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Nevada's Priority Agricultural Weeds: Perennial Pepperweed

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INTRODUCTION

Perennial pepperweed (*Lepidium latifolium L.*), also commonly called tall whitetop, is a long-lived perennial weed native to Eurasia. This weed arrived in North America as an ornamental plant, but subsequently spread throughout the Western states, where it inhabits many different environmental settings. Perennial pepperweed typically inhabits areas where the soil remains damp to wet for most of the growing season. These areas include irrigated or subirrigated meadows and pastures, stream banks and associated riparian areas, irrigation ditches, marshes, estuaries, floodplains, shorelines, exposed lakebeds, irrigated cropland, and areas that receive abundant run-on moisture (e.g., roadsides, cracks in pavement and seasonal streams). Both alkaline and saline soils are susceptible to invasion.

At the state level, 40% of Nevada's agricultural producers ranked perennial pepperweed as problematic (their fourth most problematic weed in the state). Just over half of public land managers (51%) rated the weed problematic (third in the state). Within Nevada, perennial pepperweed is considered less problematic in the southern region (not in the top 10 problem species), than in the northeast, central and western regions. For the latter three regions, agriculturalists always ranked perennial pepperweed within the four most problematic species.

At the county level, at least 40% of the agricultural producers in Elko (54%), Humboldt (52%), Washoe and Storey (47%), Pershing (42%), Churchill (42%), Douglas and Carson City (41%), and Eureka and Lander Counties (40%) identified perennial pepperweed as problematic. The only counties where 20% or less of the agricultural producers considered the weed problematic were White Pine (17%), and Clark and Lincoln (10.6%).

At the national level, perennial pepperweed occurs in at least 20 states, including all 11 far-Western states, with an estimated infestation of over two million acres.

The adverse effects from perennial pepperweed are numerous. They include decreased forage quality for livestock and wildlife; the loss or decline of desired plants important for providing high-quality habitat; excessive accumulations of dead plant material (litter), which prevents desired plants from establishing and also may increase fire danger; greater soil salinity; altered soil chemistry and nutrient cycling; and increased soil erosion. A solitary plant can develop into a large dense stand and displace most of the desired vegetation. This ultimately decreases the land's productive, esthetic and economic value.

Perennial pepperweed's root system is broad and often deep, but not dense. Thus, root structure does not hold soil together very well. Where patches of perennial pepperweed occur adjacent to flowing water, especially where the velocity and/or volume are high, there is a high risk for severe erosion, particularly during flood events. The deep root

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system also facilitates the redistribution of salts to the soil surface, which typically harms the more desired plants.

PLANT BIOLOGY

Reproduction occurs from two sources: seed and the perennating buds that develop on the roots. The roots often develop one bud per inch of root, which results in hundreds to thousands of buds per plant. Once the seed of perennial pepperweed germinates, the rapidly growing seedling quickly establishes a tap root that grows downward deep into the soil (**Figures 1a and 1b**). The taproot can reach a depth of almost 3 feet in less than 90 days. As the plant matures, the majority of the root system resides in the top 2 feet of the soil, but can reach depths greater than 10 feet, often tapping into a shallow water table. The root system usually has an extensive network of lateral roots, whose growth can approach 10 feet per year. Root biomass typically exceeds shoot biomass; thus, perennial pepperweed's roots store a large amount of energy (carbohydrate reserves) for future use during its yearly growth cycle.

Both flooding (and associated erosion) and tillage break perennial pepperweed's large roots into small pieces. Root segments as short as 1 inch long and 0.1 inches in diameter can contain a bud capable of developing into a new plant. New infestations are common immediately after a flood. This occurs because root segments and seeds are deposited downstream and reside on or just below the surface of the newly deposited sediment. Moist and bare sediment is an optimal growing site for new plants of perennial pepperweed.

New plants from seed can establish on small patches of bare ground in otherwise well-vegetated meadows and pastures, and develop lateral roots that extend far into the area occupied with desired perennial grasses. Some of the buds on these lateral roots eventually develop shoots that emerge above-ground. These shoots enable the perennial pepperweed plant to compete with the desired vegetation for the resources needed for plant growth (e.g., sunlight, water and nutrients).

