Use of 2,4-D and Other Phenoxy Herbicides Pastureland, Rangeland, Alfalfa Forage, and Invasive Weeds in the United States

Mark Renz, University of Wisconsin
Byron Sleugh, Corteva Agriscience

- Rangeland, pastureland, forests, conservation areas and other rural land make up roughly half the land area of the United States. All are ecologically important, and some have significant agricultural importance as well.
- Noxious and invasive weeds can infest these lands, at best reducing their effectiveness, at worst becoming unusable. 2,4-D is an important tool for managing many of the worst of these weeds.
- Loss of access to 2,4-D would hurt small producers and landowners, who do not have the budget or equipment for alternative herbicides.

Introduction

Approximately 51% of the total land area of the contiguous 48 states, Hawaii, Puerto Rico and the US Virgin Islands is made up of Rangeland, Pastureland, forest land, Conservation Reserve Program land, and other rural land (USDA-NRCS, 2012). These areas serve a vital role in protecting and providing ecosystem functions and are important for agricultural production and sustainability. These sites receive varying levels of management and are often infested by noxious or invasive weeds that affect agricultural production, recreation, land value, and general ecosystem services and functions. Duncan and Clarke (2005) provided a summary of the scientific literature that addresses economic, environmental, and societal losses to range and wildland by 16 key invasive species in the United States and estimated the current (2005) area covered to be approximately 126 million acres (51 million hectares). With estimated annual spreading rates ranging from 1.3-35% depending on species, it is clear that successful management requires an integrated and sustained effort with as many available tools as possible. One successful tool has been selective herbicides that will control the undesirable species and cause minimal or no response in the desirable vegetation or the wider environment.

Within some of these areas, 2,4-D has and continues to be widely used for suppression or eradication of annual, biennial, and perennial weeds, as well as invasive and noxious plants (including woody vegetation). Based on available information and consultation with academia, industry, and federal agency staff, it is estimated that between 15 and 29 million pounds of 2,4-D is used annually across these landscapes on between 16 and 28 million acres. This value is similar to the previous estimate in 1992 (21 million pounds across 23 million acres) (Bovey 1993), indicating that use has not changed significantly over the last 20 years.

Herbicide use was highest in pastures and rangelands, with an estimate of between 11 and 20 million pounds of 2,4-D applied annually. This would likely equate to between 9 and 14 million acres treated. Use is predominately for suppression of weeds that limit forage productivity and utilization. Use of 2,4-D is well associated with pastures in central, midwestern, eastern, and southern regions, and less common in the rangelands of the western US. 2,4-D is also used in alfalfa production systems. Producers use this active ingredient to help terminate old stands that will be rotated to another crop. An estimated 2 to 3 million pounds of 2,4-D is used for this purpose annually. Another 1 to 3 million pounds are annually applied for noxious and invasive weed control in natural areas/wildlands. This is a significant decrease compared to the previous estimate and is likely due to the reduction in pesticide use for noxious weed control, an adoption of other active ingredients, and more integration of weed management practices.

Elimination of 2,4-D use in the US would result in an increase in costs to current users. Producers wishing to obtain similar results with herbicides with different active ingredients would spend 2 to 4-fold more. Some producers would likely forgo treatment due to the increased costs, and this would result in increased losses of forage production and utilization in pastures and rangeland due to the presence of weeds or brush. Even though some weeds may be consumed, livestock managers need to be wary of the potential negative health impacts on grazing animals and the impact on grazing distribution and pasture utilization. “As heterogeneity of vegetation and topography increase, so does the variation in the use of the area by grazing animals” (Vallentine, 2000). Three months after herbicide application, cattle residence time in herbicide-treated pasture areas was 1.3 to 5 times greater than in areas not treated with herbicide in the same pastures (Sather et al. 2013).

Elimination of 2,4-D use in the United States would result in an increase in costs to current users. Producers wishing to obtain similar results with herbicides with different active ingredients would spend 2 to 4-fold more.

This type of preference for grazing in an area treated with a herbicide was also reported by Scifres et al. (1981), who observed an increased level of grazing in sites treated with herbicides compared to areas that were not treated. Producers would need to purchase additional feed, rent/buy more acreage, or reduce stocking rates to offset these losses in forage. While non-chemical management options are available, besides mowing and fertilization, few other treatments would likely be implemented as these require large-scale changes to infrastructure to implement (e.g., changing to rotational grazing from continuous grazing). 2,4-D use often occurs in conjunction with other active ingredients. Mixing allows producers to both reduce cost and widen the spectrum of control from application. Loss of the use of 2,4-D with other active ingredients will likely cause industry and consumers to substitute other active ingredients that are more costly.

