AN ABSTRACT OF THE THESIS OF

Sugae Wada for the degree of Master of Science in Horticulture presented on December 8, 2005.

Title: Nursery Container Weeds Response to Modification of Substrate pH, Substrate Particle Size, and Applied Nitrogen Form.

Abstract approved:

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Experiments were conducted to determine the influence of cultural management practices on weed growth in nursery containers. Experiments 1 and 2 evaluated the effects of dolomitic lime rate and application method on substrate pH, creeping woodsorrel (*Oxalis corniculata* L.) establishment in containers, and growth of azalea (*Rhododendron* 'Rosebud') and pieris (*Pieris japonica* 'Claventine'). Creeping woodsorrel shoot fresh weight was negatively correlated to substrate pH ($r = -0.67$, $p = 0.0001$). Creeping woodsorrel germinated and established poorly in substrates with pH greater than 6.7. In Experiment 3 and 4 containers were topdressed with a uniform layer of pulverized or pelletized dolomitic limestone at several rates. The most significant pH effect occurred on the surface layer. Topdressing containers with 40 g of lime provided creeping woodsorrel control. In Expeiment 5 incorporating the same lime rates used in Experiment 3 and 4 caused chlorosis in azalea and pieris while topdressed lime ultimately caused no change in growth or foliar color regardless of rate applied.

The effect of nitrogen (N) form on establishment and growth of bittercress

(*Cardamine oligosperma* Nutt.), prostrate spurge (*Chamaesyce maculata* L.), pearlwort (*Sagina procumbens* L.), common groundsel (*Senecio vulgaris* L.), northern willowherb (*Epilobium ciliatum* Rafin.), or creeping woodsorrel. Injectors delivered 150 ppm N using either ammonium sulfate ($(NH_4)_2SO_4$) (AS), ammonium nitrate (NH_4NO_3) (AN), calcium nitrate plus magnesium nitrate ($Ca(NO_3)_2$+ $Mg(NO_3)_2$) (CMN), or urea ($CO(NH_2)_2$) (UR). Weeds in containers receiving no N (non-treated controls) germinated in lower numbers and produced less biomass. Nitrogen form affected container weed establishment and growth especially in creeping woodsorrel and prostrate spurge. Across all species, CMN tended to reduce growth and flower number compared to other N forms. Weeds fertilized with AN were always among the largest with the most inflorescences.

The effects of substrate particle size and herbicide rate on weed establishment and growth in containers were evaluated in three experiments. Across the three experiments, pearlwort established with higher numbers in containers with the finest substrate. Subsequent pearlwort growth was reduced in two of the three experiments with coarser substrates. As rate of Rout increased pearlwort growth decreased. Northern willowherb (*Epilobium ciliatum* Rafin) responded more to herbicide rate than substrate particle size in one experiment 2, however, in Experiment 3 it germinated and grew larger in fine bark compared to medium bark. Common groundsel (*Senecio vulgaris* L.) established and grew larger with decreasing particle size and herbicide rate.

Nursery Container Weeds Response to Modification of Substrate pH, Substrate Particle Size and Applied Nitrogen Form.

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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CHAPTER 1: INTRODUCTION & LITERATURE REVIEW

Weed management in container crops

The nursery container environment is dramatically different from field soils. Container substrates are comprised primarily of bark (60 to 80%) amended to some extent or not at all with sand, peatmoss, pumice, or perlite. Field soils are not used in container substrates because their small particle size clogs pores and reduces drainage. Containers are isolated, while field crops grow in a continuous and expansive medium (the soil) that supports crop and weed growth. The unique environment in containers provides challenges and opportunities for weed management.

Challenges for weed management in container crops include more intense weed competition, lack of postemergence herbicide options, lack of cultivation equipment for efficient weed removal, and difficulties in properly managing irrigation.

Containers provide a limited volume of substrate for crop growth, thus weed competition may be exacerbated (Mathers, 2003). One redroot pigweed (*Amaranthus retoflexus*) plant reduced the dry weight of Japanese holly (*Ilex crenata*) by 47% in 2.4 liter and 30% in 6.0 liter containers (Fretz, 1972). This suggests that in smaller size containers competition is more severe.

Weed control in containers must be preventative. There are little to no applications for using postemergence herbicides or cultivation equipment for removing weeds. If weeds establish, they must be removed by hand-weeding. Postemergence herbicides cannot be used for controlling weeds in containers directly. The only exceptions are graminicides such as clethodim, sethoxydim, and fluaziflop, and spray-applied flumioxazin and oxyfluorfen. While the grass-active compounds are effective, they only control weeds in the family Poaceae and plants from this family constitute a very minor fraction of weed species in containers. Spray-applied oxyfluorfen and flumioxazin are also labeled for use in dormant conifers; however, these products are not labeled for over-the-top applications to herbaceous, deciduous, or broadleaf evergreen crops which constitute a major fraction of container-grown ornamentals. Oxyfluorfen and flumioxazin are labeled for directed sprays around deciduous and broadleaf evergreen crops; however, directed applications are not practical or efficient in small containers.

Weed removal with cultivation equipment is not possible, or at least not commonly practiced. Containers can be arranged in an infinite number of patterns and densities on the production site. And rarely are they arranged in predictably straight lines. Varying container arrangements makes use of mechanized weed removal devices impractical. Furthermore, the container substrate surface is often 1 to 2 cm below the top edge of the container itself, which would be an impedance to mechanical equipment.

The most common option for removing weed infestations is hand-weeding, which is very expensive. Nursery growers estimate that they spend \$1235 to \$9880/ha of containers for manual removal of weeds, depending upon weed species being removed (Mathers, 2003). Darden and Neal (1999) calculated \$1367 per 1000 pots over a 4 month period for hand-weeding, and that effective preemergence herbicide use reduced this cost to just $67 per 1000 containers.

Another challenge to container weed control is poor irrigation management. Excessive irrigation reduces preemergence herbicide efficacy (Ross and Lembi, 1999) and improves the chances of weed establishment. Precision irrigation is needed so that only the amount of water necessary for crop growth is applied, thus reducing unnecessary water that might decrease herbicide efficacy. Precision irrigation relies on two factors: 1) determining how much and when to irrigate, and 2) irrigation uniformity. The major detriment to irrigation precision is lack of uniformity. Containers irrigated with pressure-compensating micro-irrigation can be watered uniformly; however, these types of systems have not been successfully designed for small containers (< #7 (≈ 25 L)) which dominate the Oregon nursery industry. Small containers are irrigated with overhead sprinklers, which are notoriously non-uniform (Beeson and Yeager, 2002). Lack of uniform irrigation dictates that all crops be irrigated until the least irrigated plants have received sufficient water, which results in the rest of the crop being over-watered. Irrigation uniformity is a challenge for weed control, but nursery growers have few options to mitigate this. Technology is the limiting factor in irrigation uniformity. New irrigation systems or devices must be developed to improve this situation.

Opportunities for weed management in container production include a constantly renewable growing substrate, an initially weed-free substrate, an initially nitrogen-free substrate, and greater control of the chemical and physical properties of the growing substrate.

Each successive crop of containers is filled with new substrate. In field production, historical management practices can change the chemical, biological, and physical properties of the soil and thus adversely influence future crops; this is not a concern in container production. Many residual herbicides used for preemergence weed control have a plant-back date indicating how soon a new seed crop can be planted after a herbicide application is made. These issues are not a concern with container production.

Bark used as a container substrate is initially weed-free. Substrate components account for a minor part of seed influx into a nursery system (Cross and Skroch, 1992). Because there is no seed bank associated with containers, efforts to prevent seed introduction into the production area can have a substantial influence on overall weed management. In field soils, weed seed in the seed bank can persist for decades (Darlinton and Steibauer, 1961). Even with perfect exclusion of weed seed from the production site, seed preexisting in field soil must be controlled. Lack of a seed bank in container substrates is an overwhelming advantage for container nursery managers. Weed seed in container nursery systems originate from within the nursery or in surrounding areas and infest the crop after it has been potted. Complete sanitation in and around the nursery will eliminate the source of all weed seeds, dramatically improving weed management. Container nurseries are typically constructed on gravel or with a woven polypropylene fabric, so there are no concerns of erosion from lack of stabilizing vegetation. Thus, sanitation through complete vegetation suppression is possible and desirable.

Container substrates have no available N to support weed seedling establishment. Nitrogen is an essential nutrient for all plants, especially early in their life cycle. Without available N, seedlings may germinate but will not grow beyond the cotyledon stage. Nitrogen, phosphorus, and potassium fertilizers are commonly applied in the form of controlled release fertilizer (CRF). Strategic fertilizer placement to avoid N on the substrate surface will dramatically improve weed control. For example, CRF applied below the container substrate surface results in poor weed establishment and excellent weed control with or without herbicides (Altland et al., 2004; Fain et al., 2003).

The greatest opportunity regarding weed management in container production is that nursery managers have complete control over the chemical and physical properties of the container substrate. Chemical properties of the raw materials used in container production, as well as methods for modifying those properties, have been well documented (Buamscha and Altland, 2005). Modification of physical properties has the most pronounced effect on water and air relations in the container (Argo, 1998). Through mixing of multiple substrate components (bark, peatmoss, perlite, etc.) nursery producers can create substrates with an infinite range of physical properties. However, the influence of chemical and physical properties on weed management has not been studied adequately enough to make recommendations. The influence of lime rate, lime type, and applications method might have important consequences on substrate surface pH. Modification of substrate surface pH could affect weed establishment. Nitrogen form has been shown to influence the growth of ornamental crops and field weeds (Elmer, 2000; Walden and Epelman, 1988; Teyker et al., 1991). It is possible that N form could be used strategically to reduce weed vigor and improve overall weed management. Substrate particle size can also have important consequences on weed establishment and herbicide efficacy. These cultural factors of container management should be studied on select container weed species.

The container environment can be characterized as a predominantly organic substrate, fertilized with high rates of applied N, irrigated daily or nearly so, and isolated from the soil and other containers. Few weed species are adapted to disseminate into and survive in this environment. In field crops of the North Willamette Valley, as many as 70 to 80 weed species are present. The Oregon State University Crop and Soil Science Department lists 78 weed species from 22 families (Oregon State Univ., 2002) as being present in field soils in the Willamette Valley of Oregon. In contrast, only eight weed species in the same geographic area are prevalent in container nurseries (Altland, 2004). Creeping woodsorrel (*Oxallis cornitculata* L.), bittercress (*Cardamine* spp.), common groundsel (*Senecio vulgaris* L.), northern willowherb (*Epilobium ciliatum* Rafin), pearlwort (*Sagina procumbens* L) and prostrate spurge (*Chamaesyce maculata* (L.) Small) are among the most common weed species adapted to the container environment. The biology of these weeds is reviewed here to gain a better understanding of how cultural practices might influence their establishment and growth.

Weed species

Oxalis corniculata L.

Creeping woodsorrel (*Oxalis corniculata*) is a troublesome weed throughout the U.S. It is most problematic in greenhouse and container production. Creeping woodsorrel reduces growth of container and greenhouse crops by competing with plants for water and nutrients, and in some cases by outgrowing and shading smaller ornamental plants (Bachman and Edgar, 2001). Landscape professionals also note its persistence in the landscape. Most landscape infestations likely arise from contaminated nursery stock. Its competitive effects in production and its nuisance in the landscape make control of this weed imperative.

The genus name *Oxalis* is derived from the Greek word *osys*, which means 'sour or sharp tasting'. The specific epithet *corniculata* means 'horned'. Carl Linnaeus narrowed its use as a generic name to include only plants of the family Oxalidacae (Peirce, 1997). There are several commonly used synonyms with this species including *O. repens* Thumb, *Xanthoxallis corniculata* (L.) Small and *X. langloisii* Small. There are three taxa closely related to *O. corniculata* including: *O. stricta*, *O. dillenii* Jacq. ssp. *Dillenii*, and *O. dillenii* Jacq. ssp. *Filipes* (Small) Eiten (Lovett, et al.,1985).

Creeping woodsorrel is a cosmopolitan weed species, which commonly occurs in inhabited regions throughout the world with the exception of the Arctic and Antarctic. It is likely that cold winter conditions restrict naturalization in polar regions. Favorable habitats are greenhouses and surrounding areas, and gardens. The similar yellow woodsorrel (*O. stricta*) is more widespread and usually found in cultivated fields, roadside ditches, lawns and woodland edges. Both yellow and creeping woodsorrel are noted as weeds of container crops; however, creeping woodsorrel is the dominant species in Oregon container production.

Creeping woodsorrel is believed to have arisen somewhere in tropical Asia, Malaysia, Australasia, or in high islands in the western Pacific (Eiten, 1963). It is not likely indigenous to North America. A slimy substance collects in the mouth when the leaves are chewed; this substance is used by magicians to protect their mouth when they eat glass for performances (British website, 2004). This herbal use may have aided in its global spread.

Physical characteristics have been described previously (Lovett et al., 1981; Lovett et al., 1985; Eiten, 1963; Holm et al., 1977; Whitson, 2000; Hitchcock and Cronquist, 2001). Cotyledons are smooth, oblong, and green. Margins and veins on lower leaf surfaces of young seedlings are sparsely hairy. Leaf arrangement is alternate. Leaves are trifoliate with an apical notch. Leaflets are usually green to purple-tinged (from anthocyanin) with a very characteristic heart-shape making it easily distinguishable from other species. Leaf color varies from dark purple green when grown in full light to lighter green when grown in shady environments. Plants grow up to 20 cm tall with a creeping or decumbent habit with stolons that root at the nodes. Flowers occur in clusters that are umbel-like and arise from long stalks at leaf axils. Each flower has five yellow petals, 4-9 mm long. Seed are contained in cylindrical capsules 4-28 mm long with two to many seed per locule.

Creeping woodsorrel produces a prolific number of seed which are expelled forcefully from the parent plant (Whitson, 2000; Holm et al., 1977). There are no data on how many seed are produced by creeping woodsorrel; however, the closely related yellow woodsorrel has been documented to produce on average 860 seed per plant and as many as 3300 seed per plant (Salisbury, 1976). As a stoloniferous herb, creeping woodsorrel also reproduces vegetatively by rooting at nodes. As stolons root and create new plantlets, they send another taproot deep into the container substrate. In controlled indoor environments such as greenhouses that lack in the seasonality of outdoor environments, it may grow and reproduce year-round (Elmore et al., 1979).

When seed pods mature, they burst open and forcefully expel the seed up to 3 m or more from the mother plant. Each seed has several transverse ridges. Seed are sticky and rough with ridges so that they adhere to surfaces of machinery or clothing and disperse further. Creeping woodsorrel seed are small and light so that they can be carried by surface run-off water, natural streams, drainage channels, or irrigation water. This species is predominantly inbreeding (Holt, 1987), but has retained the capacity to outcross; this in breeding system likely contributes to its success as an aggressive and colonizing weed in disturbed habitats (Ornduff, 1972; Lovett, et al., 1981).