Seedlings develop a rosette of leaves on the root crown. At the six- to eight-leaf growth stage, the plant develops perennating buds on the roots. At this growth stage, perennial pepperweed plants (seedlings) become perennial and are capable of vegetative reproduction. The buds on the roots and root crown are what allow the plant to regrow the next growing season. Once the roots develop buds, elimination of the plant requires killing all of the buds throughout the entire root system. Only then is regrowth from existing plants not possible.

Figures 1a and 1b. Perennial pepperweed seedlings at four to six weeks of age (1a) and a one-year-old plant (1b). The seedlings have developed a taproot but have not become perennial. The yearling plant has developed a lateral root from which a new shoot has developed. Additional buds are present throughout the root system of the yearling plant.

a

b

Each spring, existing plants develop new shoots from buds on the established root system. These shoots develop a rosette of leaves. The leaves in the rosette produce many carbohydrates, which the plant uses for further growth, largely in the form of stems (tillers) that grow upward from the rosette.

Most rosettes, particularly when growing conditions are good, develop a high density of erect stems. The tip of each stem has a terminal growing point called the apical meristem. When the primary stem(s) begin to flower the terminal growing point loses its dominance over plant growth. This permits other buds on the upper one-third of each stem to become active and develop relatively short lateral stems. These short lateral stems initially develop many leaves, but the tip usually develops a panicle of flowers, which largely resides directly above the leaves.

By the time flowering occurs, more leaves on a perennial pepperweed plant reside in the upper one-third of the plant canopy, than near the plant's base. The carbohydrates produced by these "upper leaves" largely move upward within the plant to produce flowers and the developing seed. Most of the carbohydrates used to develop and sustain the buds on the roots originate from the leaves found in the lower part of the plant. As the plant matures, the development of the upper leaves and the flowers creates a physical barrier for placement of an herbicide on the lower leaves. Placement of an herbicide on the lower leaves typically provides better movement of the chemical to the growing points in the roots, which must be killed for effective weed control to occur.

Perennial pepperweed has exceptionally high seed production, reaching values of 3,000 seeds per inflorescence and 16 billion seeds per acre. Up to 14% of the seed may remain in the seed heads into December. The retention of seed in the seed heads reduces the amount of seed lost to insects, soil pathogens, deep burial and other processes that typically reduce the number of viable seeds (of any species) on a site. High retention of seed in the seed head may improve the efficacy of using fire to destroy seeds, provided the site can be safely burned before seed dispersal. Seed longevity in the soil is believed to be short (one to two years), but no comprehensive viability studies have occurred; thus, potential longevity is not known. Seed can remain submerged for at least 12 to 18 months and be viable (**Figure 2**).

Figure 2. The lakebed of Chimney Dam Reservoir in June 2007, following drawdown for irrigation. This area had been underwater for about 18 months. The small brown clumps are perennial pepperweed seedlings that germinated after the water receded in late April. The seedlings turned brown following an herbicide treatment in early June.

Seed production is greatest when perennial pepperweed grows in moist, nonsaline soil, and declines substantially when soils remain saturated most of the growing season and/or have high salinity. Up to 95% of the seed crop is viable and nondormant, and can germinate immediately if it contacts moist soil, and if temperature conditions are adequate for germination. The highest germination rates occur when buried seed resides less than 0.4 of an inch deep and the soil is moist (i.e., 75% water-holding capacity). Almost no seedlings emerge from seed buried at least 1 inch deep. This suggests that recently flooded areas with abundant bare ground and slow-drying soil are an optimal germination and establishment site. They should be included for periodic scouting as part of an early detection, rapid-response program.

The stored energy reserves of perennial pepperweed provide several functions for the plant: 1) they keep the roots and their buds alive during long dormant periods, which can last upwards of eight months;

2) they provide the carbohydrates the plant uses to create new leaves when dormancy ends; and 3) stored energy allows the plant to regrow its leaves and stems after an intense disturbance removes the previous leaves and stems (e.g., mowing or herbivory). Once the first few leaves establish (or reestablish) the plant has enough leaf area for photosynthesis to meet the plants energy needs for additional growth and development.

The maximum translocation of carbohydrates to the roots (i.e., energy storage) typically occurs during the short period between flowering and seed production. Once seed production ends, perennial pepperweed usually becomes dormant quite rapidly. There is a rapid and large decline for the movement of carbohydrates to the root system.

