.4 kg/m^3 (12 lbs/yd^3) of 17-6-12 (17N-2.6P-10K), Polyon control-release fertilizer (CRF), 0.45 kg/m^3 (1 lb/yd^3) of lime, and 0.68 kg/m^3 (1.5 lbs/yd^3) Micromax in both experiments. Pour through extraction were conducted at 21, 56, and 85 DAP for pH and electrical conductivity (EC) (27). Substrate container capacity, airspace, total porosity, and bulk density were determined following procedures described by Bilderback et al. (1). In general physical and chemical characteristics were within acceptable ranges (28) (Table 1). Containers [10.2 cm (4 in.)] were filled on June 15, 2005, watered in and the following day (June 16, 2005) two herbicides were applied: Rout [oxyfluorfen + oryzalin at 2.24 + 1.12 $kg.ha^{-1}$ (3 lb/aia)] or Ronstar [oxadiazon at 4.48 $kg.ha^{-1}$ (4 lb/aia)]. Non-treated controls were maintained throughout the study. One day after herbicide application, containers were overseeded with 25 spotted spurge seed and placed in full sun with overhead impact irrigation. Data collected included spotted spurge number at 30 and 60 days after treatment (DAT), and spurge fresh weights at 60 DAT. The experiment was a complete randomized 9 × 3 factorial with 10 single pot replications. Data was analyzed using a generalized linear model with least significant difference means separation.

Experiment Two

Materials and methods were similar to experiment one with the following exceptions. August 29, 2005, containers were filled and watered in (8:00 – 11:00 AM) and around 3:30 PM herbicides were applied and placed in full sun under overhead impact irrigation. Composted poultry litter was added as a substrate amendment and the fertilizer rate was increased to 9.1 kg/m^3 (20 lbs/yd^3), in one set of substrates. Substrates evaluated included: PWCH2, WTC, PBS, PWCH2 + 12.5 % composted poultry litter (CPL) [PWCH2:CPL (6:1 v:v)], WTC:CPL (6:1 v:v), PWCH2 incorporated with 9.07 kg/m^3 (20 lb/yd^3) Polyon control release fertilizer (CRF) (PWCH2:CRF), WTC:CRF, and

PBS:CRF. Weed number and weed fresh weights were taken at 30 and 60 DAT. This experiment was a complete randomized 8 x 3 factorial with 10 replications and both experiments were conducted at the Auburn University Paterson Greenhouse Complex, Auburn, AL (32° 36' N × 85° 20' W, USDA Hardiness Zone 8a). Data were analyzed using a generalized linear model with Least Significant Difference and Duncan’s Multiple Range Test, alpha set at 0.05 (22).

Results and Discussion

Experiment 1

At 30 DAT, spurge number was similar for WTC, PWCH1, PWCH2 and WTC:PB with WTC having a lower spurge number than the other five substrates (Table 2). These trends continued at 60 DAT with WTC having lower spurge number than any of the other substrates with the exception of PWCH2. Lower spurge number in these substrates could be a result of the large particle sizes, which are not as conducive for weed germination (20). Spurge fresh weights were 78 % and 65 % lower in PWCH2 and WTC respectively than PBS.

Overall, Rout provided superior spurge control throughout the study (Tables 2, 3). For example, spurge numbers were less per container at 30 (77 %) and 60 (41 %) DAT and spurge fresh weights (79 %) than containers treated with Ronstar. These results concur with previous rankings of herbicide efficacy comparing Rout and Ronstar for spurge control (17).

Comparison of herbicide efficacy among individual substrates show excellent spurge control was obtained in all treatments except WTCH (Table 3). While all treatments except WTCH treated with Rout were statistically similar, there was a trend for PWCH1, PWCH2, and WTC to have fewer spurge per container than substrates containing pinebark. With Ronstar, the least spurge control tended to occur in the PBS commercial substrate and combinations with PB. Spurge numbers in non-treated containers varied with substrates. At 30 DAT, WTC, WTCH and WTC:PB had the lowest spurge number while PBS and substrates with PB tended to have the greatest spurge number per container. Spurge fresh weights were least in WTC, PWCH2, PWCH2:PB and WTCH:PB. With the exception of PWCH1, all alternative substrates tended to have less spurge fresh weights than PBS.

Experiment 2

A herbicide pooled comparison of efficacy at 30 and 60 DAT showed that substrates with PWCH2 tended to have the least spurge per container (Table 4). Spurge fresh weight data were similar to experiment 1 in that PWCH2 (92 %) and WTC (76 %) treated were lower than the PBS treated substrate. Spurge fresh weights tended to be highest in substrates with CPL or with PBS plus additional CRF. For example, with PWCH2 the addition of CPL increased spurge fresh weights by 95 % and with WTC spurge fresh weights were increased 86 %. These data concur with previous work showing herbicide adsorption is affected by organic matter (19). Unlike experiment 1, spurge control was similar with Rout and Ronstar throughout experiment 2.

Evaluation of herbicide efficacy in individual substrates showed that spurge number at 30 and 60 DAT and spurge fresh weight tended to be greatest in the WTC:CPL substrate (Table 5). Spurge numbers were almost 2X at 30 and 60 DAT and spurge fresh weights were 3X greater than WTC alone. In the non-herbicide containers, the least spurge growth tended to be in PWCH2 treatments. For example at 30 DAT spurge numbers were 1.1, 4.8, and 2.1 respectively for PWCH2, CPL, and CRF. In contrast the greatest spurge fresh weight occurred with PWCH2:CPL, WTC:CPL, and PBS:CRF.

Generally, all alternative substrates treated with Rout and Ronstar had less spurge number compared to PBS in both experiments. Additionally, substrates with added pinebark tended to have more spurge compared to non-amended substrates (Exp. 1). In experiment 2, spurge number and fresh weights tended to be greater with the addition of CPL. These data show that control of spotted spurge with commonly used pre-emergent applied herbicides may actually be improved with some of the alternative substrates currently being evaluated.

Literature Cited

1. Bilderback, T.E., W.C. Fonteno, and D.R. Johnson. 1982. Physical properties of media composed of peanut hulls, pinebark, and peatmoss and their effects on azalea growth. J. Amer. Soc. Hort. Sci. 107:522-525.

2. Boyer, C.R., G.B. Fain, C.H. Gilliam, T.V. Gallagher, H.A. Torbert, and J.L. Sibley. 2006. Clean chip residual: A new substrate component for container-grown plants. Proc. SNA Res. Conf. 51:22-25.

3. Caberera, A., L. Cox., and W.C. Koskinen. 2006. Soil organic amendment as affecting herbicide fate. American Chemical Society Abstracts. p. 99.

4. Everest, John W., Charles H. Gilliam and Ken Tilt. 1998. Weed control for commercial nurseries. Al. Coop. Ext. Sys. Auburn University. Oct. ANR-465.

5. Fain, G.B., C.H. Gilliam, and J.L. Sibley. 2006. Processed whole pine trees as a substrate for container-grown plants. Proc. SNA Res. Conf. 51:59-61.

6. Gartner, J.B., M.M. Meyer, Jr. and D.C. Saupe. 1971. Hardwood bark as a growing media for container-grown ornamentals. Forest Prod. J. 21:25-29.

7. Gilliam, C.H., D.C. Fare, and A. Beasley. 1992. Nontarget herbicide losses from application of granular Ronstar to container nurseries. J. Environ. Hort. 10(3)175-176.

8. Gouin, F.R. 1993. Utilization of sewage sludge compost in horticulture. HortTech. 3:161-163.

9. Gruda, N. and W.H. Schnitzler. 2004. Suitability of wood fiber substrate for production of vegetable transplants I. Physical properties of wood fiber substrates. Sci. Hortic-Amsterdam 100:309-322.