Creeping woodsorrel is a perennial (Lovett, 1985), but may act as an annual in colder climates. Germination rate is high, from 86-90% in a greenhouse environment

(Holt, 1987; Wada and Altland, 2004). Creeping woodsorrel germinate in low levels of light (5 µmol $m^{-2}s^{-1}$or approximately 0.25% of full sunlight) although germination increases with increasing light levels (Holt, 1987). Creeping woodsorrel will not germinate in total darkness. Germination in low light levels is an advantage for container weed species that often germinate beneath the canopy of the ornamental crop. Because of small seed size and the requirement of light for germination, buried seed will likely form a seed bank in the soil and lie in induced dormancy. This induced dormancy could allow seeds to lie dormant until they are re-exposed to the soil surface when planted in the landscape. Creeping woodsorrel germinate in the temperature range of 10 to 30 C, although peak germination is between 15 and 20 C (Holt, 1987). Seed will not germinate below 9 C or above 30 C. Continual germination throughout most of the year would be expected in many greenhouse environments.

Holt (1987) demonstrated that germination capacity of dry, aerobically stored seed is reduced after 8 months, perhaps by induction of secondary dormancy over time, but most likely by natural decay and loss of viability. This has little relevance for management in container nursery systems, but may be important for researchers collecting and storing seed for future experiments. This research also showed that greenhouse produced creeping woodsorrel seed possesses low levels (<10%) of primary dormancy.

The main apex is determinate, but lateral shoots born on stolons are indeterminate in growth and continue to produce flowers as they grow. Containers filled with creeping woodsorrel flower prolifically for a period of time, then stop flowering for no apparent reason (personal observation). It could be that containers were filled to the point where new growth from stolons was not possible and existing vegetation had flowered determinately.

Senecio vulgaris L.

Common groundsel is a winter or summer annual, and one of the most widespread and troublesome annual weeds throughout Oregon and the U.S.A.. It is listed as a noxious weed by 43 states (USDA Plants Database, 2005). It is especially problematic in nurseries and greenhouses (Senesac, 1991), and is the only weed problematic to both container and field nursery production.

Common groundsel belongs to the family Asteraceae. The genus name *Senecio* is derived from the Greek word '*senex*' which means 'old man', probably referring to the white pappus. The specific epithet *vulgaris* is Latin for 'common'. The name groundsel is old in origin, being derived from the Anglo-Saxon *groundeswelge*, meaning literally, 'ground swallower,' (Simpson and Weiner, 1989) probably referring to the rapid way the weed spreads. Its other common name old-man-in-the spring (Hitchcock and Cronquist, 2001) is likely another reference to its pappus.

Common groundsel is adapted to range of habitats. It grows primarily in cultivated soil, but is also commonly found in pastures, along roadsides, and other disturbed areas. It is best adapted to wet environments and nutrient rich soils, so it is rare to find populations during hot and dry summers. In the controlled environments of greenhouses and containers nursery where there is abundant moisture from irrigation, plants can germinate and grow year-round.

Common groundsel is native to Europe, where it was noted to follow civilized man wherever he settled (Grieve, 1959). Seed probably mingled with grain which the European farmers took with them to the foreign countries.

Physical characteristics of this weed have been described previously (Georgia, 1942; Uva et al., 1997; Whitson et al., 2000; Hitchcock and Cronquist, 2001). Common groundsel is tap-rooted. Cotyledons are narrowly elliptic to oblong, with rounded-acute tips 3-11 mm long that are glabrous or scruffy and often purplish below. Leaf bases are tapered and sheathing. First leaves are ovate with tips broadly acute and margins coarsely shallow-toothed, 8-12 mm long and glabrous or with a few hairs. Leaves are alternate and deeply pinnatifid with irregularly toothed margins usually 2-10 cm long. Stems are more or less erect, single or branched from the crown, sometimes rooting at lower nodes. Plants grow up to 46 cm tall and are easily identified by its irregularly branched stems. Heads occur in terminal corymbose clusters consisting of yellow disk florets, and without any ray florets. Green bracts are cylindrically arranged, bracteoles are black-tipped, and principal involucrate bracts are about 21 in number (Hitchcock and Cronquist, 2001). Seed are achenes which are pubescent between ribs. Pappus size is equal or larger than its disk corollas.

Common groundsel reproduces by seed. It is primarily a selfing monocarpic ephemeral weed that is one of only a few species in central Europe capable of growing, flowering, and fruiting all year round (Haldimann et. al., 2003). Kadereit (1984) reported that common groundsel is a plant of ruderal habitats, which can complete its life cycle in a very short time and can be found flowering year round. Seed are dispersed by wind. Each plant can quickly produce about up to 1400 seeds per plant that are over 80% viable (Leishman et al., 1999; Salisbury, 1976). Common groundsel in agricultural habitats has higher levels of nutrients due to constant fertilization; plants of these habitats have an increased reproductive seed output up to 1,373 (Leiss and Heinz, 2001). Seed typically germinate early spring through late fall and almost year-round in nursery containers.

Groundsel seed can germinate within a few days after they land on a suitable surface. Because seedlings mature rapidly, three or more generations can occur in one season. Fluctuating temperatures, light, cold stratification, leaching with water or scarification stimulate seed germination. Fresh seed germinate in light over a temperature range of 10-25 C, with the percentage varying according to time of year that seed is produced (Ren and Abbott, 1991).

Hilton (1983) documented that seed of common groundsel showed very low germination in darkness at 20 C; however, germination could be induced when seed were exposed to white or red light for 8 h per day. In contrast, seed exposed to far-red light for 8 h per day failed to germinate within 12 days.

Seed dormancy may vary among populations. Research on the germination behavior of two seed populations of non-radiate *S. vulgaris* var. *vulgaris* showed that seed derived from a Mediterranean population has strong innate dormancy over a wide temperature range (Ren and Abbott, 1991). In contrast, seed of British groundsel exhibited more than 80% germination at 20 C almost immediately after sowing. The innate dormancy exhibited by seed on non-radiate Mediterranean groundsel enables the species to adopt a winter annual life cycle which is typical of Mediterranean ephemerals.

Hilton (1983) speculated that flushes of seedling emergence observed in June and September may be the result of increased seed shedding at these times of the year and are not likely due to environmental germination triggers.

The cinnabar moth (*Tyria jacobaeae*) feeds on both common groundsel and tansy ragwort (*Senecio jacobaea* L.). The caterpillars alone are not capable of sufficiently controlling groundsel infestations and a combination of control measures is recommended. Research is currently evaluating a rust fungus (*Puccinia lagenophorae*) for biological control. Paul and Ayres (1986) found that seed weight was little changed by rust infection. The fungus does not kill the plant; however it does delay flowering 1 to 2 weeks (Aldrich-Markham, 1994).

Sagina procumbens L.

Pearlwort (*Sagina procumbens* L.) is a perennial weed introduced from Europe (Hitchcock and Cronquist, 2001). This plant resembles moss because of its needle-like linear shaped leaves and mat-like growth habit.

Pearlwort belongs to the family Caryophyllaceae. The name is derived from the Latin word *sagina*, which means ‘nourishing or flattening’ (Hitchcock and Cronquist, 2001). The specific name *procumbens* is a synonym for prostrate, which describes its growth habit. Several common names are used such as beads, birdseye, or procumbent pearlwort.

It naturally occurs in cool moist climates typical of coastal regions, and thus it becomes particularly troublesome on moist, frequently irrigated turf (Elmore et al., 1989) or container nursery sites. It also grows in a variety of situations such as lawns, flower beds, pathways, walls, stream-sides, ditches and in short grasses.

This species has a worldwide distribution, occurring in both North America and Eurasia as a native plant. In North America, habitats include sandy ridges in open woodlands, rocky open ground, and urban areas. It can be found in either natural or disturbed areas where there is scant vegetation on the ground and is considered invasive in some ecosystems. Broughton and McAdam (2002) reported that pearlwort is an undesirable non-native species in Falkland Islands where it had been most successful at integrating itself into the natural ecosystems and comprises an almost ubiquitous component throughout the archipelago.

Physical characteristics of this weed have been described previously (Hitchcock and Cronquist, 2001; Crow, 1979; Uva et al., 1997). Pearlwort has slender taproots. Cotyledons are small and needle-shaped. Leaves are opposite and needle-shaped to narrow-linear, with a cusp and hairy. Leaves are sessile and basal with secondary rosettes present. Leaves are usually connated proximally, sometimes forming a scarious cup with or without auxiliary fascicles. The leaf blade is one-veined and linear to subulate in shape. The leaf apex is acute to mucronate or apiculate. Leaves are arranged oppositely along the stem with each pair merging together and wrapping around the stem. Stems are slightly swollen where each pair of leaves occurs, and may appear whorled. Each leaf is about 1.5 cm long and is bright green. Stems are procumbent, simple or branched, and terete to slightly angular. Inflorescences occur in terminal or axillary cymes. Flowers are solitary with foliaceous and paired bracts. Flowers are small and hypogynous, which tends to favor inbreeding (Crow, 1979). Pedicels are erect or spreading. There are four sepals, mostly smaller than 2.5 mm.

The blooming period for pearlwort occurs from mid to late spring and lasts about 1 month for a colony of plants. Most vegetative growth occurs during the spring while the weather is moist and cool. The flowers can develop fertile seed without insect pollinators. Seed are about 0.3 mm wide, light tan to dark or reddish brown in color, and with superficial ridges and tubercules. Seed of pearlwort are obliquely triangular in outline, grooved along the two dorsal ridges, and with slightly concave lateral surfaces (Crow, 1979).Pearlwort is a prolific seed producer. Salisbury (1976) investigated the reproductive capacity of pearlwort as an exceptionally fruitful plant and found that it produces 4,600 (average output) to 26,300 (maximum) seed per plant. Akinola et al. (1998) documented that pearlwort seed populations had changed very little over seven years in soil seed banks, confirming its longevity in soil.

Small plant fragments can regenerate, which has important implications in hand-weeding of nursery containers.

Epilobium ciliatum Rafin

Northern willowherb (*Epilobium ciliatum* Raf., *E. adenocaulon* Hauss., or *E. watsonii* (Barbey) Hoch & Raven) is a perennial weed in the family Onagraceae. The genus name *Epilobium* derives from two Greek words *epi*, which means 'upon', and *lobos*, which means 'pod or capsule'. The flower and capsule appear together with the corolla being borne on the end of the ovary. The specific epithet name *ciliatum* refers to the slight fringing of the petals, resembling an eyelash.

Northern willowherb is native to North America and is common in the Pacific Northwest to British Columbia (Sarah, 1997). Northern willowherb is abundant in diverse conditions from moist to wet sites, open to wooded sites, and plains to mountainous regions. It is commonly found in disturbed places, often in wet habitats including meadows and along the shores of rivers and lakes. Keating et al. (1982) reported that northern willowherb shows considerable diversity in perennation structures with its wide range of distribution and habitat tolerances. Northern willowherb is very successful in container nurseries where it has become one of the most prolific weeds along the west coast of the U.S.A.

Physical characteristics of this weed have been described previously (Sarah, 1997; Hitchcock and Cronquist, 2001). Roots are fibrous with occasionally short rhizomes. Cotyledons are ovate-rhomboidal, and rounded at the tip. They are entire, glabrous and elliptical shaped, reddish to greenish, and 3-6 mm long. Lower true leaves are oppositely arranged while upper leaves are alternately arranged. Leaves are oblong-lanceolate shaped with minutely dentate outer margins and rounded to subcodate at the base with a short (1-4 mm) and broad petiole. Stems are erect to 1 m tall, reddish in color, shortly glandular-pubescent, and with two to four longitudinal lines. Flowers are small, less than 6 mm wide, white or pink, and with four deeply notched petals. Inflorescences are loose terminal racemes which arise from the leaf axils. Individual flowers are borne on medium to long flower stalks from July to September. The stigma is entire. Fruits are linear capsules up to 5 cm long, much longer than the pedicels which are narrow and elongate, pointing upward with whitish hairs.

Northern willowherb can flower and seed in its first year, but nonetheless has a perennial life cycle. Seed are 1 mm wide, ridged, and attached to a tuft of whitish hairs (Sarah, 1997). It is equipped with pappus for effective wind-dispersal. Parker et al. (1995) compared the mating systems of northern willowherb and fireweed (*E. angustifolium*), sympatric species. He concluded that northern willowherb showed higher autogamy rates (more inbreeding), lower pollinator visitation. Northern willowherb shows no inbreeding depression for seed number or percent germination, but significant inbreeding depression of biomass late in the life cycle. In contrast, fireweed (typically outcrossing) shows high inbreeding depression at all stages.

Northern willowherb is well adapted for growing in the container environment where it out-competes smaller ornamental crops. Northern willowherb seed can germinate in low-light conditions (Myerscough and Whitehead, 1966), making them well adapted to germination under the canopy of container crops. Seed can germinate over a range of temperatures from 4 to 30 C, although germination is more rapid in warmer conditions. This allows for germination to occur virtually year-round in Oregon container crops, especially those protected from cold during winter months. Seed germinate without stratification in nursery container substrates in about 4 days (personal observation). Plants bolt immediately in warm spring and summer months, but during cool winter months often enter a variable dormancy period at the 8 to 12 leaf stage for overwintering (Keating et al., 1982). Bulcke et. al. (1987) reported that seed have no innate dormancy.

Michaud (1991) reported that this species demonstrates strong apical dominance, and therefore, is a strong competitor for light (Grime, 1979). Irwin and Aarssen (1996) documented that the benefit of apical dominance (in terms of capsule production) was most evident when competing with plants grown under high nutrient levels where competition for light is expected to be most intense. These conditions are characteristic of virtually all container substrates.

Cardamine oligosperma L.

Bittercress (*Cardamine* sp.) is common in nursery containers throughout the U.S.A., Canada, and Europe. There is a great deal of confusion as to which species of *Cardamine* occurs in containers. Most researchers throughout the U.S.A. identified the container species as *C. hirsuta*. However, recent research by Fain et al. (2005) using molecular techniques suggests that *C. hirsuta* does not occur in significant numbers in container crops anywhere in the U.S., despite the fact it occurs naturally in the surrounding landscape. Landscape species of bittercress in Oregon were identified as *C. hirsuta*, however, container species could not be identified based on internally transcribed sequences deposited in GenBank. *C. oligosperma* is often cited as the species prevalent in Oregon container crops. Morphological characteristics support this; however, it cannot be confirmed. Detling (1937) declared that *C. oligosperma* is so similar to *C. hirsuta* that there is no question that it is derived from it. Because bittercress species are so similar and there is scarce information on any one of the species, I will review biological aspects of several species in an effort to gain a better understanding of the genera.