Management practices that deplete energy reserves should weaken the plants, reducing growth, root biomass and seed production. Sustained treatments, for a long enough period, at a high enough frequency, can eventually kill the plant. This process, however, could take several years or more and most likely is best used in conjunction with other control methods.

Perennial pepperweed often grows in areas where the soils are seasonally saturated. Saturated soils, however, result in a dramatic decline (up to 62% after three days) in perennial pepperweed's production of carbohydrates from photosynthesis; growth slows substantially. This dramatically reduces the movement of carbohydrates to the roots, which is the primary way that herbicides move from the leaves to the buds on the roots. Mature plants that keep some leaves above the water have the ability to tolerate and survive flooding quite well but grow poorly during the high-water period. Systemic herbicides applied under these conditions are not likely to result in substantial control of the weed because there will be poor movement of the active ingredient to the buds.

CONTROL METHODS

Nonchemical Controls

Mechanical Tillage

Tillage may work for seedlings before they become perennial (six- to eight-leaf growth stage), but does not work as a stand-alone, one-time treatment for mature stands. For tillage to work, the treatment must occur every couple of weeks for two years or more. Tillage typically breaks the large but shallow roots into many small fragments. Most root segments have one to several buds capable of developing into a new plant. Tillage, therefore, creates hundreds to thousands of root segments, with each segment capable of using its stored energy to develop new plants. New plants can become perennial in as few as three to four weeks; thus, frequent tillage is needed to kill the newly emerged plants before they become perennial.

Repeated tillage eventually results in complete depletion of the energy reserves and death of all growing points. In reality, no producer has sufficient financial resources to effectively use tillage frequently, for several years, at a large scale. Also, frequent tillage is likely to adversely affect soil quality. Finally, tillage treatments typically do not affect the plant's deep roots, below the tilled depth. These roots also have many buds and a large amount of stored energy. Their deeper depth does not prevent the formation of new plants when tillage separates the deep roots from their stems and associated shallow roots. It only delays their eventual emergence. Several feet or more of root length can provide a substantial amount of stored energy for regrowth.

The success of mechanical or physical control techniques (including mowing, see next section) depend greatly upon plant age. These approaches are most successful on seedlings before they become perennial (six- to eight-leaf stage of development), and usually unsuccessful on mature plants with large established root systems. Mature plants have a large number of buds on their extensive root system and large energy reserves. This facilitates rapid regrowth following tillage, hand-pulling and other types of physical disturbance. Tillage and cultivation treatments typically increase the weed problem because they create many root fragments, each of which can become a new plant. Mechanical treatments also can move root fragments beyond the established infestation if the soil is wet and root fragments in the mud adhere to the equipment or vehicles.

Mowing

Mowing perennial pepperweed during the growing season typically stimulates established plants to develop new shoots. Treatments (e.g., fire, mowing) that remove top growth (new or old dead material), however, can improve access to the lower leaves of subsequent regrowth, which is where an herbicide should be placed to achieve the best results. In California, mowing perennial pepperweed at the bud stage of development and applying an herbicide to the regrowth at the flower-bud stage dramatically improved overall control, particularly with glyphosate. On a research plot in Nevada, mowing followed by herbicide application to the regrowth provided enhanced control (but often not much) for some, but not all herbicides. In that study, a single application of chlorsulfuron (Telar®), with or without any mowing treatment, resulted in the complete absence of perennial pepperweed in mid-July of the following growing season. Also, there were substantial increases in desired perennial grasses. Regrowth of perennial pepperweed from the 2,4-D and glyphosate treatments was common, in most treatment plots, but still less than in untreated plots.

Another approach applicable to small areas where an herbicide cannot be applied is to sequentially mow and/or till the site, and then cover it with a tarp. The mowing and tillage components effectively kill the aboveground biomass (or most of it) and the tillage breaks the shallow roots into small pieces. Each root segment can produce a new plant, but their small size limits the amount of stored energy available to support each new plant. The tarp prevents sunlight from reaching any regrowth, and the new shoots eventually deplete their stored energy reserves and die. It may take some additional time to deplete the energy reserves of the large intact roots that reside below the tillage zone. The desired residual vegetation also is likely to die (or be severely depleted); thus, the site would have to be revegetated with desired species to reduce the risk of reinfestation by either perennial pepperweed or another weed.