10. Guerrero, F., J.M. Gascó, and L. Hernandez-Apaoloaza. 2002. Use of pine bark and sewage sludge compost as components of substrates for *Pinus pinea* and *Cupressus arizonica* production. J. Plant Nutr. 25:129-141.

11. Hernández-Apaolaza, L., A.M. Gascó, J.M. Gascó, and F. Guerrero. 2005. Reuse of waste materials as growing media for ornamental plants. Bioresour. Technol. 96:125-131.

12. Ingelmo, F., R. Canet, M.A. Ibañez, F. Pomares, and J. García. 1998. Use of MSW compost, dried sewage sludge and other wastes as partial substitutes for peat and soil. Bioresour. Technol. 63:123-129.

13. James, T.K., P.T. Holland, A. Rahman, and Y.R. Lu. 1999. Degradation of the sulfonylurea herbicides chlorsulfuron and triasulfuron in a high-organic-matter volcanic soil. Weed Res. 39:137-147.

14. Lu, W., J.L. Sibley, C.H. Gilliam, J.S. Bannon, and Y. Zhang. 2006. Estimation of U.S. bark generation and implications for horticultural industries. J. Environ. Hort. 24:29-34.

15. Lumis, G.P. 1976. Using wood waste compost in container production. Am. Nurseryman 163:10-11, 58-59.

16. Lennartsson, M. 1997. The peat conservation issue and the need for alternatives. In: Proceedings of the IPS International Peat Conference on Peat in Horticulture. Schmilewski, Amsterdam, 112-121.

17. Neal, J.C. and J.F. Derr. 2005. Weeds of container nurseries in the United States. North Carolina Association of Nurserymen, Inc. ISBN: 0-89892-312-3.

18. Ortega, M.C., M.T. Moreno, J. Ordovás, and M.T. Aguado. 1996. Behaviour of different horticultural species in phytotoxicity bioassays of bark substrates. Sci. Hortic-Amsterdam 66:125-132.

19. Rao, V.S. 2000. Principles of Weed Science; Herbicide resistance and genetic engineering. 2nd edition science publishers Inc., Enfield NH, USA printed in India Pg 305.

20. Richardson, B. 2006. Effective non-traditional weed control in container-grown nursery production, MS Thesis. Auburn University, Auburn, AL.

21. Ruter, J.M. and N.C. Glaze. 1992. Herbicide combinations for control of prostrate spurge in container-grown landscape plants. J. Environ. Hort. 10:19-22.

22. SAS Institute. 2003. SAS/STAT User's Guide: Release 9.1 ed. SAS Inst., Cary, NC.

23. Spark, K.M. and R.S. Swift. 2002. Effect of soil composition and dissolved organic matter on pesticide sorption. Sci. Total Environ. 298:147-161.

24. Warren, G.F. 1973. Action of herbicides in soilà. Affected by organic matter. Weeds Today 4:10-11.

25. Wilson, S.B., P.J. Stofella, and D.A. Graetz. 2002. Development of compost-based media for containerized perennials. Sci. Hortic-Amsterdam 93:311-320.

26. Wright, R.D. and J.F. Browder. 2005. Chipped pine logs: A potential substrate for greenhouse and nursery crops. HortScience 40:1513-1515.

27. Wright, R.D. 1986. The pour-through nutrient extraction procedure. HortScience 21:227-229.

28. Yeager, T.H., C.H. Gilliam, T.E. Bilderback, D.C. Fare, A.X. Niemiera, and K.M. Tilt. 1997. Best Management Practices Guide for Producing Container-Grown Plants. Southern Nursery Assn., Marietta, GA.

Table 3 - 1. pH, electrical conductivity, and physical properties of alternative substrates.

Substrates	pH[z] 21 DAP[u]	pH[z] 85 DAP	EC 21 DAP	Container capacity[y] (% vol)	Air space[x] (% vol)	Total porosity[w] (% vol)	Bulk density[v] ($g \cdot cm^{-3}$)
Experiment 1							
PWCH1[t]	6.0fg[s]	6.0ab	0.3a	48.2b	32.1de	80.3bc	0.1efg
PWCH2[r]	6.2ef	5.9abc	0.3ab	29.6f	39.0c	86.8a	0.1efg
WTC[q]	6.7b	6.1a	0.2c	29.6f	51.5a	81.1bc	0.2def
WTCH[p]	6.4d	5.8bcd	0.3ab	36.2de	50.8a	86.9a	0.1g
PWCH1:Pb[o]	6.4cd	5.3e	0.2b	48.4b	33.0d	81.4bc	0.2de
PWCH2:PB	5.9g	4.8f	0.3ab	41.2c	37.6c	78.8cd	0.1def
WTC:PB	6.4cd	5.6cd	0.2bc	28.6f	46.1b	74.6d	0.2bc
WTCH:PB	6.3de	5.2e	0.2bc	36.3de	45.7b	82.0bc	0.1fg
PBS[n]	6.6bc	5.6d	0.3a	38.5cd	28.8e	67.2e	0.3a
Experiment 2							
PWCH2:CPL[m]	7.2a	6.0ab	0.3a	54.0a	30.1de	84.2ab	0.2bc
WTC:CPL	7.2a	6.1a	0.3ab	33.5e	45.1b	78.6cd	0.2cd

[z]pH range was acceptable as reported by Yeager et al., 1997. Best Management Practicses Guide for Producing Container-grown Plants.

[y]Container capacity is (wet weight - oven dry weight) ÷ volume of the sample.

[x]Air space is volume of water drained from the sample ÷ volume of the sample.

[w]Total porosity is container capacity + air space.

[v]Bulk density after forced-air drying at 105°C for 48 h ($1\ g \cdot cm^{-3} = 62.43\ lb/ft^3$).

[u]DAP - days after potting.

[t]PWCH1 - pine wood chips (100% wood) hammer-milled to pass a 0.4 cm screen.

[s]Means (within a column) with different letters are significantly different, within substrates or herbicides according to Least Significant Difference test (α=0.05).

[r]PWCH2 - pine wood chips hammer-milled to pass a 0.64 cm screen.

[q]WTC - whole pine tree chipped (particle size distribution: 4% was above 5.1 cm, 9% between 2.5 - 5.1 cm, 26% between 1.3 - 2.5 cm, and 61 % was less than 1.3 cm.

[p]WTCH - WTC-hammer-milled to pass a 0.48 cm screen.

[o]Substrates with pinebark added 1:1 (v:v).

[n]PBS - pinebark:sand 6:1 (v:v).

[m]Substrates with composted poultry liter 6:1 (v:v).

Table 3 - 2. Eight alternative substrates evaluated on herbicide efficacy, Experiment 1.

		Weed number[z]		Fresh weight[y]
Alternative Substrates	**Ratio/Rate**	**30 DAT[x]**	**60 DAT**	**60 DAT**
PWCH1[w]	100 %	1.8abc[v]	3.0ab	8.7ab
PWCH2[u]	100 %	1.6bc	2.1bc	2.4f
WTC[t]	100 %	0.8c	1.5c	3.7ef
WTCH[s]	100 %	1.9ab	3.4a	9.0ab
PWCH1:PB[r]	1:1	2.0ab	3.2a	7.9abc
PWCH2:PB	1:1	2.0ab	3.0ab	4.3def
WTC:PB	1:1	1.2bc	2.9ab	5.7cde
WTCH:PB	1:1	1.9ab	3.4a	6.8bcd
PBS[q]	6:1	2.7a	2.7ab	10.7a
Herbicide				
Rout	3 lb/aia	0.2c	1.0c	1.4c
Ronstar	4 lb/aia	0.9b	1.7b	6.7b
Non-treated	-	4.2a	5.8a	11.9a
Main Effects				
Substrate		0.013	0.002	0.001
Herbicide		0.001	0.001	0.001
Interaction		0.001	0.401	0.001

[z] Spurge number per container overseeded at 25 seed per container.