Cardamine is derived from the Greek word *karadamon*, used by Dioscorides, which refers to any plant in the mustard family (Hitchcock and Cronquist, 2001; Haragan, 1991), and *hirsute* is Latin for 'hairy'. *Oligosperma* is Latin for 'few seeds'; however, this is not an accurate description for the bittercress growing in either containers or landscapes in Oregon.

Bittercress is a native of temperate areas of the northern hemisphere (Auld and Medd, 1987). It is an introduced species from Europe where is most common in open habitats created by recent man-made constructions. Yatsu et al. (2003) attributed the spread of bittercress to the recent expansion of urban habitats and associated human activities.

Bittercress is found and naturalized throughout the northern half as well as the southeastern United States. It usually occurs in cool, moist, shaded habitats as a weed of gardens, nurseries and glasshouses (Auld and Medd, 1987). However, Detling (1937) reported that the species of *Cardamine* represented in the Pacific States can not be traced back to one original stock, and owing to the fact that they do not constitute a single homogeneous group; the problem of their origin and relationships is complicated.

Physical characteristics of this weed have been described previously (Auld and Medd, 1987; Grime et al., 1988; Stace, 1997; Hitchcock and Cronquist, 2001). .Bittercress is a small, usually annual herb with a basal rosette of numerous pinnate leaves arranged in a compact rosette. Roots are slender taproot, much branched and yellowish in color. Cotyledons are orbicular, petiolated and emarginated in its apex. Cotyledons and first true leaves are hirsute. Subsequent leaves consist of two to four pairs of leaflets arranged alternately along the central leaf stem. Stems are erect and glabrous, branched at the base, and reaching 20 cm in height. Flower stems can reach 30 cm tall in nutrient-rich conditions (Stace, 1997). Leaves are divided into three to six pairs of segments with the terminal leaflet more rounded. Upper leaves are larger than lower basal leaves. Leaves can reach 8 cm in length. Individual leaflets are round in outline and occur on a distinctly hirsute petiole. Flowers occur in racemous clusters at the ends of the flowering stems. The flowers are perfect and self-fertile. Individual flowers are small, 3-5 mm in diameter and consist of four white petals. The landscape species of bittercress in Oregon is *C. hirsuta* while the container species is probably *C. oligosperma*. These two species can be differentiated by their stamen number (Al-Shehbaz, 1998). *C. hirsuta* flowers have a variable number of stamen with most flowers having four stamen (80%), some having five (18%), and few having six (2%). *C. oligosperma* always has six stamens. The fruit is a silique, 2 to 3.5 cm long, linear and slightly compressed, and readily dehiscent with many seed. Seed are projected as much as 3 m from the mother plant by a spring-like action of the locule.

Bachman and Whitwell (1994) reported that a single plant of *C. hirsuta* (probably misidentified) produces 675 to 4980 seed per plant. Seed have up to 99% viability (Leishman et al., 1999) and can germinate in about five days. Bittercress will germinate year-round in container grown ornamental plants and greenhouses (Altland et al., 2000). However, Yatsu et al. (2003) reported that *C. hirsut*a showed strong seed dormancy during summer and behaved as a typical winter annual. Observations of dormancy by Yatsu confirm the molecular survey by Fain in that *C. hirsuta* is not likely the species prevalent in nursery containers that has been observed to germinate and grow year-round.

Conclusion

Nursery production in containers differs from production in field soils. Container substrate volume is limited, isolated, and different with respect to its biological, physical, and chemical properties. Weed management in container nurseries has been studied for decades; however, most of these studies have focused on herbicidal activity and safety in container production. The manner in which manipulation of common cultural practices affects weed growth in containers has been studied very little. Another difference with container substrates is the limited number of weed species that thrive in such an artificial and unique environment. Due to the limited number of species, there is an opportunity to more thoroughly understand the interactions between cultural management practices, traditional weed management practices (preemergence herbicides) and weed biology. Understanding these interactions will improve weed management decisions by nursery professionals, thus reducing weed control costs, overuse of chemical herbicides, and negative impacts on the surrounding ecosystem.

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CHAPTER 2: THE EFFECT OF DOLOMITIC LIME RATE & APPLICATION METHOD ON SUBSTRATE PH & CREEPING WOODSORREL ESTABLISHMEHNT.

Abstract

Experiments were conducted to evaluate the effect of dolomitic lime rate and application method on substrate pH, creeping woodsorrel establishment in containers, and growth of azalea (*Rhododendron* ‘Rosebud’) and pieris (*Pieris japonica* ‘Claventine’). In Experiment1 and 2 pulverized dolomitic limestone was incorporated at 0, 6, 12, 24, or 47 kg/m^3 (0, 10, 20, 40, or 80 lbs/yd^3). Containers were overseeded with twenty seeds of creeping woodsorrel (*Oxalis corniculata* L.). Substrate pH was measured with a pour through technique. Substrate pH increased linearly and quadratically with increasing lime rate. Creeping woodsorrel shoot fresh weight was negatively correlated to substrate pH ($r = -0.67$, $p = 0.0001$). Creeping woodsorrel germinated and established poorly in substrates with pH greater than 6.7. In Experiment 3 and 4 containers were topdressed with a uniform layer of pulverized or pelletized dolomitic limestone at 0, 5, 10, 20, or 40 grams per pot. Substrate pH was measured in 2.5 cm (1 in) layers from the top to the bottom of the container using a modified saturated media extraction procedure. At each lime rate, pH was greater when topdressed with pulverized compared to pelletized lime. Across all lime types and rates, pH was lower in the 2.5 to 5.1 cm (1 to 2 inch) layer compared to the surface layer which indicates that the most significant pH effect occurs on the surface layer. Topdressing containers with 40 g of lime provided creeping woodsorrel contro**l.** In Experiment 5 incorporating the same lime rates used in Experiment 3 and 4 caused

chlorosis in azalea and pieris while topdressed lime caused no change in growth or foliar color by 125 days after potting, regardless of rate applied.

Significance to the nursery industry

Data herein provide nursery producers with important information on how surface-applied lime affects substrate pH from the substrate surface through to the bottom of the container. This paper discusses the practical application of using surface-applied lime for management of creeping woodsorrel.

Alternatives to preemergence herbicides are needed for some facets of nursery production. Our data shows that creeping woodsorrel establishment and growth is inhibited by elevated substrate pH. However, it generally grows vigorously in the same range of substrate pH as most nursery crops. This research further shows that surface-applied lime will change pH of the substrate surface, without changing pH through the bulk of the container substrate. Topdressing containers with 40 g of lime provided creeping woodsorrel control; however, rates of surface-applied lime necessary to sufficiently control creeping woodsorrel could not be practically applied in a commercial nursery setting. Assuming containers were placed pot to pot, the 40 g per container rate is equivalent of 20 ton/ha (18,000 lbs/acre) of lime compared to 111- 222 kg/ha (100-200 lb/acre) for most granular preemergence herbicides.

Despite a lack of practical application in using surface-applied lime for weed control, these data also demonstrate how lime from different sources moves through the container profile. In our experiments, lime tended to form a hard crust on the container surface, and thus was physically impeded from filtering down through the container profile. These data also show that among containers receiving no lime, irrigation water alkalinity affects pH on the substrate surface and less so in lower layers.

Introduction

Weed control is important for producing quality container crops. Weeds in container systems are commonly controlled with preemergence herbicides; however, herbicides are not practical in every situation. Some crops such as hydrangea (*Hydrangea macrophylla*) and azalea (*Rhododendron obtusum*) are sensitive to preemergence herbicides (Moore et al., 1989), and no preemergence herbicide is labeled for use inside enclosed structures such as greenhouses. Understanding weed biology and environmental factors that influence weed growth may provide alternatives to herbicidal control.

Substrate pH has a major influence on plant growth. Changes in pH can increase or decrease mineral nutrients to toxic or deficient levels (Niemiera and Wright,1984), so that only a few species grow equally well in both alkaline and acidic soils (Nelson, 1998; Peterson, 1981). Substrate pH in the range of 5.5 to 6 is often considered desirable; however, some crops favor more acidic substrates with pH as low as 4.5 (Argo and Fisher, 2002). The optimum range for substrate pH is that which allows micronutrients to be soluble enough to satisfy plant needs without becoming so soluble they are toxic (Brady and Weil, 2004).

Organic container components such as bark and peat moss typically have lower pH than mineral soil and can sometimes cause problems with iron (Fe), manganese

(Mn) and zinc (Zn) toxicity (Buerkert et al., 1990). Substrate pH is commonly raised using a liming material such as dolomitic lime ($CaCO_3 + MgCO_3$). There are two types of dolomitic lime, pulverized and pelletized, commonly used in the Oregon nursery industry. Pulverized lime raises pH more quickly due to its smaller particle size (Altland, 2004).

Soil pH has been shown to influence the severity of weed infestations. Research in field soils demonstrated that broadleaf weed densities decreased as pH increased above 5.5 (Stephenson and Rachcigle, 1991). Also in a field soil, *Oxalis martiana* leaf number, plant height, and dry weight decreased with increasing soil pH (Choudhary et al., 1993).

Creeping woodsorrel (*Oxalis corniculata* L.) is a troublesome weed throughout the U.S. It is most problematic in greenhouse and container production. Creeping woodsorrel reduces growth of container and greenhouse crops by out-competing plants for water and nutrients, and in some cases by outgrowing and shading smaller ornamental plants (Bachman and Edgar, 2001). Landscape professionals also note its persistence in the landscape. Most landscape infestations likely arise from contaminated nursery stock. Its competitive effects in production and its nuisance in the landscape make control of this weed imperative.

Leda and Wright (1991) demonstrated that surface applications of lime are not effective at raising substrate pH throughout the bulk of soil profile. Surface application of lime likely only affects the substrate surface. Because creeping woodsorrel seed is small, seed must germinate near the substrate surface. It is possible that a surface application of lime could inhibit creeping woodsorrel establishment. Once an optimal or detrimental pH range is established, cultural practices that modify pH at the container surface might be developed to inhibit creeping woodsorrel growth and establishment.

The objective of this research was to determine the influence of substrate pH on creeping woodsorrel establishment, growth, and reproduction. Following this, a secondary objective was to determine if surface applications of lime could be used to inhibit creeping woodsorrel growth on the container surface without adversely affecting ornamental crop growth.

Materials and Methods

Experiment 1. The first experiment was conducted in a heated hoophouse at the North Willamette Research and Extension Center (NWREC) in Aurora, OR. Containers 14 cm (5.5 inches) tall and wide were filled with 100% Douglas fir (*Pseudotsuga menziesii* (Mirbel) Franco) bark amended with 0.9 kg/m^3 (1.5 lbs/ yd^3) Micromax micronutrients (The Scott's Co., Marysville, OH) and 7.1 kg/m^3 (12 lbs/yd^3) Osmocote 14-14-14 (The Scott's Co.). Pulverized dolomitic limestone (99% passed through 10 mesh, calcium carbonate equivalency (CCE) of 102%) (Woodburn Fertilizer Inc., Woodburn, OR), was incorporated at 0, 6, 12, 24, or 47 kg/m^3 (0, 10, 20, 40, or 80 lbs/yd^3). Twenty seeds of creeping woodsorrel were applied to on the surface of each pot December 19, 2003. Containers were overhead irrigated with 0.6 cm (0.25 inch) per day. Substrate pH was measured with the following pour through technique. Containers were saturated with overhead irrigation and then allowed to drain for 15 minutes. After draining, 150 ml of deionized water was poured over the substrate surface and the resulting leachate was collected and measured for pH with a Thermo Orion pH meter (Thermo Electron Corp. Milford, MA). The experimental design was completely randomized with 10 single pot replications. Data collected included measurement of substrate pH 40, 70, and 81 days after potting (DAP), weed germination numbers 40 DAP, flower number 70 DAP, estimation of percent coverage of the container surface by creeping woodsorrel 70 and 81 DAP, and shoot fresh weight (SFW) 81 DAP.

Experiment 2. The second experiment was conducted similarly to Experiment 1 with the following exceptions. It was conducted in a greenhouse at Oregon State University (OSU), Corvallis, Oregon. Containers were filled with Douglas fir bark and peat moss (9:1 v:v) amended with the same nutrients used in Experiment 1. Pulverized dolomitic limestone was incorporated at 0, 6, 12, 24, or 47 kg/m^3. Fourteen seeds of creeping woodsorrel were applied to each pot on February 1, 2004. Containers were overhead irrigated with 0.6 cm (0.25 inch) per day. Data collected included substrate pH 34, 60 and 74 DAP, percent germination 34 DAP, percent creeping woodsorrel coverage 60 and 74 DAP, flower number 74 DAP, seed pod number 74 DAP, and shoot fresh weight 74 DAP. Substrate pH was measured with the same pour through technique, but with an Accumet AR15 pH meter (Fisher Scientific, New York, N.Y.).

Experiment 3. This experiment was conducted similarly to Experiment 1 with the following exceptions. It was conducted outside on a gravel container yard at OSU. Containers were topdressed with a uniform layer of pulverized or pelletized dolomitic limestone at 0, 5, 10, 20, or 40 grams per pot English units on June 25, 2004. Pulverized and pelletized lime are from the same source material, however, pelletized lime is coagulated into prills to facilitate handling in agricultural operations. Twenty seeds of creeping woodsorrel were applied to each pot on July 5, 2004. Containers were overhead irrigated with 0.6 cm (0.25 inch) per day. Substrate pH was measured in 2.5 cm (1 in) layers from the substrate surface down through the container profile (five layers). The substrate was scraped away in 2.5 cm layers with a metal spoon. Substrate from each layer was placed in a 250 ml beaker, filling it to the 200 ml demarcation. Deionized water was subsequently added to saturate the substrate up to the 200 ml demarcation. The saturated substrate was allowed to incubate at room temperature for 60 minutes, and then it was filtered gravimetrically with Whatman No.1 Qualitative filter paper (Whatman International Ltd. Maidstone, England). The pH of the extractant was measured with an Accumet AR15 pH meter. The experimental design was completely randomized with 10 single pot replications. Data collected included substrate pH in each of the five layers 32 and 87 DAP. Established creeping woodsorrel plants were counted at 32 DAP, and SFW was measured 81 DAP.

*Experiment 4***.** The experiment was conducted similarly to Experiment 3 with the following exceptions. It was conducted in a greenhouse at OSU. Containers were topdressed with a uniform layer of pulverized or pelletized dolomitic limestone on

November 19, 2004. Twenty seeds of creeping woodsorrel were applied to each container on November 21, 2004. Data collected included substrate pH in five layers of each pot 22 and 58 DAP. Established creeping woodsorrel plants were counted at 18 DAP, and SFW was measured 54 DAP.