Fire

Fire is unlikely to be a successful stand-alone treatment for mature plants. Mature, green perennial pepperweed can be difficult to burn, and fire does not adversely affect the viability of the buds on the root system. Regrowth will occur either the year of the fire treatment, provided soil moisture is adequate, or the following year. Targeted flaming, however, can effectively control young seedlings before they become perennial.

In some situations, fire may be an appropriate tool when combined with other treatments, particularly an herbicide. Fire can remove old, decadent, dead and/or taller vegetation that would reduce the amount of an herbicide reaching the leaves of perennial pepperweed plants. Also, fire may stimulate buds on the roots to produce additional stems and leaves, potentially increasing leaf surface area, which can result in greater herbicide uptake.

Grazing

Cattle, sheep and goats will graze perennial pepperweed, particularly at the rosette growth stage. Goats generally will select a greater proportion of perennial pepperweed in their diet, than will the other livestock species. As the plants mature, coarse stems develop, and the leaves often form waxy coatings. Both conditions decrease palatability and selection, especially for cattle. Seed germination can increase substantially (15 to 17 times) following

48 to 96 hours of ruminal incubation in cattle. This suggests grazing should occur no later than the flowering stage.

Grazing typically suppresses perennial pepperweed but does not reduce its spatial extent. Once grazing stops (whether for that year or several consecutive years), perennial pepperweed tends to quickly regrow. This is due to the large amount of stored energy in the roots and large number of buds capable of producing new shoots.

An important consideration anytime a grazing animal is used to control weeds, is how the timing, duration and intensity of defoliation used to control the perennial pepperweed will affect the desired residual species that one wants to inhabit the site, post-treatment. The control of perennial pepperweed should not result in a permanent adverse effect on the desired species; otherwise, the perennial pepperweed will return to the site, or some other weed will establish on the bare ground.

Perennial pepperweed can store more energy in its roots than can most (and perhaps all) perennial grasses, and each perennial pepperweed plant typically has more buds for future growth than do perennial grasses. This physiological trait permits perennial pepperweed to withstand heavy prolonged use better than the desired perennial grasses.

Cultural Techniques

Weed management is about reducing the risk of a weed rapidly invading a site. The best management approach to reduce the risk of perennial pepperweed quickly occupying an area is to promote a dense stand of vigorous deep-rooted perennial grasses with very little bare ground. When bare ground is largely absent, there are few sites available for viable seed to inhabit and subsequently germinate. There are even fewer sites for seedlings to survive long enough to establish a root system sufficient to guarantee the plants' survival.

Tall, dense and vigorous perennial grasses with deep roots and a large root biomass will extract and use most of the resources (water, nutrients and sunlight). This condition reduces the potential for both seed germination and seedling establishment of perennial pepperweed.

Flooding is a useful management tool where water depth can be controlled for long periods. This approach appears to work best when the entire plant is submerged for at least several months, and perhaps as long as six months. The mature plants will die, but any seed in the soil appears to survive submergence for at least 12 to 18 months.

Biological Control

There are no known biological controls for perennial pepperweed.

Chemical Control

There are numerous herbicides labeled to control perennial pepperweed (**Table 1**). Most have a lengthy soil residual, which helps prevent seedlings the following growing season. A number of research studies have shown 2,4-D and glyphosate provide less long-term control than most other herbicides. These two herbicides, however, may have a very appropriate role in some situations, particularly new infestations where first year seedlings (before six- to eight-leaf stage) are the only perennial pepperweed plants present. The applied herbicide only has to move a short distance from the leaves to the root crown, not throughout the entire root system, since no buds are present at this young age (**Figure 1a**). Glyphosate has the disadvantage of being non-selective and adversely affecting desired vegetation.

Chlorsulfuron and metsulfuron have proven very effective on numerous sites in Nevada and other states, with chlorsulfuron perhaps being slightly more effective. Also, chlorsulfuron seems a little less harsh on the desired grasses and shrubs (neither are known to cause mortality to mature herbaceous plants).

The key to achieving the best potential success with any herbicide treatment is placing the herbicide on the plant's lower leaves. Placement at this location improves translocation to the buds (sites of action) on the roots (**Figures 3a-3c**). This should occur when the plant will be actively growing with high photosynthetic rates for several weeks. The long growth period after application improves the potential for moving the herbicide deep into the root system and potentially killing the most root buds.