[y]Fresh weight at 60 DAT (grams).

[x] DAT - days after treatment.

[w]PWCH1 - pine wood chips (100% wood) hammer-milled to pass a 0.4 cm screen.

[v]Means (within a column) with different letters are significantly different, within substrates or herbicides according to Least Significant Difference test (α=0.05).

[u]PWCH2 - pine wood chips hammer-milled to pass a 0.64 cm screen.

[t]WTC - whole pine tree chipped (particle size distribution: 4% was above 5.1 cm, 9% between 2.5 and 5.1 cm, 26% between 1.3 and 2.5 cm, and 61% was less than 1.3 cm).

[s]WTCH - WTC-hammer-milled to pass a 0.48 cm screen.

[r]Substrates with pinebark added 1:1 (v:v).

[q]PBS - pinebark:sand 6:1 (v:v).

Table 3 - 3. Weed control in alternative substrates with commonly used pre-emergence, Experiment 1.

	Rout			Ronstar			Non-treated		
	Weed number[z]		FW[y]	Weed number		FW	Weed number		FW
Alternative Substrates	**30 DAT[x]**	**60 DAT**	**60 DAT**	**30 DAT**	**60 DAT**	**60 DAT**	**30 DAT**	**60 DAT**	**60 DAT**
PWCH1[w]	0.0a[v]	0.6bcd	0.3b	0.9abc	2.5ab	7.1abc	4.4bc	5.8ab	18.8a
PWCH2[u]	0.0a	0.2cd	0.1b	0.0c	0.4c	0.1d	4.8ab	5.6abc	6.8e
WTC[t]	1.1a	0.1d	0.1b	0.3c	0.8bc	5.5bcd	1.1d	3.9c	5.8e
WTCH[s]	1.0a	2.1a	6.0a	1.8ab	2.7a	8.5abc	2.9c	5.4bc	12.6cd
PWCH1:PB[r]	0.0a	1.0abcd	1.2b	0.8abc	1.5abc	7.7abc	5.2ab	7.3a	14.9bc
PWCH2:PB	0.0a	1.6ab	1.5b	0.6abc	1.6abc	2.4cd	5.3ab	5.9ab	9.0de
WTC:PB	0.0a	0.5bcd	1.1b	0.4bc	1.9abc	4.5bcd	3.1c	6.3ab	11.6cd
WTCH:PB	0.0a	1.4abc	1.1b	1.1abc	2.4ab	10.4ab	4.9ab	6.7ab	9.2de
PBS[q]	0.0a	1.1abcd	1.5b	1.9a	1.6abc	13.0a	6.2a	5.4bc	17.5ab

[z] Spurge number per container overseeded at 25 seed per container.

[y] Fresh weight at 60 DAT (grams).

[x] DAT - days after treatment.

[w] PWCH1 - pine wood chips (100% wood) hammer-milled to pass a 0.4 cm screen.

[v] Means (within a column) with different letters are significantly different, within substrates or herbicdes according to Least Significant Difference test (α=0.05).

[u] PWCH2 - pine wood chips hammer-milled to pass a 0.64 cm screen.

[t] WTC - whole pine tree chipped (particle size distribution: 4% was above 5.1 cm, 9% between 2.5 and 5.1 cm, 26% between 1.3 and 2.5 cm, and 61 % was less than 1.3 cm.

[s] WTCH - WTC-hammer-milled to pass a 0.48 cm screen.

[r] Substrates with pinebark added 1:1 (v:v).

[q] PBS - pinebark:sand 6:1 (v:v).

Table 3 - 4. Alternative substrates evaluated on herbicide efficacy, Experiment 2.

		Weed number[z]		Fresh weight[y]
Alternative Substrates	**Ratio/Rate**	**30 DAT[x]**	**60 DAT**	**60 DAT**
PWCH2[w]	100 %	0.4e[v]	0.6e	0.3d
WTC[u]	100 %	3.4ab	3.3bc	0.9cd
PBS[t]	6:1	2.2cd	2.8bc	3.8abc
PWCH2:CPL[s]	6:1	1.8d	2.0cd	5.8ab
WTC:CPL	6:1	4.0a	5.5a	6.6a
PWCH2:CRF[r]	100% + 20 lb CRF	1.1de	1.4de	0.9cd
WTC:CRF	100% + 20 lb CRF	2.3bcd	3.4bc	3.1bcd
PBS:CRF	6:1	3.2abc	3.8b	5.8ab
Herbicides				
Rout	3 lb/aia	0.8b	1.0b	1.2b
Ronstar	4 lb/aia	0.9b	1.3b	1.5b
Non-treated	-	5.2a	6.2a	7.7a
Main Effects				
Substrate		0.0001	0.0001	0.0001
Herbicide		0.0001	0.0001	0.0001
Interaction		0.0018	0.0001	0.0002

[z] Spurge number per container overseeded at 25 seed per container.

[y] Fresh weight at 60 DAT (grams).

[x] DAT - days after treatment.

[w]PWCH2 - pine wood chips hammer-milled to pass a 0.64 cm screen.

[v] Means (within a column) with different letters are significantly different, according to Least Significant Difference test (α=0.05).

[u]WTC - whole pine tree chipped.

[t]PBS - pinebark:sand 6:1 (v:v).

[s]Substrates with composted poultry liter 6:1 (v:v).

[r]Substrates with the addition of 20 lb polyon control release fertilizer.

Table 3 - 5. Herbicide efficacy in alternative substrates, Experiment 2.

	Rout			Ronstar			Non-treated		
	Weed number[z]		FW[y]	Weed number		FW	Weed number		FW
Alternative Substrates	30 DAT[x]	60 DAT	60 DAT	30 DAT	60 DAT	60 DAT	30 DAT	60 DAT	60 DAT
PWCH2[w]	0.0b[v]	0.0c	0.0b	0.0b	0.0c	0.0b	1.1c	1.9c	0.8c
WTC[u]	1.6ab	2.4ab	0.8b	1.5ab	2.3ab	0.8ab	7.0a	5.1bc	1.3c
PBS[t]	0.0b	0.0c	0.0b	0.6ab	0.7bc	2.8ab	5.9a	7.5ab	9.4abc
PWCH2:CPL[s]	0.5ab	0.5c	0.7b	0.1b	0.3c	0.2b	4.8ab	5.4bc	16.6a
WTC:CPL	2.1a	3.1a	4.6a	2.6a	3.6a	3.5a	7.4a	9.9a	11.7ab
PWCH2:CRF[r]	0.0b	0.0c	0.0b	1.1ab	1.6bc	1.0ab	2.1bc	2.5c	1.7c
WTC:CRF	1.1ab	1.4bc	1.3b	0.1b	1.1bc	1.4ab	5.5a	7.8ab	7.0c
PBS:CRF	0.8ab	1.0bc	2.1b	1.1ab	0.6bc	2.5ab	7.6a	9.8a	13.0ab

[z] Spurge number per container overseeded at 25 seed per container.

[y] Fresh weight at 60 DAT (grams).

[x] DAT - days after treatment.

[w] PWCH2 - pine wood chips hammer-milled to pass a 0.64 cm screen.

[v] Means (within a column) with different letters are significantly different, according to Least Significant Difference test (α=0.05).

[u] WTC - whole pine tree chipped.

[t] PBS - pinebark:sand 6:1 (v:v).

[s] Substrates with composted poultry liter 6:1 (v:v).

[r] Substrates with the addition of 20 lb polyon control release fertilizer.