Experiment 5. This experiment was conducted simultaneously at OSUand NWREC. Containers 3.8 L (#1) were filled with 100% Douglas fir bark amended with Apex 14-14-14 (Simplot Turf and Horticulture, Lathrop, CA) 9.5 kg/m^3 (16 lb/yd^3) and 0.9 kg/m^3 (1.5 lbs/ yd^3) Micromax micronutrients. Containers were incorporated with pulverized or pelletized lime at 0, 6, 12, 24, or 47 kg/m^3, with 0, 5, 10, 20, or 40 g per pot. Topdress rates were calculated to deliver the same amount lime as was contained in the five incorporated rates. Azalea (*Rhododendron* 'Rosebud') and pieris (*Pieris japonica* 'Claventine') were potted on April 7, 2005. Containers were overhead irrigated with 0.6 cm (0.25 inch) per day. Substrate pH was measured with the same pour through procedure described in Experiment 1. The experimental design was completely randomized with eight single pot replications of azalea and six single pot replications of pieris. Data collected included substrate pH 46 DAP, leaf chlorophyll content measured with a Minolta SPAD-502 Chlorophyll Meter (Spectrum Technologies, Inc. Illinois) 86 and 125 DAP, and growth index ((height + width + width) /3) 125 DAP.

Results and Discussion

Experiment 1. Substrate pH increased linearly and quadratically with increasing lime rate (Table 2-1). Other research has shown that pH in pine bark substrates also increased with increasing lime rates (Niemiera and Wright, 1984). Germination rate decreased linearly and quadratically with increasing lime rates (Table 1). Germination at 40 DAP was negatively correlated to substrate pH (r = -0.67, p = 0.0001) dropping from 96% at a pH of 4.9 to 17% at pH 8.4. *Oxalis martiana* leaf number, plant height and dry weight decreased also with increasing soil pH in a field soil (Choudhary et al., 1993).

By 70 DAP, substrate pH still increased linearly and quadratically with increasing lime rate. Substrate pH dropped almost one point with 6 and 12 kg/m^3 (10 and 20 lb/yd^3)between 40 and 70 DAP, but did not change substantially at other rates of incorporation. Coverage of the container surface by creeping woodsorrel decreased linearly and quadratically with increasing lime rates. Coverage was also negatively and strongly correlated to substrate pH (r = -0.91, p = 0.000l), although reduced coverage with increasing lime rate could also be a function of reduced germination. Flower number also decreased linearly and quadratically with increasing lime rate and was negatively correlated to substrate pH (r = -0.80, p = 0.0001). This and other species of Oxalis spread seed by explosive dehiscence (Whitson, 2000); thus, reduced flower numbers could have a major impact on spread of this weed in container production systems.

Substrate pH changed very little within an incorporation rate or between 70 and 81 DAP. Coverage still decreased linearly and quadratically with increasing lime rates and was highly correlated with substrate pH (r = -0.83, p = 0.0001). Creeping woodsorrel completely covered the surface of containers treated with 0 to 12 kg/m^3. Containers treated with 24 and 47 kg/m^3 had substrate pH of 8.0 and 8.2 respectively, had significantly reduced creeping woodsorrel coverage. Creeping woodsorrel SFW was negatively correlated to substrate pH (r = -0.84, p = 0.0001) and positively correlated with creeping woodsorrel coverage (r = 0.84, p = 0.0001).

Experiment 2. By 34 DAP, substrate pH increased linearly and quadratically with increasing lime rate (Table 2-2). Substrate pH readings were lower compared to those in Experiment 1. This lower pH could have been caused by using a substrate with 10% peat moss in Experiment 2 and 100% bark in Experiment 1. However, Altland (2004) reported that adding up to 50% peat moss to Douglas fir bark had no effect on substrate pH, regardless of lime rate. It is also possible that pH readings were lower in Experiment 2 because irrigation water at the Oregon State University greenhouses in Corvallis contained lower alkalinity levels (34 ppm vs. 111 ppm). Creeping woodsorrel germination rate decreased linearly and quadratically with increasing lime rate. Germination at 32 DAP was negatively correlated to substrate pH (r = -0.50, p = 0.0003) although the change in germination over the range of 6 to 47 kg/m^3 was small.

By 60 DAP, substrate pH still increased linearly with increasing lime rate. Within a given incorporation rate, substrate pH changed little between 32 and 60 DAP. Coverage decreased linearly and quadratically with increasing lime rates and was more highly correlated with substrate pH (r = -0.79, p = 0.0001) than germination rates at 32 DAP. Despite the weak response of germination to substrate pH (low correlation coefficient), subsequent growth as measured by percent coverage of the container surface was responsive to increasing lime rate. Although plants germinated, they grew poorly thereafter.

Substrate pH changed little within a given rate of lime incorporation between 60 and 74 DAP. Surface coverage by creeping woodsorrel still decreased linearly and quadratically with increasing lime rates and was highly correlated with substrate pH ($r = -0.70$, $p = 0.0001$). Creeping woodsorrel flower number was negatively correlated to substrate pH ($r = -0.45$, $p = 0.0009$) as was seed pod number ($r = -0.50$, $p = 0.0002$). At 47 kg/m^3, no flowers or seeds were produced. Similar to Experiment 1, SFW was highly negatively correlated to substrate pH ($r = -0.67$, $p = 0.0001$).

Experiments 1 and 2 demonstrate that creeping woodsorrel germination and subsequent growth are highly dependent on substrate pH. However, substrate pH needs to exceed 7 to 7.5 in order to reduce creeping woodsorrel growth to an acceptable level. Unfortunately, a substrate pH of 7.5 would not be conducive to growth of most crops in container production.

Experiment 3. At 32 DAP, there was a three-way interaction between lime type, lime rate, and substrate layer (Table 2-3). Among containers receiving no lime, substrate pH was higher on the surface layer than the bottom three layers. Irrigation water alkalinity can cause increases in substrate pH over time (Wiedenfeld and Cox, 1988). These data suggest that changes in substrate pH may be greater on the surface compared to the bottom layers of the container.

The pH of the surface layer increased linearly and quadratically with increasing lime rate among both pulverized and pelletized lime. At each lime rate, pH was greater when topdressed with pulverized lime compared to pelletized lime.

Within containers receiving pulverized lime, substrate pH increased in the 0 to 2.5 cm and 2.5 to 5.1 cm layers. Within the 5.1 to 7.6 cm layer, substrate pH increased quadratically up to the 10 g rate then decreased slightly. Below this layer there was no rate response to lime rate. Among containers receiving pelletized lime, pH of all substrate layers below the surface layer the pH increased linearly with increasing lime rate. However, this rate response may have been heavily influenced by the 40 g rate. According to LSD comparisons, substrate pH below the surface layer in containers treated with 5 to 20 g lime was similar to non-limed containers.

Across all lime types and rates, pH was lower in the 2.5 to 5.1 cm layer compared to the surface layer. This indicates that the most significant pH effect occurs on the surface layer. Comparing substrate pH from the 2.5 to 5.1 cm layer to the 5.1 to 7.6 cm layer, only containers topdressed with 20 or 40 g of pulverized lime and 40 g of pelletized lime were greater. Within each lime rate, there were no differences in substrate pH from the 5.1 to 7.6 cm layer and below.

By 81 DAP, the influence of lime throughout the container substrate was more evident. Among containers receiving pulverized lime, substrate pH increased with increasing lime rate within each layer. Substrate pH was greatest on the surface layer, however, pH increased greater than non-limed containers when topdressed with 20 or 40 g. Within each lime rate, substrate pH decreased from the surface to the container bottom.

The pH responses of substrate receiving pelletized lime were slower. By 81 DAP, substrate pH increased with increasing lime rate in the surface and 2.5 to 5.1 cm layers. Substrate pH also increased in the 5.1 to 7.6 cm layer, although only slightly. Substrate pH in the bottom 2 layers did not respond to lime rate.

These data suggest that pulverized lime increases substrate pH faster than pelletized lime. Substrate pH is elevated along the container surface, and to some degree in layers up to 5.1 cm (2 in) below the container surface. However, at least within 81 DAP, substrate pH below the surface 5.1 cm is relatively unaffected unless very high rates of pulverized lime were applied. In this experiment, both pulverized and pelletized lime products seemed to aggregate and form a hard shell across the container surface. This aggregation may have formed a physical barrier, not only impeded the movement of lime particles into the substrate and thus limited its influence on substrate pH, but also suppressed creeping woodsorrel germination.

At 32 DAP, as substrate pH on the surface layer increased with lime rate, creeping woodsorrel numbers decreased (Table 2-4). Creeping woodsorrel produce small seed, and thus must germinate near the substrate surface. It is reasonable to suggest that substrate pH on the surface layer will influence creeping woodsorrel germination more than pH of layers deeper in the container substrate.

By 81 DAP, substrate surface pH in containers topdressed with pulverized lime increased to 6.1 and resulted in reduced SFW of creeping woodsorrel. However, substrate surface pH in containers topdressed with pelletized lime only increased to 5.3

and did not an affect creeping woodsorrel SDW. Despite reduced germination numbers at 32 DAP, by 81 DAP plants that established and were able to grow to a similar size as those in non-limed containers.

Experiment 4. Results in Experiment 4 were similar to those in Experiment 3 with one major exception. At 22 DAP, substrate pH increased with increasing pulverized lime rate in each layer of the container while pelletized lime only influenced the top three layers. This is different from what occurred in Experiment 1 when pH was measured 32 DAP. Based on results in Experiments 1 and 2 and other similar research (Altland, 2004), one would expect pulverized lime to affect substrate pH in the bottom layers of the container more than pelletized lime. The cause of this discrepancy between Experiments 3 and 4 is unknown.

Creeping woodsorrel response to lime applications was similar to that observed in Experiment 3 (data not shown).

Experiment 5. All lime treatments increased substrate pH above non-treated controls as measured by pour-through technique (Table 2-6) with pH increasing linearly or linearly and quadratically with increasing lime rate. Among topdressed containers, pulverized lime increased pH more than pelletized lime at the highest rate only. Non-amended Douglas fir bark has an initial pH of 3.5 to 4.0 (Buamscha and Altland, 2005). Topdressing lime even at the highest rate only increased substrate pH in this experiment to 4.6 (as measured with the pour-through technique). Incorporating lime had greater impact on substrate pH than topdressing. Within each lime type and rate, incorporating lime increased substrate pH more than topdressing.

These results concur with Experiments 1 through 4.

At 86 DAP all lime treatments except for the low rate of topdressed pulverized lime and incorporated pelletized lime decreased azalea chlorophyll content (Table 2-6). However, by 125 DAP none of the topdressed lime applications reduced chlorophyll content or plant growth. Incorporated lime decreased azalea chlorophyll content with increased lime rates with both pelletized and pulverized lime. Pulverized lime had a greater influence on azalea chlorophyll content, with each rate reducing chlorophyll content more than that of pelletized lime (except for the 5 g rate). Incorporating pulverized lime also decreased azaleas growth linearly with increasing lime rate, while incorporated pelletized lime had no affect.

Pieris chlorophyll content at 86 DAP decreased with 20 and 40 g/pot of topdressed pelletized lime and all rates of incorporated lime. Topdressed pulverized lime at 10 g/pot resulted in plants with inexplicably low chlorophyll content, and in contrast incorporated pelletized lime at 20 g/pot resulted in plants with inexplicably high chlorophyll content. Similar to results with azalea, no topdressed treatment reduced pieris chlorophyll 125 DAP. Incorporated pulverized lime reduced pieris chlorophyll content and growth with increasing lime rate while pelletized lime had no effect.

Prior to potting, Azalea and Pieris plants were well established in their propagation flats and suffering from slight nutrient deficiency. It is possible that reduced chlorophyll content of Azalea at 86 DAP could have been due to those plants taking longer to ‘green up’ after potting. By 125 DAP, plants with topdressed lime were as green and large as non-limed control plants. Azalea and pieris are in the family Ericaceae, and are especially sensitive and responsive to high substrate pH. Their growth in containers with topdressed lime is considered a severe test of ornamental tolerance to such applications. Because these two species did not respond negatively, it is unlikely that others would.

These data indicate that creeping woodsorrel respond to substrate pH. Furthermore, topdressing lime at 40 g/pot will raise the substrate surface pH and subsequently reduce creeping woodsorrel growth to a level that should be considered acceptable for control. These topdressed applications should have little or no adverse effects on growth of common container plants.

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Table 2-1. Influence of lime rate on substrate pH, creeping woodsorrel (*Oxalis corniculata* L) germination, growth, flowering and shoot fresh weight (Expt. 1).

	40 DAP[z]		70 DAP			81 DAP		
Lime rate (kg/m^3)	pH	Germination (%)	pH	Coverage (%)	Flower number	pH	Coverage (%)	SFW[y] (g/pot)
0	4.9	96	5.1	91	16	5.3	100	21.0
6	7.2	87	6.1	84	21	6.2	100	25.0
12	7.7	87	6.8	66	17	6.6	99	17.0
24	8.0	69	7.6	15	11	7.5	68	5.0
47	8.4	17	8.2	3	4	8.2	4	0.4
Significance	L***Q***	L***Q***	L***Q***	L***Q***	L***Q**	L***Q***	L***Q***	L***Q***

[z] Days after potting

[y] Shoot fresh weight

L and Q represent linear and quadratic rate responses, respectively.

*, **, and *** represent significance when $P \leq 0.05$, 0.01, and 0.001.

Table 2-2. Influence of lime incorporation rate on substrate pH, creeping woodsorrel *(Oxalis corniculata* L.) germination, growth, flowering and shoot fresh weight (Expt. 2)

	32 DAP [z]		60 DAP		74 DAP				
Lime rate (kg/m^3)	pH	Germination (%)	pH	Coverage (%)	pH	Coverage (%)	Flower number	Seed pod number	SFW [y] (g)
0	4.4	82	4.5	100	4.4	100	12	9	10.6
6	6.0	55	6.0	70	5.4	94	12	2	9.5
12	6.4	54	6.1	54	6.2	75	16	6	7.8
24	6.7	62	6.3	31	6.8	67	5	0	3.6
47	7.5	49	7.3	7	7.4	8	0	0	0.5
Significance	L***Q***	L**Q***	L***Q***	L***Q***	L***Q**	L***Q**	L***Q***	L***Q***	L***Q***

[z] Days after potting.

[y] Shoot fresh weight.

L and Q represent linear and quadratic rate responses, respectively.

*, **, and *** represent significance when $P \leq 0.05$, 0.01, and 0.001.

Table 2-3: Effect of surface applications of dolomitic lime on pH in depth of 5 layers of the container substrate (Expt. 3).