If the treatment area has desired vegetation that needs to increase following the herbicide application, it is important to use a chemical that will not harm those plants. Herbicide selection should always consider the effectiveness of the chemical on the weed and its effects on nontarget desired species. Every infestation is unique, as are all management operations, and all tools need to be evaluated accordingly.

The movement of a foliar applied herbicide to, and then through the large root system, largely follows the movement of carbohydrates from the leaves to the rest of the plant. For perennial pepperweed, the plant typically moves more carbohydrates to the root crown and roots between the bud and late-flowering/early seed production stages of development. For a foliar herbicide treatment to be effective, however, the leaves must be actively photosynthesizing, which requires adequate soil moisture and warm temperatures. The mere presence of green leaves does not guarantee the plant is photosynthesizing and moving carbohydrates to the roots (**Figures 4a and 4b**).

Herbicide applications to green plants under either dry or saturated soil conditions typically are much less successful than when the soil is merely moist. Also, it is important to apply the chemical to the plants lower leaves, as they export the most carbohydrates to the root system. Upper leaves tend to send more carbohydrates to flower and seed production. Consult chemical labels for selection of proper spray nozzles and pressure for optimum efficacy.

It is important to have good to excellent growing conditions for a couple of weeks after an herbicide application. Research with other weed species has found that most of the herbicide that reaches a leaf surface is not absorbed by the leaf and subsequently moved to the roots, where death of the buds (growing points) must occur for successful weed control. For example, in Russian knapweed, only about 10% of the applied herbicide was absorbed into the plant, and most of that was in the first 30 minutes after application. When growing conditions are suboptimal at and shortly after herbicide application, weed control often declines substantially. Consult chemical labels for use of surfactants/adjuvants for optimum efficacy.

An important question following all herbicide treatments is, was I successful? Your level of success cannot be determined until the year after the application occurred, and probably not before the middle of that. It is always possible that an herbicide application may kill the shallow roots while leaving many deeper roots alive. It may be three or more months after the start of the growing season before new growth from those deep roots appears above the soil surface. Declaring success early in the growing season due to the absence of leaves at that time may result in the incorrect conclusion that your treatment was successful. Always revisit a treated area several times for a year after treatment occurs to fully assess its success and which follow-up procedures may be appropriate.

INTEGRATED WEED MANAGEMENT

Weeds are complex organisms, and they establish and grow across complex landscapes. Very seldom does a single type of treatment or management address this complexity. The result is that using only one treatment action, even multiple times within or across years, eventually fails, and weeds persist.

Figures 3a-3c. Figure 3a shows a perennial pepperweed infestation treated with Imazapic in late July 2005 (a wet year) shortly after peak flowering. Treatment occurred with an ATV, with the boom located below the flowers. When the boom passed through the infestation, it pulled the perennial pepperweed plants over and exposed the lower leaves to the herbicide. Figure 3c shows the same location as Figure 3a, one year after treatment. Only a few perennial pepperweed plants were present one year after treatment.

a

b

c

Figures 4a-4b. A stand of mature perennial pepperweed treated with an aerial application of metsulfuron, dicamba, and 2,4-D (Cimarron® Max) in early June 2007 (Figure 4a), and one year later (Figure 4b). The application occurred near peak flowering and during a very dry year. The result was very little control the following year. Physical protection of the lower leaves from an herbicide application located well above the flowers and poor growing conditions contributed to an unsuccessful treatment. Subsequent aerial treatments of this site when growing conditions were better resulted in much better success.

a

b

Any weed management program for perennial pepperweed (or any weed) should develop a long-term integrated management approach. An integrated management strategy uses two or more methods of weed control across a series of years, while also deploying strategies to prevent weeds from establishing in areas not infested.

Figure 5a illustrates that an integrated weed management program uses both proactive strategies and reactive approaches. Where perennial pepperweed (or any weed) is not present, management should focus on preventing its establishment. This may occur through management actions that prevent seed from being introduced on the site, controlling seed banks if viable seed has been introduced or remains after an effective treatment, or managing the crop or vegetation to competitively exclude the weed.

When weed prevention fails and one or more populations inhabit the area, the next proactive strategy is to identify all locations inhabited by the weeds, and document the scope and context of the infestation. Pairing this information with the biology of the weeds allows one to make decisions about which direct control methods to use for the specific situation being addressed. Prevention, however, should still be emphasized on areas that remain uninfested, as well as areas with successful treatments.