CHAPTER IV

EFFECTS OF MULCH DEPTH ON WEED CONTROL IN NURSERY CONTAINERS

Abstract

With environmental concerns increasing, non-chemical weed control in container plant production is increasing in the United States. Pine bark mini-nuggets were evaluated as a non-chemical weed control technique for two weed species *Chamaesyce maculata* (spotted spurge) and *Eclipta alba* (eclipta). On June 20, 2006 seed (25/container) were directly placed on the potting substrate surface before mulching with pine bark mini-nuggets to a depth of 0, 1.27 cm (0.5 in.), or 2.54 cm (1.0 in.). Remaining treatments consisted of applying the pine bark mini-nugget mulch at 1.27 (0.5 in.) or 2.54 (1.0 in.) cm on the potting substrate then overseeding spotted spurge or eclipta. Results showed eclipta number per container were 87 % less 60 days after seeding (DAS) with the 1.0 in. mulch depth compared to the non-mulched containers. Furthermore, spotted spurge fresh weight (FW) was reduced by 45 % (0.5 in.) and 87 % (1.0 in.) compared to the non-mulched treatment. These results suggest that properly applied pine bark mini-nuggets can be used effectively for weed control in container nurseries.

Index words: pine bark mini-nuggets, container production, non-chemical control

Significance to the Nursery Industry

For many years pine bark mini-nuggets have provided successful weed control in the landscape. Pine bark is readily available, economical and aesthetically acceptable to consumers. Our results show that pine bark mini-nuggets as a mulch can provide excellent weed control in container grown nursery crops. Therefore, potential to reduce herbicide use in nursery production with pine bark mini-nugget mulch exists. Current practice for nursery growers is to reapply herbicides as often as eight weeks or after scouting for weeds; often making five or more applications annually, by utilizing pine bark mini-nuggets herbicide applications can be reduced.

Introduction

Traditionally, weed control during nursery production has been primarily managed through hand weeding and/or herbicides. Cost of weed control in the 1970s was estimated to cost as much as 20 % of the total cost of production (30). Since then an increase in labor cost has made hand weeding cost prohibitive as a sole weed control practice. In 1990, hand-weeding costs in Alabama ranged from $608 to $1401/ha ($246 to 567/acre) annually (10). Research by Judge et al. (13) indicated hand-weeding costs ranged from $2,389 to $5,506/ha ($967 to $2,228 per acre) in North Carolina. With increasing labor costs, pre-emergence applied herbicides have become standard practice for container-nursery weed control (9).

One key to a successful weed control program is to prevent habitats that are conducive for weed germination and growth. This is particularly important in container-grown crops where water and light conditions are favorable for weed growth. Once weeds infest container-grown crops they become competitors with the marketable crop for water, light and nutrients (2) and can reduce the growth of container-grown nursery crops (13). Furthermore, container plants infested with weeds are less marketable than weed-free containers (20).

Environmental concerns over chemical controls have forced the nursery industry to evaluate alternative weed control options (18). Controlling unwanted plants, as well as preventing weed growth with the use of non-chemical control methods has been steadily on the increase since the early 1990s in European countries (19). In the United States, non-chemical control methods were re-addressed in 1984 after herbicide resistance became an issue (1). Ryan (26) first reported herbicide resistance in common groundsel (*Senecio vulgaris*) to Atrazine and Simazine. Warwick (29) stressed the importance of non-chemical weed control after discovering more than 100 herbicide resistant species. Rao (23) reported an increase of herbicide resistance in a 10 year span equal to that reported by Holt and LeBaron (12) of insecticide resistant biotypes over a 50 year span. Relying merely on herbicides for weed control can lead to herbicide resistant weeds (16) and a decrease in density and diversity of the weed flora (28). Once the diversity of weed flora has been altered, no one herbicide can be used exclusively and hence the significance behind choosing the right herbicide rotation program (25). Recommendations have been made to rotate herbicides with different mode of actions (MOAs) (16, 11) by using several MOAs, herbicide resistant weeds are less likely to pose a threat. Furthermore, herbicide resistance if not controlled can lead to an increase in herbicide use as a result of inadequate weed control with current herbicides (16).

Incorporating a non-chemical weed control program can help reduce the use of herbicides (15). In theory applying mulch over a soil surface or substrate prevents the passage of light to the existing seed bank (14), which can prevent some weed species from germinating (3). Billeaud and Zajicek (4) used pinebark nuggets as a form of weed control in a field study and results indicated less weed number compared to the control (no mulch). Additionally, the suppression of weed growth reduced moisture loss through transpiration and allowed the soil surface layer to stay moist longer (25). Duryea et al. (8) analyzed the chemical make up of several mulches including pinebark and concluded that pinebark based on subsidence, decomposition, allelopathy, soil pH and color change ranked in the top three landscape mulches. More recently pinebark used as mulch in a field study had no affect on soil pH or N concentrations (5). Additionally, large particle size and hydrophobic properties of fresh pine bark are not conducive for weed germination (24). Richardson et al. (24) reported reduced spurge number in large containers (# 7) by 100 % when pine bark mini-nuggets were applied to a depth of either 1.5 or 3 inches. Therefore, our objective was to evaluate pinebark mini-nugget mulch as a form of weed control in small containers.

Materials and Methods

Experiment 1

On June 19, 2006, at the Paterson Greenhouse Complex Auburn University, Auburn, AL. (zone 8), #3 containers were filled with pinebark:sand (6:1) (v:v), amended with 6.35 kg/m^3 (14 lbs/yd^3) of 17-6-12 (17N-2.6P-10K) Polyon (control-release fertilizer), 2.27 kg/m^3 (5.0 lbs/yd^3) of dolomitic lime, and 0.89 kg/m^3 (1.5 lbs/yd^3) of Micromax, and irrigated with overhead impact sprinklers. Pine bark mini-nuggets were obtained from a local supplier for \$ 16/yd^3. Pine bark mini-nuggets to be used as mulch had a particle size distribution of: 11 % between 2.54 and 5.08 cm (1 - 2 in.), 68 %

between 1.27 and 2.54 cm (½ - 1 in.), 14 % between 0.64 and 1.27 cm (¼ - ½ in.), and 7 % was less than 0.64 cm (¼ in.). Each weed species was evaluated in a separate set of containers. Weed seed were collected the previous summer and stored overwinter in a 473.2 mL container at 34° F. In February, 2007, 25 seed were counted and placed in individual vials (10 mL) and returned to cold storage until time of seeding. Three treatments consisted of broadcasting 25 *Chamaesyce maculata* (spotted spurge) or 25 *Eclipta alba* (eclipta) seed directly onto the potting substrate surface and then pine bark mini-nugget mulch was hand applied at 0, 1.27 (0.5 in.), or 2.54 cm (1.0 in.). Remaining treatments consisted of hand applying pine bark mini-nugget mulch at 1.27 (0.5 in.) or 2.54 cm (1.0 in.) onto the potting substrate then overseeding the 25 spurge or eclipta seed. After treatment application, containers were placed in full sun under overhead irrigation and irrigated again. Weed number was recorded at 15, 30, and 60 days after seeding (DAS) and weed fresh weight was collected 60 DAS. This study was a factorial experiment consisting of five treatments with eight single pot replications, complete random design. Data were analyzed using generalized linear model to test main effects and interactions and mean separation using Duncan's Multiple Range Test (27).

Experiment 2

Materials and methods were the same as Experiment 1. On August 30, 2006, containers were filled and overseeded with spurge or eclipta at 25 seed per container. Weed number was recorded at 15, 30, and 60 DAS and weed fresh weight was collected 60 DAS.

Results and Discussion

Experiment 1 – Eclipta

Eclipta number per container was less in mulched containers compared to non-mulched containers (Table 1). This is a typical response when using mulch as a form of weed control (5, 22). Eclipta per container were similar regardless of whether seed was placed below or above the mulch. Our data was similar to previous research, indicating that an increase in thickness of mulch improves weed control (4, 21, 26). Fifteen and 30 DAS, weed number was reduced by 67 and 57 % (0.5 in.) and 99 and 93 % (1.0 in.) compared to the non-mulched treatment. Sixty DAS, weed number was reduced by 54 (0.5 in.) and 87 % (1.0 in.) compared to the non-mulched treatment. Eclipta FW was significantly less in both mulching depths; 49 (0.5 in.) and 89 % (1.0 in.) less compared to the non-mulched treatment. Mulching to a depth of 1.0 in. resulted in better weed control compared to mulch applied at 0.5 in. on all dates. Additionally, there was an interaction between placement of seed and mulch depth in FW of eclipta (Table 2). Eclipta seed placed either below or above 1.0 in. mulch had less FW compared to all other treatments, with seeds placed 1.0 in. below mulch having the least FW.