	32 DAP [z]											
	Pulverized lime						Pelletized lime					
Depth in layers (cm)	0 g	5 g	10 g	20 g	40 g		0 g	5 g	10 g	20 g	40 g	
0 .0 to 2.5	3.8	4.8	5.5	5.9	6.3	L***Q***	3.8	4.2	4.5	4.7	4.9	L***Q***
2.5 to 5.1	3.6	3.9	4.1	4.3	4.2	L***Q***	3.6	3.7	3.8	3.8	4.4	L***
5.1 to 7.6	3.4	3.8	4.0	3.7	3.8	Q*	3.4	3.6	3.6	3.7	4.1	L***
7.6 to 10.2	3.5	3.6	3.8	3.7	3.8	NS	3.5	3.6	3.6	3.6	4.0	L***
10.2 to 12.7	3.5	3.7	3.9	3.7	3.7	NS	3.5	3.6	3.6	3.7	4.1	L***
	LSD [y]=0.3											
Depth in layers (cm)	81 DAP											
0 .0 to 2.5	4.1	5.0	5.3	5.7	6.1	L***Q***	4.1	4.6	4.7	5.2	5.3	L***Q***
2.5 to 5.1	3.5	4.0	4.6	5.0	5.5	L***Q***	3.5	3.8	4.0	4.2	4.6	L***
5.1 to 7.6	3.4	3.6	3.8	4.5	5.0	L***Q*	3.4	3.3	3.5	3.7	3.8	L***
7.6 to 10.2	3.4	3.4	3.6	4.0	4.8	L***	3.4	3.3	3.4	3.5	3.5	NS
10.2 to 12.7	3.6	3.6	3.7	4.0	4.4	L***	3.6	3.4	3.5	3.6	3.5	NS
	LSD=0.3											

[z] Days after potting.

[y] Fisher's protected least significant difference.

L and Q represent linear and quadratic rate responses, respectively.

*, **, and *** represent significance when $P \leq 0.05$, 0.01, and 0.001.

NS represent no significance when $P \leq 0.05$.

Table 2-4: Effect of surface application of dolomitic lime of pH in 0 to 1 inch layer, creeping woodsorrel (*Oxalis corniculata* L.) germination and shoot dry weight (Expt. 3).

		32 DAP ^{z}		81 DAP	
Lime type and rate (g)		pH on substrate surface	Germination number	pH on substrate surface	Shoot dry weight (g)
	0	3.8	10.9	4.1	1.7
Pulverized lime	5	4.8	7.5	5.0	1.9
	10	5.5	2.5	5.3	1.4
	20	5.9	0.9	5.7	0.8
	40	6.3	0.0	6.1	0.3
			L***Q***	L***Q***	L**
Pelletized lime	5	4.2	9.5	4.6	2.1
	10	4.5	6.0	4.7	2.1
	20	4.7	3.4	5.2	2.5
	40	4.9	0.0	5.3	1.8
			L***	L***Q***	NS

^{z}Days after potting

L and Q represent linear and quadratic rate responses, respectively.

*, **, and *** represent significance when $P \leq 0.05$, 0.01, and 0.001.

NS represent no significance, $P > 0.05$.

Table 2-5. Effect of surface applications of dolomitic lime on pH in layered sections of the container substrate (Expt. 4).

	22 DAP[z]											
	Pulverized lime						Pelletized lime					
Depth in layers (cm)	0 g	5 g	10 g	20 g	40 g		0 g	5 g	10 g	20 g	40 g	
0 .0 to 2.5	3.9	4.7	5.1	5.4	6.3	L***Q***	3.9	4.3	4.6	4.7	5.2	L***Q***
2.5 to 5.1	3.5	3.8	4.4	4.5	4.3	L***Q*	3.5	3.7	3.4	3.8	4.0	L**
5.1 to 7.6	3.4	3.8	3.8	4.5	4.4	L***Q*	3.4	3.5	3.4	3.7	3.5	Q*
7.6 to 10.2	3.5	3.9	4.0	4.3	4.4	L*Q***	3.5	3.7	3.6	3.7	3.7	NS
10.2 to 12.7	3.4	4.0	4.1	4.2	4.2	L***	3.4	3.7	3.5	3.5	3.6	NS
	LSD[y]=0.2											
Depth in layers (cm)	58 DAP											
0 .0 to 2.5	3.9	5.0	5.4	5.6	6.0	L***Q*	3.9	4.5	4.5	4.9	5.2	L***
2.5 to 5.1	3.8	4.2	4.2	4.4	4.6	L**Q***	3.8	4.1	4.0	4.0	4.2	L*
5.1 to 7.6	3.8	4.0	4.1	4.2	4.3	L***Q*	3.8	3.9	4.0	4.0	3.9	NS
7.6 to 10.2	3.7	3.9	4.0	4.1	4.1	L***	3.7	3.9	3.9	3.9	3.8	NS
10.2 to 12.7	3.8	3.8	4.0	4.0	4.1	L**Q*	3.8	3.9	3.9	3.8	3.8	NS
	LSD=0.5											

[z] Days after potting.

[y] Fisher's protected least significant difference.

L and Q represent linear and quadratic rate responses, respectively.

*, **, and *** represent significance when $P \leq 0.05$, 0.01, and 0.001.

NS represent no significance when $P \leq 0.05$.

Table 2-6. Azalea and pieris response to dolomitic lime type, application method, and rate (Expt. 5).

		Lime	Substrate	Azalea			Pieris		
Lime	Lime	rate	pH	Chlorophyll		Growth index	Chlorophyll		Growth index
placement	type	(g/pot)	46 DAP ^{z}	86 DAP	125 DAP	125 DAP	86 DAP	125 DAP	125 DAP
Control		0	4.0	39.5	56.0	25.3	48.6	54.1	20.8
Topdressed	Pulverized	5	4.2	34.3	50.3	25.5	51.9	50.5	21.3
		10	4.2	27.6	54.6	32.1	38.3	48.9	19.4
		20	4.3	26.7	55.4	23.4	49.1	51.9	20.1
		40	4.6	24.0	55.6	22.6	49.0	49.3	20.6
			L***	L***Q***	NS	NS	NS	NS	NS
	Pelletized	5	4.2	36.2	57.1	23.2	48.9	51.8	19.8
		10	4.2	28.2	60.0	22.9	45.2	55.3	20.0
		20	4.3	29.7	53.8	21.1	42.3	53.3	18.9
		40	4.4	30.7	52.7	22.9	42.2	50.5	20.3
			L***Q*	L**Q***	NS	NS	L*	NS	NS
Incorporated	Pulverized	5	4.9	25.9	54.8	19.6	39.8	48.8	19.8
		10	5.4	23.3	49.1	20.6	27.0	42.8	17.2
		20	5.8	23.7	43.7	18.2	21.5	43.8	16.6
		40	5.9	16.3	32.9	18.4	21.2	40.7	15.1
			L***Q***	L***Q***	L***	L*	L***Q***	L**	L***Q*
	Pelletized	5	4.7	40.0	56.1	24.0	41.9	53.4	18.5
		10	4.7	32.0	54.8	19.4	42.8	54.2	20.0
		20	5.0	31.4	55.1	24.0	50.1	51.7	20.2
		40	5.2	24.1	51.5	20.7	40.3	49.1	20.1
			L***Q***	L***	L*	NS	NS	NS	NS
LSD $_{(\alpha = 0.05)}$			0.15	4.7	5.5	5.5	5.8	8.1	2.1

^{z} Days after potting.

L and Q represent linear and quadratic rate responses, respectively.

*, **, and *** represent significance when $P \leq 0.05$, 0.01, and 0.001.

NS represent no significance when $P \leq 0.05$.

CHAPTER3: EFFECTS OF NITROGEN FORM ON WEED ESTABLISHMENT & GROWTH IN CONTAINERS.

Abstract

The effect of nitrogen (N) form on container weed establishment and growth was evaluated in two experiments conducted in Corvallis, Oregon. In both experiments, containers were overseeded with twenty seeds of the following weed species: bittercress (*Cardamine oligosperma* Nutt.*)*, prostrate spurge (*Chamaesyce maculata* L.), pearlwort (*Sagina procumbens* L.), common groundsel (*Senecio vulgaris* L.), northern willowherb (*Epilobium ciliatum* Rafin.), or creeping woodsorrel (*Oxalis corniculata* L.). Each species was seeded in separate pots. Injectors delivered 150 ppm N using either ammonium sulfate ($(NH_4)_2SO_4$) (AS), ammonium nitrate (NH_4NO_3) (AN), calcium nitrate plus magnesium nitrate ($Ca(NO_3)_2 + Mg(NO_3)_2$) (CMN), or urea ($CO(NH_2)_2$) (UR), as the N source. Throughout the experiment, weeds in containers receiving no N (non-treated controls) germinated in lower numbers and produced less biomass. Nitrogen form affected container weed establishment and growth especially in creeping woodsorrel and prostrate spurge. Across all species, CMN tended to reduce growth and flower number compared to other N forms. Weeds fertilized with AN were always among the largest with the most inflorescences.

Introduction

In container production, nitrogen (N) is usually applied directly to the container in the form of controlled release fertilizers, or via liquid fertilizer injected through the irrigation system. Commonly used N forms include ammonium, nitrate, urea or a combination thereof.

Nitrogen form can affect plant growth. Walden and Epelman (1988) demonstrated that boxwood growth is greater with nitrate-N compared to ammonium-N. Elmer (2000) documented that eggplant (*Solanum melongena* L.) canopy size and flower number increased with fertilization with ammonium sulfate ($(NH_4)_2SO_4$) compared to calcium nitrate ($Ca(NO_3)_2$). Plants that have a preference for a particular N form still germinate and grow with other N forms, although somewhat less vigorously when non-preferred forms are supplied. Due to their small size, stimulative or depressive effects of N form on weed seedlings could be more pronounced than on larger, rooted ornamental plants. Selectivity of stimulative and depressive effects of N form have been observed in other weeds. For example, Teyker et al. (1991) reported that redroot pigweed (*Amaranthus retroflexus* L.) shoot biomass was reduced 75% when nitrogen was supplied as ammonium rather than nitrate, whereas corn shoot growth was unaffected by N form. Higher tissue NH_4^+ levels and the general appearance of the plant suggest that pigweed suffered from NH_4^+ toxicity where maize did not.

Some weed species may be biologically programmed to respond to certain N forms. Liebman et al. (2001) theorized that tillage and other soil disturbances stimulate decomposition of organic matter and nitrification of the ammonium released by decomposition. The presence of nitrate thus indicates not only enhanced availability of mineral nutrients, but also the elimination of competing vegetation. An environmental signal indicating no competing vegetation would be especially important for small weeds or those with a prostrate growth habit, characteristics of many weeds common in container nurseries. Thomas et al. (2003) reported that seedling traits were modified by distinct forms of mineral N, thus, seedling growth of annual and perennial grasses were generally greater when provided NO_3^- rather than NH_4^+. However, it is possible that not all seedlings respond to N form. Hillhost et al. (1988) documented that the combination of light and nitrate stimulates the synthesis of gibberellins (GA's) and thereby enhances germination of hedgemustard (*Sisymbrium officinale*), but not mouseear cress (*Arabidopsis thaliana*). Mouseear cress seeds germinated readily in water after being saturated with red light, whereas germination response of hedgemustard seeds to red light was dependent on nitrate.

Within the life cycle of plants, the seedling stage is the most vulnerable one (Fenner, 1987) and thus more susceptible to injury from misapplication of fertilizers. Urea is converted to ammonium carbamate as a precursor to ammonium. Ammonium carbamate is unstable and yields NH_3 and carbonic acid (Witt et al., 2002) which are both volatile and have been shown to kill or severely injure small seedlings (Wild, 1998). Deibert (1986) reported that urea causes extreme germination damage when N rates exceed 22 kg/ha (20 lb/acre) in direct application with small grain seed. Urea is commonly used as a fertilizer source for ornamental crop production; however, its effect on growth of small container weed seedlings has never been documented. Urea has adverse effects on seed germination, seedling growth, and early plant establishment in soil (Bremmer and Krogmeier, 1988). These adverse effects are caused largely, if not entirely, by ammonia produced through hydrolysis of urea fertilizer by soil urease. These effects have been attributed to urea itself, biuret, and other impurities in urea fertilizer (Court et al., 1964). Therefore, it is possible that this N form could be selectively phytotoxic to weed seedlings while having no negative effect on growth of larger, rooted ornamental plants.

While manipulating N form may not be enough to suppress weed growth altogether, reduced weed vigor from N form selection could improve efficacy and longevity of herbicidal weed control. Injection of N fertilizers in irrigation water of container nurseries is common. If weed species common to container crops were found to have a preference for one N form over another, it might be possible to develop fertilization programs which utilize the most suppressive N form, thus reducing weed vigor and improving overall control. Therefore, the objective of this research is to determine the effect of N form on the container weed establishment and growth of common container weed species.

Materials and Methods

Experiment 1. The experiment was conducted under a retractable roof greenhouse at the North Willamette Research and Extension Center (NWREC) in Aurora, OR. Containers 3.8 L (#1) were filled with 100% Douglas fir bark (*Pseudotsuga menziesii* (Mirbel) Franco) amended with 0.9 kg/m^3 (1.5 lbs/ yd^3) Micromax micronutrients (Scott's Co. Marysville, OH.), 1.8 kg/ m^3 (3.0 lbs/ yd^3) dolomitic limestone, 0.9 kg/m^3 Treble super phosphate 0-45-0 (Woodburn Fertilizer

Inc. Woodburn, OR), and 0.6 kg/m^3 (1.0 lbs/ yd^3) sulfate of potash 0-0-50 (Woodburn Fertilizer Inc.). Containers were potted July 29, 2005. On the same day individual containers were overseeded with twenty seeds of one of the following species; bittercress (*Cardamine oligosperma* Nutt.*)*, prostrate spurge (*Chamaesyce maculata* L.), pearlwort (*Sagina procumbens* L.), common groundsel (*Senecio vulgaris* L.), northern willowherb (*Epilobium ciliatum* Rafin.), or creeping woodsorrel (*Oxalis corniculata* L.).

Fifteen independently irrigated plots were constructed, each 2.3 m^2 (25 ft^2). The irrigation main-line was split into five separate irrigation lines, each passing through one of four Dosatron (Dosatron International, Clearwater, FL) injectors (the fifth line received no injection materials and served as a control). The five irrigation lines were randomly assigned to three plots each. Injectors were set to a dilution factor of 1:100 so that each delivered 150 ppm N using either ammonium sulfate ($(NH_4)_2SO_4$) (AS), ammonium nitrate (NH_4NO_3) (AN), calcium plus magnesium nitrate ($Ca(NO_3)_2 + Mg(NO_3)_2$) (CMN), or urea ($CO(NH_2)_2$) (UR). Irrigation was applied twice daily for a total of 1.3 cm (0.5 in) per day. Fertilizers were injected at both irrigation events on three days each week.