In summary 2,4-D used alone and in combination with other active ingredients is widely utilized across pastures, rangelands, and wildlands/natural areas for noxious weed/invasive plant control. While other options are readily available to replace 2,4-D with no reductions in control, this will come at an additional expense. The added cost would likely result in less

acreage being treated by the consumer resulting in an increase in the impact from weeds/invasive plants in these areas.

2,4-D Use in Pastures/Rangeland[1]

USDA Economic Research Service's Major Land Use Data reports that over 655 million acres in the US are classified as grassland, pasture or range (USDA ERS, 2017). The majority of these acres do not receive management inputs such herbicide or fertilizer applications, or seeding of improved forage varieties. Herbicide use in pastures varies considerably depending on the type of pasture, species planted, pasture management practices, weed species present, and geographic region. Continuously grazed pastures receive treatment most often because selective grazing by animals minimizes forage growth and allows for establishment and spread of non-palatable plants (weeds). In heavily used continuously grazed pastures herbicide application can occur annually to minimize weed competition. In contrast, rotationally grazed pastures (animals moved on and off a pasture, allowing forages to regrow after grazing) are generally treated less frequently as forage competition is improved by implementing this practice. In rotationally grazed pastures, treatments typically focus on isolated spots or individual plants that are very competitive and not suppressed by the competitive forage (e.g., shrubs, Canada thistle). While both practices are found throughout the US, rotational grazing is less common. Adoption varies considerably by region however, with higher adoption in the Eastern and Midwestern US. For example, in Wisconsin, a recent survey estimated 22% of dairies utilize rotational grazing (USDA 2007).

Rangelands cover 18% of the total land area of the US. Although herbicide use is common, its frequency is much less compared to pastures. This is due to many factors that encompass this environment which is minimally managed. While both continuous and rotational grazing are implemented across rangelands, grazing practices have less impact on weed presence when compared to pastures. Unlike pastures where much of the weed control is focused on herbaceous species, the majority of target species are trees, shrubs, and other woody to semi-woody species that reduce productivity and utilization of forage species present on rangelands.

Less than 10% of pastures and rangeland in the US receive any herbicide application in any year. In consultation with industry, academia, and federal agency staff who work in this area it is estimated that between 30 and 50 million acres are treated in any one year, with most of this acreage consisting of pastures. Limited use of herbicides in these areas compared to more intensive production systems is due to a combination of factors, including lower profitability of pastures/rangelands, difficulty in treating the area (terrain, access), and competitiveness of forage species present that limits the impact of weed species.

[1] Pastures are defined as grazing lands planted to primarily forage species, that receive periodic renovation and cultural treatments such as tillage, fertilization, mowing, weed control, and irrigation, but are not in rotation with agronomic crops. Rangelands are lands that consist of primarily of native vegetation that is managed for grazing with few inputs.

Of these treated pastures and rangelands, use of 2,4-D alone has historically been high, as it was estimated that 13.6 million acres were treated with 15.2 million pounds of 2,4-D annually (Bovey 1993). Based on communication with industry and academic experts it is estimated that in 2013, 19% of pastures and rangelands were treated with 2,4-D alone (6 to 10 million acres). Others have estimated that between 10 and 15 million pounds of 2,4-D was applied annually to pastures, rangelands, and hay fields (alfalfa) between 1992 and 2009 (Stone 2013). Assuming that 1.1 lbs of 2,4-D/acre was applied per treatment, this would provide similar acreage as the estimate we provide, when subtracting use in alfalfa (2-3 million lbs, see alfalfa section below). The decline in the use of 2,4-D alone is likely due to the increase in the use of products that mix 2,4-D with other active ingredients. Based on consultation with industry, academia, and federal agency staff, we estimate that the use of these premixed products (e.g., GrazonNext HL®, Weedmaster®) that contain 2,4-D to be between 5 and 9 million acres. Assuming that 0.75 lbs of 2,4-D /acre is added in the pre-mixed product this would result in an additional 3.8 to 7.5 million pounds of 2,4-D applied to the landscape. Combining these two uses (2,4-D alone and pre-mixed with other active ingredients) results in an estimated annual use between 12 and 20 million pounds of 2,4-D across 11 to 19 million acres.. These results are similar and potentially higher than previous estimates by Bovey (1993).

While use of 2,4-D is similar or higher than estimates from two decades ago (1992), it appears more producers are using pre-mixtures that contain another active ingredient in addition to 2,4-D. These premixes are popular because acceptable control is usually observed across a wider range of weed species at a reduced cost. While the active ingredients tank-mixed with 2,4-D often are more effective at controlling troublesome weed species at lower rates compared to 2,4-D alone (e.g., aminopyralid), these active ingredients typically cost substantially more than 2,4-D (typically 2-4 times more expensive) and the combination of active ingredients expands the spectrum of broadleaf weed species control.