Experiment 1 – Spurge

Regardless of seed placement, spurge number was less in both treatments compared to the non-mulched (Table 1). Spurge seed placed below the mulch had greater spurge numbers per container at 30 and 60 DAS. While spurge FW was not significant with seed placement (0.06), FW tended to be greater where seed was placed below the mulch. Applying 1.0 in. mulch resulted in reduced weeds compared to applying 0.5 inch. Fifteen DAS weed number was reduced by 61 % (0.5 in.) and 99 %

(1.0 in.) compared to the non-mulched treatment. Thirty and 60 DAS weed number was reduced by 55 and 45 % (0.5 in.) and 92 and 74 % (1.0 in.) compared to the non-mulched treatment. At 15 and 30 DAS an interaction between mulch depth and seed placement occurred (Table 2). Placing spurge seed 0.5 in. below or 0.5 in. above the mulch reduced seed germination by 39 and 83 % respectively, 15 DAS compared to non-mulched treatments. Spurge seed placed below or above 1.0 in of mulch had a reduction in weed number by 99 and 100 % compared to the non-mulched treatment at 15 DAS and 90 and 95 % at 30 DAS. Similarly, spurge seed placed below 2.54 cm (1.0 in.) mulch had an average FW of 43.6 grams compared to 120.2 grams when spurge seed was placed above 1.0 in. mulch. Our results are typical and concur with reports indicating spurge requires light for maximum germination and seeds buried deeper than 0.5 in. do not germinate well (7).

Experiment 2 – Eclipta

Similar to the first experiment, eclipta numbers were similar regardless of seed placement (Table 3). For example, eclipta number was reduced by 56, 37, and 56 % (below mulch) and 65, 41, and 62 % (above mulch) at 15, 30, and 60 DAS. Applying mulch to a depth of 1.0 in. resulted in 85 % less eclipta per container compared to the non-mulched containers and 76 % less than the 0.5 in. application. Whereas the (0.5 in.) application reduced eclipta number by 36 % compared to the non-mulched treatment. Similar trends followed at 30 and 60 DAS; 63 and 79 % (1.0 in.) reduction compared to the non-mulched and 56 and 64 % (1.0 in.) reduction compared to the 0.5 in. Eclipta FW was similar between below and above seed placement. However, mulch applied to a depth of 1.0 in. resulted in significantly less FW (35.1 g.) compared to both the non-mulched (339.4 g.) and the 0.5 in. (176.5 g.) mulch application. There was no interaction effect between placement of seed and mulch depth.

Experiment 2 - Spurge

Similar to Exp. 1, spurge numbers tended to be greater when seed were placed below the mulch; however it was significant only at 30 DAS (Table 3). Spurge number was less, regardless of placement of seed, compared to the non-mulched. When seed was placed below mulch, spurge number per container was reduced by 84 % compared to the non-mulched, and 96 % less when spurge seed was placed above mulch, 15 DAS. Applying 1.0 in. mulch resulted in fewer spurge numbers per container at 30 and 60 DAS compared to the 0.5 in. mulch by 83 and 72 %. However, both mulch depths resulted in less weed number compared to the non-mulched; 82, 37, and 68 % (0.5 in.) and 98, 89, and 90 % (1.0 in.) at 15, 30, and 60 DAS. Applying mulch to containers, regardless of seed placement or mulch depth, reduced spurge FW compared to non-mulched containers by more than 90 %.

Results indicate pine bark mini-nuggets applied to a depth of 1.0 in. can significantly reduce eclipta and spurge numbers in container-grown crops. In both experiments spurge number was greatly reduced compared to non-mulched containers. Increased spurge numbers below mulch application suggest that mulch applied at potting may be more effective than when applied during the growing season to recently hand weeded containers. With eclipta, seed placement had no effect on weed numbers throughout the test.

Literature Cited

1. Appleby, A.P. 2005. A history of weed control in the United States and Canada—a sequel. Weed Sci. 53:762-768.

2. Berchielli-Robertson, D.L. C.H. Gilliam, and D.C. Fare. 1990. Competitive effects of weeds on the growth of container-grown plants. HortScience. 25:77-79.

3. Bewley, J.D. and M. Black. 1994. Seeds – Physiology of Development and Germination, 2nd edn. Plenum Press, New York.

4. Billeaud, L.A. and J.M. Zajicek. 1989. Influence of mulches on weed control, soil pH, soil nitrogen content, and growth of *Ligustrum japonicum*. J. Environ. Hort. 7:155-157.

5. Broschat, T.K. 2007. Effects of mulch type and fertilizer placement on weed growth and soil pH and nutrient cover. HortTech. 17:174-177.

6. Case, LT., H.M. Mathers, and A.F. Senesac. 2005. A review of weed control practices in container nurseries. HortTech. 15:535-545.

7. Cudney, D.W., C.L. Elmore, and A. Sanders. 2002. Spotted spurge. Univ. of Cal. Ag. Natural Res. Jan. 7445.

8. Duryea, M.L., R.J. English, and L.A. Hermansen. 1999. A comparison of landscape mulches: Chemical, allelopathic, and decomposition properties. J. Arboric. 25:88-97.

9. Everest, J.W., C.H. Gilliam and K. Tilt. 1998. Weed control for commercial nurseries. Al. Coop. Ext. Sys. Auburn University. Oct. ANR-465.

10. Gilliam, C.H., W.J. Foster, J.L. Adrain, and R.L. Shumack. 1990. A survey of weed control costs and strategies in container production nurseries. J. Environ. Hort. 8:133-135.

11. Hamill, A.S., J.S. Holt, and C.A. Mallory-Smith. 2004. Symposium. Contributions of weed science to weed control and management. Weed Tech. 18:1563-1565.

12. Holt, J.S. and H.M. LeBaron. 1990. Significance and distribution of herbicide resistance. Weed Technol. 4:141-149.

13. Judge, C.A., J.C. Neal, and J.B. Weber. 2004. Dose and concentration responses of common nursery weeds to Gallery, Surflan and Treflan. J. Environ. Hort. 22:106-112.

14. Juroszek, P. and R. Gerhards. 2004. Photocontrol of weeds. J. Agron. Crop Sci. 190:402-415.

15. Kempenaar, C. and L.A.P. Lotz. 2004. Reduction of herbicide use and emission by new weed control methods and strategies. Water Sci. Technol. 49:135-138.

16. Kudsk, P and J.C. Streibig. 2003. Herbicides – a two edged sword. European weed research society Weed Research 43:90-102.

17. Lohr, V.I. and C.H. Pearson-Mims. 2001. Mulching reduces water use of containerized plants. HortTech. 11:277-278.

18. Mathers, H.M. 2003. Novel methods of weed control in containers. HortTech. 13:28-34.

19. Melander, B., I.A. Rasmussen, and P. Bàrberi. 2005. Symposium. Integrating physical and cultural methods of weed control—examples from European research. 53:369-381

20. Norcini, J.G., and R.H. Stamps. 1994. Container nursery weed control. Florida Coop. Ext. Serv., Inst. Food and Agr. Serv., Univ. of Florida. Circa 678.

21. Ozores-Hampton, M. 1998. Compost as an alternative weed control method. HortScience 33:938-940.

22. Penny, G.M. and J.C. Neal. 2003. Light, temperature, seed burial, and mulch effects on Mulberry Weed (*Fatoua villosa*) seed germination. Weed Technol. 17:213-218.