The experimental design was a randomized complete block design with three replications and four containers per species (sub samples) per replication. Data collected included weed numbers 15 days after potting (DAP), percent coverage of the container surface for creeping woodsorrel, bittercress, and prostrate spurge 29 DAP, weed number and height of common groundsel and northern willowherb 29

DAP, and shoot dry weight (SDW) of all weed species 41 DAP.

Experiment 2. This Experiment was conducted similarly to Experiment 1 with the following exceptions. Containers were potted August 24, 2005. Seeds were applied August 26, 2005. Data collected included germination numbers 12 and 20 DAP, percent coverage of the container surface for creeping woodsorrel, bittercress, and prostrate spurge 34 DAP, height of common groundsel and northern willowherb 34 DAP, inflorescence number, and SDW for all species 48 DAP.

Results and Discussions

Throughout the experiment, seeds in containers receiving no N (non-treated controls) germinated in lower numbers and weeds grew less (Tables 3-1 and 3-2). All species germinated to some extent, however, by 41 DAP shoot dry weight of all species was so small they did not register on a scale to 0.1 g (thus are reported as 0.0). Nitrogen is an essential nutrient for all plants, especially early in their life cycle. Without supplemental N, small seeds typical of container weeds do not store enough nutrients for growth far beyond emergence. A similar observation was made in two other studies where placing controlled release fertilizer below the container substrate surface resulted in no N on the substrate surface and thus poor weed establishment (Altland et al., 2004, Fain et al., 2003).

Creeping woodsorrel. In Experiment 1, creeping woodsorrel numbers in containers fertilized with AN and CMN were greater than those fertilized with UR (Table l), although differences were small at 15 DAP. By 29 DAP, creeping woodsorrel fertilized with AN spread most over the container surface, followed by those fertilized with AS or CMN, with those fertilized by UR spreading the least. These data concur with Altland and Mackiewicz (2004). Despite differences in growth at 29 DAP, there were no differences in SDW 41 DAP among containers receiving some form of N.

In Experiment 2, creeping woodsorrel numbers in containers fertilized with UR and AN were greater than those fertilized with AS at 12 DAP (Table 3-3). These results differs from the results in Experiment 1; however, N form effects on creeping woodsorrel germination were minor in both experiments. By 34 DAP, creeping woodsorrel fertilized with AN and UR resulted in the greatest surface coverage. By 48 DAP, inflorescence number in containers fertilized with CMN was lower than all other N treatments. These data differ from research by Altland and Mackiewicz (2004) who reported UR reduced creeping woodsorrel flowering compared to other treatments. Fertilization with AS and CMN reduced SDW approximately 50% compared to AN and UR. Across both experiments, CMN reduced growth of creeping woodsorrel by some measure compared to other N treatments. Perhaps more significant than reduced growth is reduction in inflorescence number by 49, 65, and 78% compared to AS, UR, and AN, respectively. Creeping woodsorrel disseminate seed through explosive dehiscence, allowing it to spread up to 3 m (10 ft) from the mother plant. Any cultural practice that reduces flower or seed numbers would slow the spread of this weed through nursery systems.

Bittercress. Nitrogen form had little influence on bittercress establishment 15 DAP (Table 3-1). While weed numbers in containers fertilized with AS were higher than in those fertilized with UR, differences were small. By 29 DAP, AN resulted in greater coverage of the container surface compared to all other containers. However by 41 DAP, there were no differences in SDW among containers receiving N. Altland and Mackiewicz (2004) reported reduced coverage of the container surface and SDW of bittercress fertilized with UR. However, in that experiment fertilizers were applied by pouring the salt solutions directly to each container. It was observed with this cruder method of fertigation that some seedlings were momentarily flooded with fertilizer solution. This flooding effect at each irrigation, compared to N being injected through the overhead irrigation system described in the current study, might explain some differences in results.

In Experiment 2, N form had no influence on bittercress numbers 12 DAP (Table 3-3). By 34 DAP, containers fertilized with AN had the greatest coverage of the substrate surface, followed by AS and UR, and those fertilized with CMN spreading the least. By 48 DAP, containers fertilized with AN had more inflorescence numbers than all other treatments. Similar to Experiment 1, there were no differences in SDW 48 DAP. Plants fertilized with AN had 39% more inflorescences compared to other N treatments. Bachman and Whitwell (1994) documented that a single bittercress plant can produce up to 5000 seeds and project those seeds up to 107 cm (42 in) from the mother plant. Similar to creeping woodsorrel, the explosive dehiscence of bittercress seed makes reduction in seed production an important management consideration.

Prostrate spurge. Prostrate spurge numbers in containers fertilized with AS and AN were higher than those fertilized with CMN and UR (Table 3-1). By 29

DAP, containers fertilized with AN resulted the greatest spurge coverage over the container surface, followed by AS. Spurge fertilized with UR and CMN covered approximately 50% of the surface area covered by AN. By 41 DAP, SDW data were similar to percent coverage data, in that containers fertilized with AN or AS had greater weed mass than those fertilized with UR and CMN. These data concur with results from Altland and Mackiewicz (2004) who reported the greatest prostrate spurge growth with AN, followed by AS, and with CMN resulting in the least growth (UR resulted in growth similar to both AN and AS).

Prostrate spurge response to N form in Experiment 2 was very similar to results observed in Experiment 1 (Table 3-3). CMN reduced prostrate spurge numbers compared to AS and AN. By 34 DAP, containers fertilized with CMN and UR had spread less than those fertilized AN and AS. By 48 DAP, plants fertilized with CMN had less mass than those fertilized with AN, although differences among fertilized treatments were small.

Pearlwort. Nitrogen form had no influence on pearlwort establishment 15 DAP and percent coverage 29 DAP. By 41 DAP containers fertilized with UR resulted in less SDW than those fertilized with AN or AS, although differences were small. Pearlwort is a prostrate growing plant. In natural systems, tillage stimulates decomposition of organic matter and the sudden release of nitrate from nitrification. This is a germination cue for many weed species, indicating the soil has been recently disturbed and that there is likely little competing vegetation (Liebman et al., 2001). This type of germination cue would be particularly important for prostrate growing plants. So it is somewhat surprising pearlwort did not respond to nitrate N the sameway that spurge did. Pearlwort growth in this experiment was slow, covering less than 20% of the container surface in all treatments. This may in part explain the lack of response to N treatment.

Similar to Experiment 1, N form had no influence on pearlwort number 12 DAP. By 48 DAP, containers fertilized with AN had the greatest SDW and followed by those fertilized with AS and UR, and those fertilized with CMN the least.

Common groundsel. Nitrogen form had no effect on common groundsel numbers or height. By 41 DAP there were differences in SDW, fertilization with AN resulted in common groundsel with the largest mass while those fertilized with AS and CMN were reduced 40 and 31%, respectively, compared to AN. Common groundsel in containers with no N germinated and established with similar numbers to other fertilized containers, although these plants had drastically reduced height and SDW indicating little or no growth beyond germination. Common groundsel seeds are larger than seeds of all the other species in this experiment. Their seeds are large enough to support vigorous germination and establishment, but not subsequent growth.

N form had little effect on common groundsel establishment at 12 DAP. Weed numbers in containers fertilized with UR were highest, although differences were minor. By 34 DAP, plants in containers fertilized with AN were tallest followed by those fertilized with UR and AS, and those fertilized with CMN the smallest. A similar trend was observed with inflorescence numbers at 48 DAP.

Common groundsel seed can germinate within a few days after landing on the container surface. Seedlings mature rapidly may produce three to four generations in one season (Haldimann et al. 2003); thus, a reduction in inflorescence number could substantially slow the spread of this weed in container systems. By 48 DAP, plants fertilized with AN had the greatest SDW while all others were similar in size.

Northern willowherb. N form had little influence on northern willowherb number by 29 DAP. Containers fertilized with AN resulted in greater northern willowherb height and mass than those fertilized with CMN.

In Experiment 2, N form had no influence on northern willowherb establishment at 12 DAP. By 34 DAP, containers fertilized with AS, UR and AN had similar in height and greater than containers fertilized with CMN. By 48 DAP, SDW in containers fertilized with UR was the greatest, followed by those fertilized with AS and AN, and those fertilized with CMN the least.

N form affects container weed establishment and growth. Across all species, CMN tended to reduce growth and inflorescence number more compared to other N forms. Weeds fertilized with AN were always among the largest with the most inflorescences. Using only nitrate based fertilizers (no ammonium) with liquid feed programs can reduce weed vigor and improve overall weed management. Sanitation and preemergence herbicides are the most commonly used tools for managing weeds in container systems. Selective use of N form in combination with other weed management tools can improve overall weed management by reducing the inflorescence number of some weed species and thus reducing their reproductive potential.

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Table 3-1. Creeping woodsorrel (*Oxalis corniculata*), bittercress (*Cardamine oligosperma*) and prostrate spurge (*Chamaesyce maculata*) response to nitrogen (N) form (Expt. 1).

	Creeping woodsorrel			Bittercress			Prostrate spurge		
N-form	Weed number 15 DAP[y]	Coverage (%) 29 DAP	SDW[z] (g) 41 DAP	Weed number 15 DAP	Coverage (%) 29 DAP	SDW (g) 41 DAP	Weed number 15 DAP	Coverage (%) 29 DAP	SDW (g) 41 DAP
AS ($(NH_4)_2SO_4$)	12 ab[x]	50 b	7.2 a	16 a	55 b	10.7 a	13 a	84 b	13.6 a
AN (NH_4NO_3)	14 a	75 a	8.4 a	14 ab	72 a	9.9 a	13 a	100 a	15.2 a
CMN ($Ca/Mg(NO_3)_2$)	14 a	48 b	6.4 a	15 ab	46 b	8.0 a	9 bc	50 c	8.8 b
UR ($CO(NH_2)_2$)	11 b	35 c	5.2 a	13 b	41 b	7.1 a	10 b	53 c	9.0 b
Control	2 c	5 d	0.0 b	1 c	5 c	0.0 b	7 c	5 d	0.0 c

[z] Shoot dry weight.

[y] Days after potting.

[x] Means with different letters are significantly different according to Fisher's protected LSD (α= 0.05).

Table 3-2. Pearlwort (*Sagina procumbens*), common groundsel (*Senecio vulgaris*) and northern willowherb (*Epilobium ciliatum*) response to nitrogen (N) form (Expt. 1).

	Pearlwort			Common groundsel				Northern willowherb			
	Weed number	Coverage (%)	SDW[z] (g)	Weed number		Plant height	SDW (g)	Weed number		Plant height	SDW (g)
N form	15 DAP[y]	29 DAP	41 DAP	15 DAP	29 DAP	29 DAP	41 DAP	15 DAP	29 DAP	29 DAP	41 DAP
AS ($(NH_4)_2SO_4$)	16 a[x]	16 a	2.6 a	3 ab	4 ab	10.4 a	9.8 b	5 a	4 ab	5.1 b	8.3 ab
AN (NH_4NO_3)	14 a	16 a	2.7 a	4 a	5 a	12.6 a	16.3 a	4 a	6 a	7.0 a	8.8 a
CMN ($Ca/Mg(NO_3)_2$)	16 a	15 a	2.2 ab	4 a	5 a	10.4 a	11.3 b	5 a	5 ab	5.0 b	4.8 b
UR ($CO(NH_2)_2$)	15 a	15 a	1.2 bc	4 a	5 a	11.0 a	12.3 ab	5 a	4 b	5.5 ab	5.5 ab
Control	1 b	11 b	0.0 c	2 b	3 b	0.4 b	0.0 c	1 b	2 c	0.2 c	0.0 c

[z] Shoot dry weight.

[y] Days after potting.

[x] Means with different letters are significantly different according to Fisher's protected LSD ($\alpha = 0.05$).

Table 3-3. Creeping woodsorrel (*Oxalis corniculata*), bittercress (*Cardamine oligosperma*) and prostrate spurge (*Chamaesyce maculata)* response to nitrogen (N) form (Expt. 2)

	Creeping woodsorrel					Bittercress				Prostrate spurge		
	Weed number	Coverage (%)	Coverage (%)	Inflor. number	SDW^z (g)	Weed number	Coverage (%)	Inflor. number	SDW (g)	Weed number	Coverage (%)	SDW (g)
N form	12 DAP ^{y}	20 DAP	34 DAP	48 DAP		12 DAP	34 DAP	48 DAP		12 DAP	34 DAP	48 DAP
AS ($(NH_4)_2SO_4$)	8 b^x	9 c	24.2 b	11.6 c	2.5 b	12 ab	51.7 b	12.9 b	7.7 a	12 a	17.7 b	2.6 ab
AN (NH_4NO_3)	13 a	16 a	56.7 a	25.9 a	6.1 a	12 ab	64.6 a	21.2 a	9.0 a	12 ab	30.0 a	3.6 a
CMN ($Ca/Mg(NO_3)_2$)	11 ab	12 abc	23.8 b	5.7 d	3.3 b	14 a	31.7 c	12.1 b	5.8 a	8 c	9.2 c	2.1 b
UR ($CO(NH_2)_2$)	14 a	15 ab	47.5 a	16.5 b	5.3 a	15 a	51.7 b	14.0 b	8.2 a	9 bc	7.1 c	2.2 ab
Control	9 b	11 bc	3.0 c	0.0 e	0.0 c	11 b	3.0 d	0.0 c	0.0 b	9 c	3.0 c	0.0 c

[z] Shoot dry weight.

[y] Days after potting.

[x] Means with different letters are significantly different according to Duncan's multiple range test (α= 0.05).

Table 3-4. Pearlwort (*Sagina procumbens*), common groundsel (*Senecio vulgaris*) and northern willowherb (*Epilobium ciliatum*) response to nitrogen (N) form (Expt. 2).

	Pearlwort		Common groundsel				Northern willowherb		
	Weed number	SDW[z]	Weed number	Plant height	Inflorescence	SDW	Weed number	Plant height	SDW
N form	12 DAP[y]	48 DAP	12 DAP	34 DAP	48 DAP	48 DAP	12 DAP	34 DAP	48 DAP
AS ($(NH_4)_2SO_4$)	18 a[x]	1.9 ab	4 b	11.4 b	12 b	11.1 b	4 a	5.5 a	5.3 b
AN (NH_4NO_3)	17 a	3.7 a	5 b	13.4 a	17 a	15.9 a	4 a	4.8 a	4.8 b
CMN ($Ca/Mg(NO_3)_2$)	15 ab	1.0 b	4 b	8.0 c	9 c	7.5 b	4 a	2.8 b	2.0 c
UR ($CO(NH_2)_2$)	16 ab	1.5 ab	6 a	11.9 b	13 b	9.5 b	5 a	5.4 a	6.3 a
Control (no treated)	15 b	0.0 b	4 b	1.0 d	0 d	0.0 c	5 a	1.0 c	0.0 d

[z] Shoot dry weight.