To improve weed control across multiple broadleaf weeds companies have developed and continue to develop products and/or recommendations that add 2,4-D with other herbicide active ingredients (e.g., GrazonNext HL®, Crossbow®, Grazon P+D®, Weedmaster®). This often results in 1) a less expensive product applied that 2) has equivalent to greater control of the target species and 3) manages a wider spectrum of broadleaf weed species present.

Reliance on 2,4-D either alone or premixed with another active ingredient is still high as it is the most widely used active ingredient on pastures and rangeland in the US

Industry expects this trend of using premixes to persist over the next decade in the large operations (personal communication Corteva Agriscience, Agriculture Division of DowDuPont). In contrast to large operations, smaller pasture or rangeland owners rely heavily on 2,4-D for weed management. This is likely due to the lower cost of 2,4-D, easy access to 2,4-D at retail locations or limited access to other products from their suppliers, and sometimes a lack of training/certification required to buy or apply some premixed products. In summary, the reliance on 2,4-D either alone or premixed with another active ingredient is still high as it is the most widely used active ingredient on pastures and rangelands in the US.

2,4-D Use in Grazed Areas in Forests

127 million acres of forested area is estimated to be grazed (5% total land area). Management practices in these forests are similar to those described above in the pasture and rangeland sections.

Impact of Weeds in Pastures, Rangelands, and Noxious/Invasive Weeds

Weeds can impact the productivity, quality, and utilization of forage in pastures and rangelands, but the magnitude of these losses varies tremendously throughout the US. Bovey (1993) has previously summarized losses from weeds in rangelands and pastures. Below is an update on this assessment, primarily focusing on pastures. Impacts from noxious weeds/invasive plants are more difficult to quantify as economic impacts of most species are poorly documented (Duncan et al. 2004). Specifically, the lack of research that quantifies ecosystem impacts and challenges associated with assessing nonmarket factors make it difficult to assign a monetary value (Evans 2003).

Impact from Weeds in Pastures

As previously summarized by Bovey (1993), competitive weed species can reduce desirable forage yield in pastures. Recently, a study estimated that Canada thistle's presence in a pasture causes 0.8 pounds of desirable forage to be lost for each pound of thistle biomass present per acre (Grekul and Bork 2004). Given that Canada thistle biomass can exceed 1 ton/A in pastures, losses can be substantial (Gurda 2014). Similar to previous studies, herbicide treatments can effectively control weed species, as studies in Missouri and Kentucky found herbicide treatments reduced weed biomass for months to > one year (Sather et al. 2013, Tolson et al. 2012, Enloe et al. 2007). Herbicides are typically more effective than other common treatments such as mowing and fertilization. Tolson et al. (2012) reported that herbicide treatments applied exclusively or in combination with mowing or fertilizer application resulted in the greatest forage biomass in their studies.

While desirable forage yield is increased by herbicides, total forage production that includes weed biomass is typically reduced by herbicide treatment. This has been shown in several studies unless weed populations are very low (<10%) (e.g., Sather et al. 2013, Tolson et al.2012). Thus, to accurately determine the impact from weed species, utilization of the total forage (weeds + desirable forage) needs to be evaluated. Several studies have documented reductions in forage use by grazing animals from weeds, and found that large spiny weeds can reduce forage use by between 42 and 72% (De Bruijn and Bork 2006, Seefelt et al. 2005). However, Seefelt et al. (2005) found that not all weeds reduce grazing, and others have found that by altering grazing practices, use of weeds can be improved (De Bruijn and Bork 2006, Gurda 2014). Thus, while differences in use from weeds can be observed in pastures, these differences are specific to the pasture species composition and grazing practices.

Weeds can also impact forage quality. While weeds are generally considered to have low forage quality, values can vary depending on the weed species and stage of growth when it is eaten (Abaye et al. 1989). For instance, Canada thistle has high nutritive value, particularly in the earlier stages of growth, and can be seen as a productive contribution to forage if used when vegetative (Marten et al. 1987,De Bruijn and Bork 2006). The nutritive value of some weeds has been shown to be comparable to commonly used forage crops (Marten and Andersen, 1975; Ball et al., 2007). For example, some members of the *Amaranthus* genus have forage nutritive value that is equal to or better than commonly used forages. However nitrate poisoning is a concern, especially if harvested or grazed early (Sleugh et al., 2001). Even though weeds may be consumed, livestock managers need to be wary of the potential negative impacts on grazing animals. However, pasture grazing practices can dramatically influence the potential to use these weeds as forage. A study in Wisconsin found Canada thistle was used - on average - 42% as a forage when undergoing rotational grazing, but mob grazing or high stocking rates increased use to an average of 65% across three pastures over two years (Gurda 2014). In contrast, continuously grazed pastures have less productivity and use (Oates et al. 2011). Weed infestations can also alter livestock distribution and potentially grazing behavior. As previously mentioned, cattle distribution was 1.3-5 times greater in sections of pastures where weeds were removed with herbicide (Sather et al. 2013) compared to sections where weeds were not removed. In summary, weeds can negatively affect pastures, but the amount of impact varies dramatically based on the region, grazing management practices employed, and forage and weed species present.