23. Rao, V.S. 2000. Principles of Weed Science; Herbicide resistance and genetic engineering. 2nd edition science publishers Inc., Enfield NH, USA printed in India Pg 305.

24. Richardson, B.M., C.H. Gilliam, G.R. Wehtje, G.B. Fain. 2005. A non-chemical alternative for weed control in container nursery crops. Proc. SNA Res. Conf. 50:446-449.

25. Robinson, D.W. 1988. Mulches and herbicides in ornamental plantings. HortScience 23:547-552.

26. Ryan, G.F. 1970. Resistance of common groundsel to simazine and atrazine. Weed Sci. 18:614-616.

27. SAS Institute. 2003. SAS/STAT User's Guide: Release 9.1 ed. SAS Inst., Cary, NC.

28. Schütte, G. 2002. Herbicide resistance: Promises and prospects of biodiversity for European agriculture. Agr. Hum. Values 20:217-230.

29. Warwick, S.I. 1991. Herbicide resistance in weedy plants: Physiology and population biology. Annu. Rev. Ecol. Systems 22:95-114.

30. Weatherspoon, D.M. and W.L. Currey. 1975. Evaluation of Treflan, Lasso and Ronstar herbicides for use in woody ornamental nurseries. Proc. FL. State Hort. Soc. 88:535-540

Table 4 - 1. Main effect means of using pinebark mini-nuggets to control eclipta and spurge, Experiment 1.

	Eclipta				Spurge			
	Weed number			FW[z]	Weed number			FW
Experimental Variable	**15 DAS[y]**	**30 DAS**	**60 DAS**	**60 DAS**	**15 DAS**	**30 DAS**	**60 DAS**	**60 DAS**
Placement of Seed[x]								
Below Mulch	1.6	1.8	1.6	304	2.4	2.8	3.6	269.2
Above Mulch	1.4	2.6	2.1	343.6	0.6	1.3	2.3	166.7
Mulching Depth								
0.5 inch	2.9	3.7	2.9	529.6	2.9	3.5	4.1	354.0
1.0 inch	0.1	0.6	0.8	118.1	0.1	0.6	1.9	81.9
Non-mulched[w]	8.9	8.1	6.3	1040.4	7.5	7.8	7.4	644.5
ANOVA Main Effects:	probability							
Placement	0.641	0.172	0.383	0.543	0.001	0.005	0.125	0.063
Mulch Depth	<.001	<.001	<.001	<.001	<.001	<.001	0.013	<.001
Interaction	0.485	0.458	0.110	0.005	0.002	0.035	0.070	0.002

[z] Fresh weight (grams).

[y] DAS - days after seeding.

[x] Eclipta or spurge overseeded @ 25 seed per container below or above mulch.

[w] Non-treated - weeds were seeded directly onto the potting substrate, no mulch applied.

Table 4 - 2. Performance of selected individual treatments using pine bark mini-nuggets, Experiment 1.

Treatment		Eclipta				Spurge			
		Weed number			FW[z]	Weed number			FW
Placement[y]	Depth	15 DAS[x]	30 DAS	60 DAS	60 DAS	15 DAS	30 DAS	60 DAS	60 DAS
Below	0.5	-	-	-	606.6b[w]	4.6b	4.8b	-	494.9a
Below	1	-	-	-	1.4d	0.1c	0.8d	-	43.6c
Above	0.5	-	-	-	452.5b	1.3c	2.3c	-	213.2b
Above	1	-	-	-	234.7c	0.0c	0.4d	-	120.2bc
Non-mulched[w]	0	-	-	-	1040.4a	7.5a	7.8a	-	644.5a

[z] Fresh weight (grams).

[y] Eclipta or spurge overseeded @ 25 seed per container below or above mulch.

[x] DAS - days after seeding.

[w] Means (within a column) with different letters are significantly different, according to Duncan's Multiple Range test (α=0.05).

[v] Non-mulched - weeds were seeded directly onto the potting substrate, no mulch applied.

Table 4 - 3. Main effect means of pinebark mini-nuggets to control eclipta and spurge, Experiment 2.

	Eclipta				Spurge				
	Weed number			FW[z]	Weed number				FW
Experimental Variables	**15 DAS[y]**	**30 DAS**	**60 DAS**	**60 DAS**	**15 DAS**	**30 DAS**	**45 DAS**	**60 DAS**	**60 DAS**
Placement of Seed[x]									
Below Mulch	8.7	5.9	6.2	117.03	3.6	7.6	5	3.3	8.4
Above Mulch	7	5.6	5.3	94.6	1	2.1	3.4	2.2	3.1
Mulching Depth									
0.5 inch	12.7	7.9	8.4	176.5	4.1	8.3	7.3	4.3	9.2
1.0 inch	3	3.5	3	35.1	0.4	1.4	1.2	1.2	2.3
Non-mulched[w]	19.8	9.5	14.1	339.4	22.6	13.1	20.1	12.5	103.3
ANOVA Main Effects:	probability								
Seed Placement	0.538	0.791	0.389	0.452	0.216	0.026	0.268	0.176	0.245
Mulch Depth	0.001	0.001	<.0001	<.0001	0.079	0.006	0.000	0.000	0.136
Interaction	0.665	0.318	0.773	0.499	0.413	0.098	0.964	0.687	0.864

[z] Fresh weight (grams).

[y] DAS - days after seeding.

[x] Eclipta or spurge overseeded @ 25 seed per container below or above mulch.

[w] Non-treated - weeds were seeded directly onto the potting substrate, no mulch applied.

CHAPTER V

FINAL DISCUSSION

Herbicide Use in Propagation of Loropetalum chinense 'Ruby'

Loropetalum chinense is an evergreen nursery crop, typically propagated outside during the summer months, in the Southeastern United States. In the past decade Loropetalum has become very popular in the landscape industry with 20 named varieties in 1998. 'Ruby' Loropetalum is a true dwarf variety with purple-burgundy foliage. Because Loropetalum is easily propagated in outside areas, weed control is a major problem. Weed seed is easily blown into outdoor propagation beds and due to the sensitivity of the crop during propagation, herbicides can not be used, leaving hand weeding as the only option during propagation. With increased labor costs growers are presently spending more on weed control than in the past during propagation; thus reducing their profits. Therefore the objective was to evaluate three potential pre-emergent herbicides applied at three different times during the rooting process of 'Ruby' Loropetalum.

These studies demonstrate varied responses in using herbicides during propagation. In Experiments 1 and 2, Gallery, Ronstar, and Regal 0-0 had similar shoot growth compared to the non-treated 'Ruby' loropetalum cuttings by the end of the first year. Gallery applied to lightly or fully rooted stem cuttings of 'Ruby' Loropetalum did not cause any suppression in shoot or root growth in either experiment. In experiment 1

Ronstar had suppression in root coverage when applied BS and to LR cuttings, however in experiment 2 root coverage was similar compared to the non-treated plants. Regal 0-0 suppressed root growth regardless of application time in experiment 1 but in experiment 2 a reduction in root coverage only occurred when applied to BS and LR cuttings compared to the non-treated cuttings. From a grower's point-of-view, use of herbicides in propagation that cause slight reductions in root coverage may be more acceptable than dealing with weed pressure and added labor cost throughout the life of the crop.

Herbicide Efficacy in Alternative Substrates for Container-grown Nursery Crops

Supply of pine bark which is typically used as an amendment for potting substrates in nursery production has declined. Many factors have contributed to this decline including: use of pine bark as a fuel alternative, a trend towards in-field harvesting (leaving the bark on the forest floor), and increased foreign importation. Many substrate amendments have been used over the years in nursery production. Typically an amendment is used until, 1) something better comes along, 2) costs increase, or 3) availability is limited. Currently with limited supply and increased costs, many researchers are evaluating alternative substrates (mainly those with organic matter). Several of these alternative substrates have been evaluated for container-grown crops, yet limited research has been done regarding herbicide efficacy. Thus our objective was to compare herbicide efficacy on control of spotted spurge grown in alternative substrates compared to a traditional pine bark substrate.