[y] Days after potting.

[x] Means with different letters are significantly different according to Duncan's multiple range test ($\alpha = 0.05$).

CHAPTER 4: EFFECTS OF SUBSTRATE PARTICLE SIZE AND HERBICIDE RATE ON WEED ESTABLISHMENT AND GROWTH IN CONTAINERS

Abstract

Effects of substrate particle size and herbicide rate on weed establishment and growth in containers were evaluated in three experiments. In Experiment 1, containers were filled with four grades of Douglas fir bark (*Pseudotsuga menziesii* (Mirbel) Franco) and overseeded with twenty seeds of pearlwort (*Sagina procumbens* L.). In Experiment 2, containers were again filled with four different particle sizes and overseeded with pearlwort, northern willowherb (*Epilobium ciliatum* Rafin), and common groundsel (*Senecio vulgaris* L.). The granular preemergence herbicide Rout 3G (oryzalin + oxyfluorfen), was applied at 0, 56, or 112 kg/ha (0, 50, or 100 lb/acre). In Experiment 3, either medium or fine grade bark was used and treated with same weed species and herbicides. Across the three experiments, pearlwort established with higher numbers in containers with the finest substrate. Subsequent pearlwort growth was reduced in two of the three experiments with coarser substrates. Pearlwort growth consistently decreased with increasing Rout 3G rate. Northern willowherb responded more to herbicide rate than substrate particle size in Experiment 2, however in Experiment 3, it germinated and grew larger in fine bark than in medium bark. Common groundsel established and grew larger with decreasing particle size and herbicide rate.

Introduction

Substrate particle size is an important property of container substrates.

Particle size dictates water and air holding capacity as well as nutrient and herbicide dynamics. The influence of particle size on weed growth with or without herbicides has been studied to some extent in field soils, but not in container substrates. A consistent theme across the literature on this topic is that seed size is an important factor in the relationship between substrate particle size and seed germination. For example, Keddy and Constabel (1986) showed that of ten wetland species, those with the smallest seed generally responded most to soil particle size gradient with a preference for fine soils. Large seeded species had the broadest tolerance for variation in soil particle size. Seed of common container weeds are small. For example, pearlwort (*Sagina procumbens*) seed are about 0.4 mm wide; northern willowherb (*Epilobium ciliatum*) seed are slightly larger at approximately 0.5 wide and 1.3 mm long; and common groundsel (*Senecio vulgaris*) has the largest seed at approximately 0.5 mm wide and 3.5 mm long (personal observation).

The spatial distribution of weeds depends not only on seed dispersal mechanisms but also on spatially variable safe sites necessary for initiating germination and ensuring growth to maturity (Gaston et al., 2001). These safe sites are difficult to characterize, and vary for each weed species depending on seed size, seed appendages, and seed coat characteristics. Generally, any combination of seed characteristic and soil microsite that enhances the contact between soil water and the seed surface will improve germination (Oomes et al., 1976; Harper et al., 1965). Therefore, substrate particle size can affect seed germination through physical or mechanical means.

Container substrates are initially weed- free because there is no seed bank. Seed are deposited on the surface of containers most often via autochory or anemochory dispersal mechanisms after the containers are filled. Small seed deposited on the container surface can be flushed into coarse container substrates (Ball, 1991). However, germination of seed flushed into the substrate would be different from germination of seed buried in soil.

In field soils, particle size can affect the number of seed deposited in a given area. Chambers et al. (1991) demonstrated that larger soil particles increase the number of seed trapped in soils. However, because nursery containers are isolated and essentially surrounded by a plastic wall, seed trapping by soil particles is not an important component of weed distribution. Soil particle size can influence emergence of seedlings from differing soil depths. Emergence from different soil depths has been found to be proportional to seed energy reserves (Lafond and Baker, 1986).

Substrate particle size dictates the percent porosity of a container substrate, as well as the ratio of water and air that fills the pore spaces. As substrate particle size increases, there is an increase in large non-capillary pores that only retain a small amount of water (Puustjarvi and Robertson, 1975). A zone of saturation called the perched water table exists at the bottom of containers, with a gradient of decreasing water content up to the container surface (Fonteno, 1996). As the substrate particle size increases, the perched water table and the percent of pore spaces filled with water along the gradient decreases. Because of the moisture gradient, it is conceivable that sufficiently coarse substrates could have little or no available water at the container surface while still providing sufficient water in the remainder of the container for ornamental crop growth. In field soils, large particle sizes on the soil surface seldom have the nutrient retention or water holding capacity of small particle size soils and may not provide the close root-soil contact needed for seedling growth and survival (Chambers and MacMahon, 1994). The same may be true in container substrates.

Interactions between herbicides and soil particle size have been studied. Sorption is an important process that influences the fate and behavior of herbicides in soil (Suba and Essington, 1999). Vader (2002) reported that a decrease in soil particle size increases sorption of atrazine to soil and decreases the amount susceptible to desorption. Its high affinity to clay and silt particles is due to greater surface area compared with coarser textures (Sonon et al., 1995). Nkedi-Kizza et al. (1983) concluded that adsorption of diuron and 2,3,5-T was stronger to particles smaller than 50 µm compared to particles larger than 50 µm. Similarly, Huang et al. (1984) found that adsorption of atrazine was stronger on soil particles smaller than 20 µm in diameter.

Preemergence herbicides are bound to mineral soils to form a chemical barrier on the soil surface. Herbicides can be immobilized and rendered ineffective if applied to soils with high organic matter levels. Since container substrates are 80 to 100% organic matter (bark or peatmoss), it is surprising that preemergence herbicides work at all in container substrates. It is likely that high irrigation rates (up to 1.3 cm/day) compensate for sorption to such high levels of organic matter and thus result in herbicide concentrations in the substrate solution sufficient for weed control. Few studies have addressed the influence of substrate particle size on herbicide efficacy or sorption in container media even though it appears that a combination of chemical and physical properties of different container substrate types may affect herbicide sorption. In a peat-based media, 96% of applied isoxaben remained in the top 5.1 cm (2 in), with no detectable isoxaben below 10.2 cm (4 in) (Rouchaud et al., 1999). Over 99% of oxadiazon applied to a 3:1 pinebark:peat or 7:1 pinebark:sand media remained in the top 2.5 cm (1 in) of the container, with no oxadiazon detectable below 3 cm (1.25 in) (Wehtje and Gilliam, 1993). Oryzalin was only slightly more mobile, with 99% remaining in the top 3.8 cm (1.5 in) of the pinebark:sand media and 99% in the top 2 cm (0.75 in) of the pinebark:peat media. Decreased movement in the pinebark:peat media was likely due the higher organic matter content and increased cation exchange capacity (CEC) due to incorporation of peat instead of sand.

Substrate particle size affects many factors that directly influence weed management in containers including, but perhaps not limited to, water availability to germinating seed, herbicide sorption and availability, and subsequent growth of emerged seedlings. The objective of this research was to determine the overall effect of substrate particle size and herbicide rate on weed establishment and growth of container weeds. The influence of these two factors was tested on three species that represent the range of seed sizes among weeds prevalent in container nurseries.

Materials and Methods

Experiment 1. The experiment was conducted outside on a gravel container yard at the North Willamette Research and Extension Center (NWREC) in Aurora, OR. Douglas fir bark was screened to the following four grades from coarsest to finest: coarse (> 1.2 cm (0.5 in)), medium (< 2.24 cm (0.88 in)), fine (< 1.2 cm (0.5 in)), or very-fine (< 0.6 cm (0.25 in)). Square containers 14 cm (5.5 in) tall and wide were filled with each bark grade and topdressed with 6 g (0.21 oz.) Osmocote 18-6-12 (Scotts Co., Marysville, OH) controlled release fertilizer on July 08, 2003. Twenty seeds of pearlwort were applied to each container July 10, 2003. Pots were overhead irrigated with 1.3 cm (0.5 in) daily split in two equal cycles. Ten single pot replications were arranged in a completely randomized design. Data collected included number pearlwort 12, 36, and 49 days after potting (DAP), percent pearlwort coverage of the container surface and shoot fresh weight (SFW) at 90 DAP.

Experiment 2. The experiment was conducted outside on a gravel container yard at Oregon State University (OSU), Corvallis, Oregon. Containers 3.8 L (#1) were filled with 100% Douglas fir bark amended with 0.9 kg/m^3 (1.5 lbs/ yd^3) Micromax micronutrients (Scott's Co.) and 7.1 kg/m^3 (12 lbs/yd^3) Apex 17-7-12 (Simplot Turf and Horticulture, Lathrop, CA). The bark used was screened to the same four grades used in Experiment 1 with the exception that fine was screened to < 0.96 cm (0.38 in). Containers were potted April 9, 2004. The granular preemergence herbicide Rout 3G (oryzalin + oxyfluorfen, Scotts Co.) was applied at 0, 56, or 112 kg/ha (0, 50, or 100 lb/acre) on April 12, 2004. Seeds of pearlwort, northern willowherb, and common groundsel were applied to separate containers April 18, 2004. Twenty weed seeds were applied to each container. Immediately after herbicide application, pots were overhead irrigated with 1.3 cm (0.5 in) of water and with the same amount split in two equal cycles daily thereafter. Data collected included weed plant numbers at 40 and 67 DAP, and SFW 98 DAP.

Experiment 3. The experiment was conducted similarly to Experiment 2 with the following exceptions. It was conducted simultaneously at NWREC and OSU. The bark used was the same medium and fine grades used in Experiment 2. Containers were filled April 6 at NWREC, and April 7 at OSU. Herbicides were applied April 7 at NWREC and April 12 at OSU. Weed seeds were applied April 6 at NWEC and April 16 at OSU. Data collected at NWREC included weed number 78 and 106 DAP, percent coverage of the container surface (for pearlwort only), weed height (northern willowherb and common groundsel), and SDW 106 DAP. Data collected at OSU included weed numbers 78 and 96 DAP, and weed height and SDW 96 DAP.

Physical properties of air space, water holding capacity, and total porosity were determined with three subsamples of each bark type using methods described by Bilderback et al. (1982).

Results and Discussion

Total porosity of all bark grades were similar (Table 4-1). Increasing particle size resulted in an increase in air space along with a concomitant decrease in water holding capacity. The effects of changes in available water after irrigation on germinating seeds are discussed below.

Experiment 1. Throughout the study, pearlwort established with greater numbers in containers with the finest substrate (Table 4-2). Ultimately, containers filled with the two coarsest substrates resulted in the fewest pearlwort numbers. Seed placed on coarse substrates may have been flushed by irrigation water too deeply into the substrate to germinate, perhaps because the seed were subjected to a state of darkness. Grime et al. (1981) documented that pearlwort seed germinated readily in light or shade, but did not germinate in darkness. By 90 DAP, pearlwort growth was greatest in containers with the finest substrate particle size. Substrates used by Oregon nursery growers are similar in texture to the medium and fine bark types. Medium bark reduced pearlwort number and overall growth by 68 and 63%, respectively, compared to fine bark. Coarse bark provided excellent pearlwort control (98.5%) for 90 days with no herbicide; however, the substrate is likely too coarse for growing most nursery crops. Recommended levels for each of the measured physical properties are provided in Table 4-1. Many nursery growers in the Pacific Northwest believe substrates in this region should have higher air space and lower water holding capacity than recommended levels due to long periods of wet winter weather in the region (personal communication). Nonetheless, physical properties of the coarse bark are likely too extreme to support vigorous crop growth.

Experiment 2. Pearlwort establishment 40 DAP was low among all treatments (Table 4-3). By 67 DAP, weed numbers in the finest grade were greater than the medium or coarse grades, regardless of herbicide rate. Medium and fine grade barks used in this experiment are the same used by Oregon nurserymen. Similar to Experiment 1, pearlwort established in higher numbers in fine bark compared to medium bark although fine barks used in the two experiments were slightly different. Differences in germination in fine and medium grade barks were likely due to difference in water holding capacity (Table 4-1). Coverage of the container surface, SFW, and SDW were highly correlated ($r = 0.95$ to 0.98) and all indicated that herbicides decreased pearlwort growth with increasing rate while bark type within a herbicide rate had no influence. The fewer number of weeds in the coarser bark types were able to grow to a similar size as the greater number weeds in the finer bark types. This contradicts results in Experiment 1 where establishment as well as subsequent growth were reduced with increasingly coarse grades.

At 40 and 67 DAP, analysis of variance on northern willowherb number indicated a significant interaction between bark type and herbicide rate. Among containers treated with 0 or 56 kg/ha of Rout 3G, bark type influenced establishment whereas weed numbers were very low in containers treated 112 kg/ha regardless of bark type. At 67 DAP weed numbers decreased with increasing herbicide rate regardless of bark type. Bark type only influenced numbers of northern willowherb plant when no herbicides were applied. Among containers with no herbicide, the highest numbers were in the coarsest and finest bark types. Northern willowherb can germinate in dry to water logged soils, and is particularly well suited for establishing in dry soils compared to other species in the same genera (Myerscough and Whitehead, 1966). This may in part explain its ability to germinate in bark type extremes. By 98 DAP, only herbicide rate influenced northern willowherb SFW, in that growth decreased with increasing herbicide rate.

At 40 DAP, common groundsel numbers in containers not treated with herbicide were higher in the coarse and medium bark compared to the fine and very-fine bark, this result is similar to results with northern willowherb. Weed numbers were low in containers treated with herbicide, with few differences among bark types. By 67 DAP, there were no differences in weed number among containers not treated with an herbicide. However, within each herbicide rate containers with the two finest substrates had numerically higher numbers than containers with the coarsest substrates. Common groundsel SFW decreased with increasing herbicide rate. Bark type only affected SFW when no herbicide was applied, where the finest bark resulted in greater SFW than the coarsest bark. A similar observation was made during re-vegetation of Mt. Saint Helens following its eruption in that higher seedling emergence occurred in coarse pumice, but higher seedling survival occurred in fine pumice (Wood and Morris, 1990). In the coarsest bark type with the 112 kg/ha herbicide rate, there was little germination and no measurable growth by the end of the study.

Experiment 3. To focus only on bark types typical of container nursery producers, Experiment 3 evaluated only medium and fine grade barks. Data from NWREC and OSU could not be pooled for analysis; however, trends from both sites were similar. For brevity, data from NWREC only will be presented with the exception of common groundsel (common groundsel data at NWREC may have been biased by a management mistake so OSU data will be used).