The best direct weed control actions are going to be infestation specific, and should identify which mechanical, cultural, biological and/or chemical approaches overlap and complement one another (**Figure 5b**). The application of multiple control methods, based on the weed's biology and ecology, that reinforce one another are likely to be more effective across a longer timeframe, than any single approach applied only once or even annually.

For perennial pepperweed, elimination of root buds is needed to reduce the population to a manageable level that permits one to meet production goals and objectives for the farm or ranch. The strategy also should include management actions that limit the spread of seed or root fragments onto the site, and that reduce the potential for seed to germinate and/or seedlings to establish should viable seed disseminate onto your property.

All treatment and management approaches, except the purposeful maintenance of bare ground, must consider how to increase, and in some cases establish (seed), a high density of desired species on the infested area. A dense, vigorous stand of desired herbaceous species provides the least risk for reinfestation of a site. For rangelands, meadows and pastures, deep-rooted perennial grasses that occupy most of the soil surface and root zone are the best option for preventing large-scale seed germination and subsequent seedling survival of perennial pepperweed and other weed species.

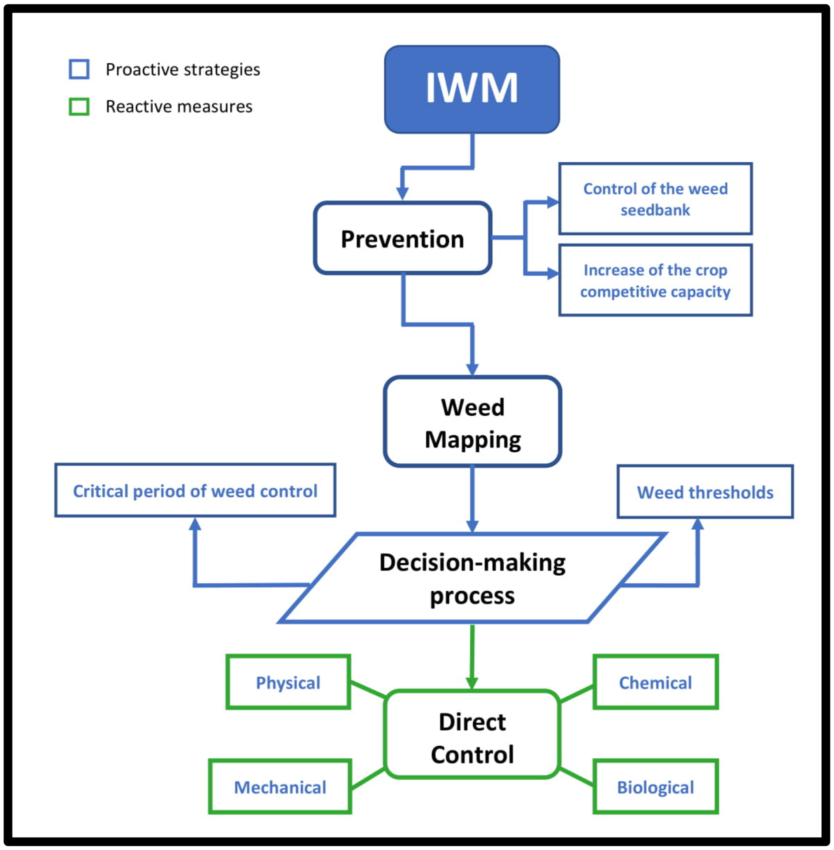

Figure 5a. Conceptual approaches to integrated weed management from prevention of new infestations or reinfestation of successfully treated areas. There are both proactive strategies to reduce the risk of infestation and reactive actions once an infestation occurs. Direct control measures should complement one another, and strengthen the effectiveness of the overall treatment program.

Diagram from Scavo and Mauromicale (2020: 3a) and Mark VanGessel (Ed: 2019 rev; 3b).