These results indicated Rout and Ronstar's efficacy were not affected by these alternative substrates. Furthermore, treated substrates generally had less spotted spurge number compared to traditional pine bark substrates. Substrates with added pine bark tended to have more spotted spurge compared to non-amended substrates (no addition of pinebark). Spurge fresh weights tended to be highest in substrates with composted poultry litter or with PBS plus additional control release fertilizer. For example, with PWCH2 the addition of composted poultry litter increased spurge fresh weights by 95 % and with WTC spurge fresh weights were increased 86 %. These data show that control of spotted spurge with commonly used pre-emergent applied herbicides may actually be improved with some of the alternative substrates currently being evaluated.

Effects of Mulch Depth on Weed Control in Nursery Containers

Mulch is a protective cover placed over the soil, which can be made from an organic or inorganic material. Typically, pine bark or cypress nuggets are used in the landscape. Many benefits are associated with applying mulch around landscape plants including; lower soil temps, added nutrients, moisture retention, and less weed germination. For many years pine bark mini-nuggets have provided successful weed control in the landscape. Recently the nursery industry has focused interest on utilizing mulch as a form of weed control due to environmental concerns and increased labor costs.

Results indicate pine bark mini-nuggets applied at 1.0 in. depth can significantly reduce eclipta and spurge numbers in container-grown crops. For example, 60 days after seeding, eclipta number was reduced by 54 % (0.5 in.) and 87 % (1.0 in.) compared to the non-mulched treatment. With eclipta, seed placement had no effect on weed numbers throughout the test. In both experiments spurge number was greatly reduced compared to non-mulched containers. Main affects suggest mulch applied at potting may be more effective than when applied during the growing season to recently hand weeded containers. For example, when seed was placed below mulch spurge number per container was reduced by 84 % compared to the non-mulched and 96 % less when spurge seed was placed above mulch, 15 DAS. Since spotted spurge requires light for germination, these results indicate that pine bark mini-nuggets are not conducive for spotted spurge germination. Additionally, there was an interaction affect between seed placement and mulch depth. For example, spurge seed placed below 1.0 in. mulch had an average FW of 43.6 grams compared to 120.2 grams when spurge seed was placed above 1.0 in. mulch. Data comparing seed placement to mulch depth suggests light is the contributing factor in spotted spurge germination and by eliminating the seed from light reduces germination.

BIBLIOGRAPHY

Altland, J. 2006. Research examines a new tool for control of creeping wood sorrel. Digger. 50:24-28.

Altland, J. E., C. H. Gilliam, J. H. Edwards, G. J. Keever, J. R. Kessler, Jr., and D. J. Eakes. 2000. Effect of bittercress size and Gallery rate on postemergence bittercress control. J. Environ. Hort 18(3):128-132.

Altland, J., R. Regan, and A. Newby. 2003. Liverwort control in propagation: Challenges and opportunities©. Comb. Proc. Intl. Plant Prop. Soc. 53:383-386.

Appleby, A.P. 2005. A history of weed control in the United States and Canada—a sequel. Weed Sci. 53:762-768.

Ashton, F.M. and A. S. Crafts. 1973. Chapter 14. Dinitroanilines in Mode of Action of Herbicides. Pg. 221-235.

Ashton, F.M. and A.S. Crafts. 1981. Dinitroanalines. pp. 201-223. *In:* Mode of Action of Herbicides. 2nd Ed. John Wiley & Sons, Inc., New York. Bul. AG-427. North Carolina State University, Raleigh, NC, pp. 104.

Bachman, G. and T. Whitwell. 1995. Hairy bittercress seed production, dispersal, and control. Proc. SNA Res. Conf. 40:288-290.

Berchielli-Robertson, D.L. C.H. Gilliam, and D.C. Fare. 1990. Competitive effects of weeds on the growth of container-grown plants. HortScience. 25:77-79.

Bewley, J.D. and M. Black. 1994. Seeds – Physiology of Development and Germination, 2nd edn. Plenum Press, New York.

Bilderback, T.E., W.C. Fonteno, and D.R. Johnson. 1982. Physical properties of media composed of peanut hulls, pinebark, and peatmoss and their effects on azalea growth. J. Amer. Soc. Hort. Sci. 107:522-525.

Billeaud, L.A. and J.M. Zajicek. 1989. Influence of mulches on weed control, soil pH, soil nitrogen content, and growth of *Ligustrum japonicum*. J. Environ. Hort. 7:155-157

Boyer, C.R., G.B. Fain, C.H. Gilliam, T.V. Gallagher, H.A. Torbert, and J.L. Sibley. 2006. Clean chip residual: A new substrate component for container-grown plants. Proc. SNA Res. Conf. 51:22-25.

Broschat, T.K. 2007. Effects of mulch type and fertilizer placement on weed growth and soil pH and nutrient cover. HortTech. 17:174-177.

Caberera, A., L. Cox., and W.C. Koskinen. 2006. Soil organic amendment as affecting herbicide fate. American Chemical Society Abstracts. p. 99.

Carpenter, P.L. 1973. Chemical weed control in container-grown nursery stock. HortScience 8:385-386.

Case, LT., H.M. Mathers, and A.F. Senesac. 2005. A review of weed control practices in container nurseries. HortTech. 15:535-545.

Cook, J.C. and J.C. Neal. 2001. Effects of herbicides and application timing on rooting of azalea and japanese holly cuttings. Proc. SNA. Res. Conf. 46:422-424.

Cudney, D.W., C.L. Elmore, and A. Sanders. 2002. Spotted spurge. Univ. of Cal. Ag. Natural Res. Jan. 7445.

Davies, F.T. and S.A. Duray. 1992. Effect of preemergent herbicide application on rooting and subsequent liner growth of selected nursery crops. J. Environ. Hort. 10:181-186.

Duryea, M.L., R.J. English, and L.A. Hermansen. 1999. A comparison of landscape mulches: chemical, allelopathic, and decomposition properties. J. Arboric. 25:88-97.

Everest, J.W., C.H. Gilliam and K. Tilt. 1998. Weed control for commercial nurseries. Al. Coop. Ext. Sys. Auburn University. Oct. ANR-465.

Fain, G.B., C.H. Gilliam, and J.L. Sibley. 2006. Processed whole pine trees as a substrate for container-grown plants. Proc. SNA Res. Conf. 51:59-61.

Gartner, J.B., M.M. Meyer, Jr. and D.C. Saupe. 1971. Hardwood bark as a growing media for container-grown ornamentals. Forest Prod. J. 21:25-29.

Gilliam, C.H., D.C. Fare, and A. Beasley. 1992. Nontarget herbicide losses from application of granular Ronstar to container nurseries. J. Environ. Hort. 10:175-176.

Gilliam, C.H., D.J. Eakes, and J.W. Olive. 1993. Herbicide use during propagation affects root initiation and development. J. Environ. Hort. 11:157-159.

Gilliam, C.H., W.J. Foster, J.L. Adrain, and R.L. Shumack. 1990. A survey of weed control costs and strategies in container production nurseries. J. Environ. Hort. 8:133-135.

Gouin, F.R. 1993. Utilization of sewage sludge compost in horticulture. HortTech. 3:161-163.

Gruda, N. and W.H. Schnitzler. 2004. Suitability of wood fiber substrate for production of vegetable transplants I. Physical properties of wood fiber substrates. Sci. Hortic-Amsterdam 100:309-322.