Among containers receiving no herbicide, pearlwort germinated in greater numbers and grew larger in fine bark compared to medium bark. This result concurs with Experiment 1 as well as results with the same bark types in Experiment 2. Pearlwort germinated and grew poorly in all containers treated with herbicides. Previous research by the author (data not published) has documented excellent pearlwort control with Rout 3G.

Northern willowherb germination was low in this experiment, with little or no measurable differences in weed number from herbicide treatment or bark type. Despite poor germination, subsequent growth of the few seedlings that did emerge was strongly influenced by bark type. At 106 DAP, among containers treated with 0 or 56 kg/ha Rout, weeds were larger in fine bark. While there is insufficient data to comment on germination in this experiment with respect to bark type, these results concur with Experiment 2 in regards to greater growth of northern willowherb in fine bark.

Common groundsel numbers in containers not treated with herbicides were greater in fine bark than medium bark. Common groundsel in containers with fine bark were over three times taller and this often results in some weeds dying due to competition or weeds growing so close to each other that they are difficult to distinguish when counting. Among containers receiving herbicides, weed numbers were similar within an herbicide rate. However, SDW was greater in fine bark than medium bark within containers treated with either 56 or 112 kg/ha. With respect to herbicide-treated containers, a similar trend was observed in Experiment 2 where common groundsel growth in fine bark was greater than growth in medium bark.

Nursery managers can modify the particle size of their substrates, as well as the herbicide rate. This research attempted to find some pattern in how the range of seed sizes of common container weeds is affected by substrate particle size and herbicide rate. While the three species studied in this experiment represent the range of container weed seed sizes, their seed differ in other ways. Common groundsel seed have achenal hairs that may anchor the seed in the substrate and improve water contact while pearlwort and northern willowherb do not. Common groundsel and northern willowherb seed are attached to a pappus which can alter the orientation of the seed on the substrate surface to improve contact between the substrate and seed parts most receptive to imbibing water (Sheldon, 1974). Based on these data, it is difficult to generalize how seed size influences germination in container substrates. All weed species responded to herbicide rate, as expected. Each species responded to substrate particle size differently. In this experiment, nitrogen was supplied in the form of controlled release fertilizer (CRF) incorporated into the substrate. Reduced saturation of the substrate surface in coarser bark grades could have reduced diffusion of the N to the substrate surface. CRF applied to the substrate surface may have altered results in this experiment. Irrigation was applied at the same rate and in two uniform cycles in all three experiments. Increasing or reducing the rate or frequency of irrigation may change how weeds germinated in various bark types. Increasing the number of irrigation cycles while maintaining the total volume applied increased the number and growth of weeds in containers (Fain et al., 2004). This result is likely because the substrate surface remains saturated for a greater fraction of the day with increasing the number of irrigation cycles. Substrate particle size influenced weed growth under the nursery-typical conditions in which this experiment was conducted. Modifying some of the cultural practices could alter the results reported herein. Our data demonstrate that substrate particle size is an important factor in weed management, although there are many other factors that need to be studied.

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Table 4-1. Physical properties of screened bark types in Experiments 1 – 3. (n = 3).

Bark grade[z]	Air space (%)	Water holding capacity (%)	Total porosity (%)
Coarse	61 a[x]	24 d	85
Medium	43 b	40 b	83
Fine - Exp. 1	46 b	35 c	81
Very fine	31 c	49 a	80
Recommended[y]	10-30	45-65	50-85

[z] Bark types were screened to the following sizes with wire mesh: coarse (> 1.2 cm), medium (< 2.24 cm), fine – Exp.1 (< 1.2 cm), fine – Exp. 2 (<1.0 cm), or very-fine (< 0.6 cm).

[y] Bilderback, 1982.

[x] Means with different letters are significantly different according to Duncan's multiple range test (α= 0.05).

Table 4-2. Effect of substrate particle size on establishment and growth of Pearlwort (*Sagina procumbens*) (Expt. 1).

	Weed number			Coverage (%)	SFW[z]
Bark grade[y]	12 DAP[x]	36 DAP	49 DAP	90 DAP	90 DAP
Coarse	0.0 b[w]	0.0 c	0.1 c	1.5 c	0.1 c
Medium	0.2 b	0.5 c	1.5 c	18.2 bc	2.1 bc
Fine	1.1 b	2.8 b	4.7 b	34.5 b	5.7 b
Very fine	5.2 a	5.8 a	6.8 a	60.0 a	12.5 a

[z] Shoot fresh weight.

[y] Bark types were screened to the following sizes with wire mesh: coarse (> 1.2 cm), medium (< 2.24 cm), fine (< 1.2 cm), or very-fine (< 0.6 cm).

[x] Days after potting.

[w] Means with different letters are significantly different according to Duncan's multiple range test ($\alpha = 0.05$).

Table 4-3. Effect of substrate particle size and herbicide rate on establishment and growth of common groundsel (*Senecio vulgaris*), northern willowherb (*Epilobium ciliatum*), and pearlwort (*Sagina procumbens*) (Expt. 2).

		Pearlwort				Northern willowherb			Common groundsel		
Bark	Herbicide	Weed number		Coverage (%)	SFW[z]	Weed number		SFW	Weed number		SFW
type[y]	(kg/ha)	40 DAP[x]	67 DAP	98 DAP	98 DAP	40 DAP	67 DAP	98 DAP	40 DAP	67 DAP	98 DAP
Coarse	0	0.8 a[w]	1.0 cd	47.5 abc	10.3 ab	7.6 a	6.8 a	38.9 b	2.8 a	3.5 abc	34.5 cde
Medium	0	0.5 ab	0.3 d	29.0 abcd	8.3 ab	3.9 b	4.3 b	67.3 a	2.1 ab	3.3 abc	68.3 ab
Fine	0	0.0 b	4.9 ab	53.3 ab	11.0 a	1.3 cd	2.6 bc	41.4 ab	0.3 d	4.1 ab	50.0 bc
Ultra-fine	0	0.0 b	6.4 a	55.8 a	11.1 a	0.5 d	7.0 a	45.0 ab	0.8 cd	4.6 a	72.5 a
Coarse	56	0.3 ab	0.6 cd	21.7 abcd	4.8 abc	2.9 bc	3.6 bc	34.0 bc	1.4 bc	2.8 abcd	34.9 cde
Medium	56	0.0 b	0.1 d	0.0 d	0.0 c	1.1 cd	2.4 bc	41.5 ab	0.3 d	2.4 bcd	22.7 def
Fine	56	0.1 b	1.8 cd	18.3 bcd	4.5 abc	0.4 d	2.4 bc	28.4 bcd	0.4 cd	3.1 abc	48.2 bc
Ultra-fine	56	0.0 b	4.4 ab	31.7 abcd	6.5 abc	0.4 d	4.1 b	35.6 bc	0.5 cd	3.5 abc	38.4 cd
Coarse	112	0.0 b	0.0 d	0.0 d	0.0 c	0.8 d	1.3 c	20.6 bcd	0.1 d	0.1 e	0.0 f
Medium	112	0.0 b	0.0 d	0.0 d	0.0 c	0.4 d	1.1 c	17.6 bcd	0.4 cd	1.0 de	3.2 f
Fine	112	0.0 b	0.6 cd	9.2 d	2.6 bc	0.1 d	2.0 bc	9.2 cd	0.0 d	1.8 cde	3.8 f
Ultra-fine	112	0.0 b	3.8 abc	14.2 cd	5.0 abc	0.0 d	1.3 c	4.4 d	0.0 d	2.4 bcd	13.1 ef
Main effects	Bark	NS	***	NS	NS	***	*	NS	***	*	*
	Herbicide	*	*	***	***	***	***	***	***	***	***
	Interaction	NS	NS	NS	NS	***	*	NS	**	NS	**

[z] Shoot fresh weight.

[y] Bark types were screened to the following sizes with wire mesh: coarse (> 1.2 cm), medium (< 2.24 cm), fine (< 0.96 cm), or very-fine (< 0.6 cm).

[x] Days after potting.

[w] Means with different letters are significantly different according to Duncan's multiple range test (α= 0.05).

Table 4-4. Effect of substrate particle size and herbicide rate on establishment and growth of common groundsel (*Senecio vulgaris*), northern willowherb (*Epilobium ciliatum*), and pearlwort (*Sagina procumbens*) (Expt. 3).

		Pearlwort				Northern willowherb				Common groundsel			
Medium particle size[y]	Herbicide rate (kg/ha)	Weed numbers 78 DAP[x]	Weed numbers 106 DAP	Coverage (%) 106 DAP	SDW[z] (g) 106 DAP	Weed numbers 78 DAP	Weed numbers 106 DAP	Height (cm) 106 DAP	SDW (g) 106 DAP	Weed numbers 78 DAP	Weed numbers 96 DAP	Height (cm) 96 DAP	SDW (g) 96 DAP
Medium	0	0.0 a[w]	0.7 b	1.5 b	0.0 b	0.1 ab	0.4 ab	1.3 ab	0.5 b	2.0 b	1.7 a	7.8 bcd	0.5 cd
Fine	0	0.0 a	4.3 a	20.8 a	0.4 a	0.9 a	0.8 a	7.4 a	4.9 a	3.6 a	4.6 b	24.9 a	3.3 a
Medium	56	0.1 a	0.2 b	0.1 b	0.0 b	0.0 b	0.2 ab	1.6 ab	0.4 b	0.3 c	0.4 bc	3.0 cd	0.3 cd
Fine	56	0.0 a	0.6 b	6.8 b	0.2 b	0.5 ab	0.4 ab	6.7 ab	3.4 ab	0.4 c	1.1 c	13.5 bc	1.8 b
Medium	112	0.0 a	0.1 b	0.1 b	0.0 b	0.0 b	0.0 b	0.0 b	0.0 b	0.4 c	0.4 bc	1.9 d	0.1 d
Fine	112	0.0 a	0.1 b	0.1 b	0.0 b	0.3 ab	0.3 ab	2.6 ab	1.2 ab	0.3 c	1.1 c	10.5 bc	1.4 bc
Main effects	Bark	NS	**	**	**	*	NS	*	**	NS	***	***	***
	Herbicide	NS	***	**	**	NS	NS	NS	NS	***	***	***	*
	Interaction	NS	***	*	*	NS	NS	NS	NS	NS	**	NS	NS

[z] Shoot dry weight.

[y] Bark types wee screened to the following sizes: medium (< 2.24 cm) and fine (< 0.96 cm).

[x] Days after potting

[w] Means with different letters are significantly different according to Duncan's multiple range test (α= 0.05).

SUMMARY AND CONCLUSIONS

The scientific literature frequently addresses the interactions between herbicides and weed growth in nursery container production. Herbicide rate, frequency of application, and timing of application have been studied in numerous conditions for efficacy against many weed species. Cultural management practices such as fertilization, pH management, and selection of substrate particle size have been studied for their effects on ornamental crop growth. However, these commonly manipulated practices have never been studied for their effects on weed growth in containers. The objective of this thesis was to initiate a series of studies that evaluate the influence of cultural management practices on weed growth in nursery containers.

The influence of substrate pH by lime application on creeping woodsorrel establishment, growth, and reproduction in container was investigated. Creeping woodsorrel is one of the most competitive and noxious weed species in container production systems. The hypothesis was that modifying pH of the substrate by surface application of lime could inhibit creeping woodsorrel establishment. Creeping woodsorrel responded to substrate pH in that they germinated and established poorly when pH was greater than 6.7. At each lime rate, pH was greater when topdressed with pulverized compared to pelletized lime. Across all lime types and rates, pH was lower in the 2.5 to 5.1 cm (1 to 2 inch) layer compared to the surface layer which indicates that the most significant pH effect occurs on the surface layer. Topdressing containers with 40 g of lime provided complete creeping woodsorrel control. Effect of lime application to common ornamental crops, azalea and pieris, was also investigated. Incorporating the same lime rates used caused severe chlorosis while topdressed lime caused no change in growth or foliar color by 125 days after potting, regardless of rate applied. Despite the promise of creeping woodsorrel control with surface applications of lime, these applications cannot be performed practically in a nursery environment. Applying 40 g lime per pot would required several tons/acre of nursery containers. Other methodologies or strategies might be developed in the future to modify substrate surface pH. If so, creeping woodsorrel establishment and growth would no doubt be inhibited. Until then, surface applications of current lime products is not a satisfactory solution to the large amounts of lime necessary for adequate control.

The effect of nitrogen (N) form on container weed establishment and growth was evaluated. Nitrogen (N) is an essential for all plants, especially early in their life cycle. If weed species common to container crops were found to have a preference for one N form over another, it might be possible to develop fertilization programs which utilize the most common and well adapted six weed species, creeping woodsorrel, common groundsel, northern willowherb, pearlwort and bittercress, were investigated. Across all species, nitrate-N tended to reduce growth and inflorescence number more compared to other N forms. Weed fertilized with ammonium nitrate were always among the largest with the most inflorescences. Using only nitrate based fertilizers (no ammonium) with liquid feed programs can reduce weed vigor and improve overall weed management. Selective use of N form in combination with other weed management tools can improve overall weed management by reducing the inflorescence number of some weed species and thus reducing their reproductive potential. This strategy would be a simple adaptation to any nursery system. Due to the wide array of fertilizer products, and the flexibility of most chemical injectors systems used with nursery irrigation systems, this recommendation would be easy and economical to adapt.

Effects of substrate particle size and herbicide rate on weed establishment and growth in containers was evaluated. The influence of these two factors was tested on three species that represent the range of seed sizes among weeds prevalent in container nurseries. Substrate particle size is an important property of container substrates. It dictates water and air holding capacity as well as nutrient and herbicide dynamics. All weed species responded to herbicide rate, as expected. Each species responded to substrate particle size differently. Pearlwort established with higher numbers in containers with the finest substrate. Subsequent pearlwort growth was reduced in coarser substrates. Rout 3G consistently decreased pearlwort growths with increasing rate. Northern willowherb germinated and grew larger in fine bark compared to medium bark, which showed more response to the particle size more than to the rate of Rout 3G. Common groundsel established and grew larger with decreasing particle size and decreasing herbicide rate. Substrate particle size influenced weed growth. This is a management practice that could be adapted in most nursery production systems; however, many producers become comfortable with a particular substrate and are resistant to change. Changing the container substrate would mean altering irrigation and perhaps fertilization practices. Despite the negative effects of smaller particle size substrates, convincing nursery growers to change their substrate to one that is more coarse would be difficult.

In conclusion, cultural practices investigated herein can influence weed establishment and subsequent growth in containers. Adoption of cultural practices based on these results may be difficult. Further research is needed to develop a more efficient system for delivering pH modifying materials to the substrate surface for weed control. Modification of the applied N form and substrate particle size would be easy changes to administer; however, fear of change and how it might influence the ultimate growth of the crop is a difficult obstacle to overcome.

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