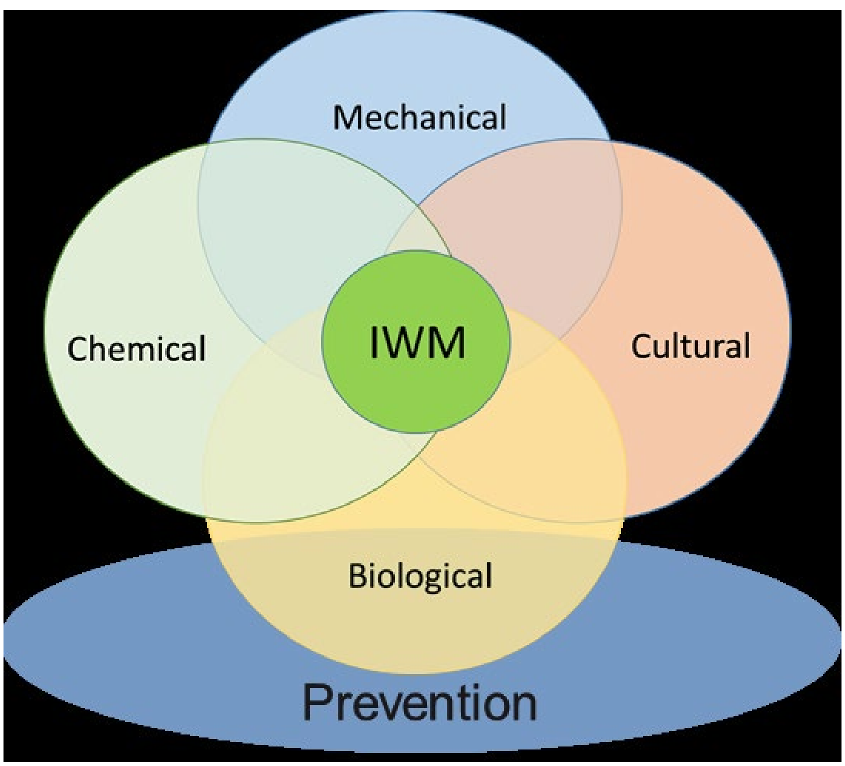

Figure 5b. Prevention is always an ongoing strategy, as there almost always are some areas that remain weed-free, and management should try to keep these areas weed-free. Prevention strategies also should occur on successfully treated areas to preclude the need for repeated direct control approaches.

Diagram from Scavo and Mauromicale (2020: 3a) and Mark VanGessel (Ed: 2019 rev; 3b).

Table 1. The list below identifies the active ingredients and many representative products known to control perennial pepperweed in the general sites or crops for which the active ingredient is labeled. The absence of an "x" in a column means no herbicide has a label for that crop or site. Use the information in this table to determine potential products for use, based upon your specific needs. Product selection should occur only after applicators have read all current product labels and identified the appropriate products for their specific situation, including potential effects to nontarget species. Many of the active ingredients listed in this table are available in premixed formulations with other active ingredients. These premixed packages (products) are not listed in this table. A complete list of all active ingredients and products labeled to control perennial pepperweed can be searched for at the Crop Data Management Systems (CDMS) websites http://www.cdms.net/LabelsMsds/LMDefault.aspx?pd=7607&t=. The order of chemicals below does not reflect any preference or efficacy. Across the spectrum of available products, some may only suppress perennial pepperweed (generally meaning, no seed production). Active ingredients and their representative products are labeled for the control of perennial pepperweed in specific settings.

Active Ingredient	Representative Products	Range and Pasture	Noncrop	Fallow	Bare Ground	Small Grains	Corn	Alfalfa	Mint	Potatoes	Selective	Soil Residual	Growth Stage
Chlorsulfuron	Telar and numerous others	x	x								Yes	Yes	Seedlings, or bud-flower to flowering stage on mature plants
Metsulfuron	Escort, Cimarron	x	x								Yes	Yes	Seedlings, or bud-flower to flowering stage on mature plants
Imazapic	Plateau and others	x	x								Yes	Yes	Seedlings, or bud-flower to later-flowering stage on mature plants
2,4-D	Many	x	x								Yes	No	Best at bud-flower to flowering stage
Glyphosate	Roundup and many others	x	x	x							No	No	Seedlings, or bud-flower to flowering stage on mature plants
Imazapyr	Habitat, Arsenal	x	x								Only at low rates	Yes	Seedlings, or bud-flower to later-flowering stage on mature plants

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Listing a commercial herbicide does not imply an endorsement by the authors, University of Nevada, Reno Extension or its personnel. Product names were used only for ease of reading, not endorsement. Herbicides should be selected for use based upon the active ingredient and the specific bio-environmental situation.