Guerrero, F., J.M. Gascó, and L. Hernandez-Apaoloaza. 2002. Use of pine bark and sewage sludge compost as components of substrates for *Pinus pinea* and *Cupressus arizonica* production. J. Plant Nutr. 25:129-141.

Hamill, A.S., J.S. Holt, and C.A. Mallory-Smith. 2004. Symposium. Contributions of weed science to weed control and management. Weed Tech. 18:1563-1565.

Hayes, C.K., C.H. Gilliam, J.W. Olive, G.J. Keever, and D.J. Eakes. 1999. Pre-emergence Applied Herbicides for Container-Grown Liriope after Division. J. Environ. Hort. 17:31-35.

Hernández-Apaolaza, L., A.M. Gascó, J.M. Gascó, and F. Guerrero. 2005. Reuse of waste materials as growing media for ornamental plants. Bioresour. Technol. 96:125-131.

Holt, J.S. and H.M. LeBaron. 1990. Significance and distribution of herbicide resistance. Weed Technol. 4:141-149.

Ingelmo, F., R. Canet, M.A. Ibañez, F. Pomares, and J. García. 1998. Use of MSW compost, dried sewage sludge and other wastes as partial substitutes for peat and soil. Bioresour. Technol. 63:123-129.

James, T.K., P.T. Holland, A. Rahman, and Y.R. Lu. 1999. Degradation of the sulfonylurea herbicides chlorsulfuron and triasulfuron in a high-organic-matter volcanic soil. Weed Res. 39:137-147.

Johnson, J.R. and J.A. Meade. 1987. Pre-emergent herbicide effect on the rooting of cuttings. Comb. Proc. Intl. Plant Prop. Soc. 36:567-570.

Judge, C.A., J.C. Neal, and J.B. Weber. 2004. Dose and concentration responses of common nursery weeds to Gallery, Surflan and Treflan. J. Environ. Hort. 22:106-112.

Juroszek, P. and R. Gerhards. 2004. Photocontrol of weeds. J. Agron. Crop Sci. 190:402-415.

Kempenaar, C. and L.A.P. Lotz. 2004. Reduction of herbicide use and emission by new weed control methods and strategies. Water Sci. Technol. 49:135-138.

Kudsk, P and J.C. Streibig. 2003. Herbicides – a two edged sword. Weed Research 43:90-102.

Langmaid, M. 1987. Herbicides used in Propagation at Wight Nurseries. Proc. Intern. Plant. Prop. Soc. 37:539-540

Lennartsson, M. 1997. The peat conservation issue and the need for alternatives. In: Proceedings of the IPS International Peat Conference on Peat in Horticulture. Schmilewski, Amsterdam, 112-121.

Lohr, V.I. and C.H. Pearson-Mims. 2001. Mulching reduces water use of containerized plants. HortTech. 11:277-278.

Lu, W., J.L. Sibley, C.H. Gilliam, J.S. Bannon, and Y. Zhang. 2006. Estimation of U.S. bark generation and implications for Horticultural Industries. J. Environ. Hort. 24:29-34.

Lumis, G.P. 1976. Using wood waste compost in container production. Am. Nurseryman 163:10-11, 58-59.

Mathers, H.M. 2003. Novel methods of weed control in containers. HortTech. 13:28-34.

Melander, B., I.A. Rasmussen, and P. Bàrberi. 2005. Symposium. Integrating physical and cultural methods of weed control—examples from European research. 53:369-381

Neal, J.C. and J.F. Derr. 2005. Weeds of container nurseries in the United States. North Carolina Association of Nurserymen, Inc. ISBN: 0-89892-312-3.

Norcini, J.G., and R.H. Stamps. 1994. Container nursery weed control. Florida Coop. Ext. Serv., Inst. Food and Agr. Serv., Univ. of Florida. Circa 678.

Ortega, M.C., M.T. Moreno, J. Ordovás, and M.T. Aguado. 1996. Behaviour of different horticultural species in phytotoxicity bioassays of bark substrates. Sci. Hortic-Amsterdam 66:125-132.

Ozores-Hampton, M. 1998. Compost as an alternative weed control method. HortScience 33:938-940.

Penny, G.M. and J.C. Neal. 2003. Light, temperature, seed burial, and mulch effects on Mulberry Weed (*Fatoua villosa*) seed germination. Weed Technol. 17:213-218.

Pradgett, J.H. and T.L. Frazier. 1962. The relationship between costs and pruning of woody ornamentals. Ga. Agr. Expt. Sta. Bul. (N.S.) 100.

Radosevich, S., J. Holt, and C. Ghersa. 1997. Weed Ecology, 2nd Edition: Implications for Management. John Wiley & Sons, Inc. New York, NY Pg 4-5, 7.

Rao, V.S. 2000. Principles of Weed Science; Herbicide resistance and genetic engineering. 2nd edition science publishers Inc., Enfield NH, USA printed in India Pg 305.

Richardson, B. 2006. Effective non-traditional weed control in container-grown nursery production, MS Thesis. Auburn University, Auburn, AL.

Richardson, B.M., C.H. Gilliam, G.R. Wehtje, G.B. Fain. 2005. A non-chemical alternative for weed control in container nursery crops. Proc. SNA Res. Conf. 50:446-449.

Robinson, D.W. 1988. Mulches and herbicides in ornamental plantings. HortScience 23:547-552.

Ruter, J.M. and N.C. Glaze. 1992. Herbicide combinations for control of prostrate spurge in container-grown landscape plants. J. Environ. Hort. 10:19-22.

Ryan, G.F. 1970. Resistance of common groundsel to simazine and atrazine. Weed Sci. 18:614-616.

SAS Institute. 2003. SAS/STAT User's Guide: Release 9.1 ed. SAS Inst., Cary, NC.

Schütte, G. 2002. Herbicide resistance: Promises and prospects of biodiversity for European agriculture. Agr. Hum. Values 20:217-230.

Simpson, C. V., C. H. Gilliam, J. E. Altland, G. R. Wehtje, and J. L. Sibley. 2004 Diuron: Postemergence Oxalis control in container-grown plants. J. Environ. Hort. 22:45-49

Spark, K.M. and R.S. Swift. 2002. Effect of soil composition and dissolved organic matter on pesticide sorption. Sci. Total Environ. 298:147-161.

Thetford, M. and C.H. Gilliam. 1991. Herbicide use in propagation: Effects on rooting and root growth of stem cuttings. J. Environ. Hort. 9:21-23.

Warren, G.F. 1973. Action of herbicides in soilà. Affected by organic matter. Weeds Today 4:10-11.

Warwick, S.I. 1991. Herbicide resistance in weedy plants: Physiology and population biology. Annu. Rev. Ecol. Systems 22:95-114.

Weatherspoon, D.M. and W.L. Currey. 1975. Evaluation of Treflan, Lasso and Ronstar herbicides for use in woody ornamental nurseries. Proc. FL. State Hort. Soc. 88:535-540

Weller, S.C., J.B. Masiunas, and P.L. Carpenter. 1984. Evaluation of Oxyfluorfen formulations in container nursery crops. HortScience 19:222-224.

Wilson, S.B., P.J. Stofella, and D.A. Graetz. 2002. Development of compost-based media for containerized perennials. Sci. Hortic-Amsterdam 93:311-320.

Wright, R.D. 1986. The pour-through nutrient extraction procedure. HortScience 21:227-229.

Wright, R.D. and J.F. Browder. 2005. Chipped pine logs: A potential substrate for greenhouse and nursery crops. HortScience 40:1513-1515.

Yeager, T.H., C.H. Gilliam, T.E. Bilderback, D.C. Fare, A.X. Niemiera, and K.M. Tilt. 1997. Best Management Practices Guide for Producing Container-Grown Plants. Southern Nursery Assn., Marietta, GA.

Zimdahl, R.L. 1991. Weed Science: A plea for thought. Colorado State University, Fort Collins, CO.