Impacts if 2,4-D was Not Available for Pastures and Rangelands

Large and small pastures and rangeland producers would be economically impacted if 2,4-D was no longer available.

Alternative active ingredients exist – and are currently registered for pastures and rangelands – that are effective at controlling common and problematic weed species found throughout the US. Despite this, large and small pastures and rangeland producers would be economically impacted if 2,4-D were no longer available. Large operations would likely still treat considerable acres using products that contain other active ingredients for weed control (e.g., aminopyralid, dicamba, metsulfuron, clopyralid, picloram, fluroxypyr). These producers have the experience and the skillset to use these products (some products have specific restrictions that need to be followed or require certification to purchase or apply). While these products would, in most cases, provide similar or greater control of the target species, the cost of these herbicides is substantially higher than 2,4-D alone (2-4 times greater). Producers would also need to decide if they will mix other active ingredients (e.g., triclopyr, dicamba) to obtain broad spectrum control, or accept the reduced weed spectrum. In either case, an increase in cost of operation will occur - producers would need to purchase herbicides at a higher cost per acre or use products that do not provide broad spectrum control of all broadleaf weeds, resulting in the need for more feed or forage, reducing the number of livestock in their operation, or acquiring more land. Some producers may also decide to treat less acreage annually due to the increased costs, which would result in a similar impact (need more feed/reduce livestock numbers). The economic impacts of not

treating these areas annually may also result in increased costs in the future to manage weed populations as extensive weed infestations that are well established often cost substantially more to manage and are adept at propagating themselves.

Some small acreage land owners are not as experienced and have less access to these other active ingredients previously mentioned. Due to this, the increase herbicide cost and low margins on which many of these land owners operate, it is much more likely that these owners will treat substantially less acres if 2,4-D was not available. This will result in an increase in their cost of production as intake from weedy pastures will be reduced, requiring owners to purchase more feed/forage or lower stocking rates.

Due to the many factors associated with pasture/rangeland production (production of land, forage species present, weed species present, alternative management methods selected, costs for feed, value of animal product produced) and the fact that several of these factors (e.g., cost of feed, value of animal product) can vary dramatically from year to year, it is challenging to derive even an estimate of losses from production.

2,4-D Use in Alfalfa

2,4-D is used in alfalfa production systems. There are approximately 50-55 million acres of alfalfa in the US (2.8% total land area of 48 contiguous states) every year. Use of 2,4-D, however, is not during the production phase of this crop, but in the termination of old stands when producers rotate to a different crop.

Alfalfa stand life can vary between 4 and 10 years across the US. Many farmers terminate the stand by tillage. However, many producers have switched to reduced or no-till systems over the past several decades, and these production systems are more reliant on herbicides for alfalfa stand termination. While alternative active ingredients are available to terminate a stand, 2,4-D is the most commonly used due to its low cost, short soil residual activity, ability to tank mix with other herbicides, effectiveness on alfalfa and other winter annual weeds present, and for glyphosate resistant weed management. Based on stand life, percent of farmers that use herbicides to terminate stands, and a use rate of 0.5-1.0 lbs/acre, it is estimated that between 2 and 3 million pounds of 2,4-D is used for this purpose annually. Producers can use other active ingredients already registered for alfalfa termination (e.g., dicamba, clopyralid) (Renz 2012), so the loss of 2,4-D would have minimal impact on production practices. However, the loss would increase cost of alfalfa termination between $5-15/acre.

2,4-D Use in Wildland/Natural Areas for Noxious/Invasive Plant Control

Rural parks and wilderness areas contribute 11% of the total land area (250 million acres) with other lands classified as miscellaneous uses (industrial areas, rural infrastructure, greenspaces, and unclassified natural areas) making up an additional 10% of land area (230 million acres) in the US. The Bureau of Land Management (BLM), US Forest Service (USFS), US Fish and Wildlife Service (USFWS), and National Park Service (NPS) own the majority of this

land. These and other groups manage noxious and invasive plants to remain in compliance with federal, state, or local law and to minimize impacts of invasive plants to the economy, environment and/or human health. Despite the large area, use of 2,4-D is limited in these areas. USFS estimated use of 2,4-D in 2004 for noxious weed control was 20,000 lbs (USDA 2004), while BLM used 39,506 pounds in 2012 across all land types (Personal communication R. Lee 2014). Although these are only two land owners, their acreage managed is >50% of the total acreage in this category. State and local agencies likely use more 2,4-D, and while Bovey (1993) estimated that 7 million acres were treated with 2,4-D in 1992, current use is likely substantially less. Based on communication with industry and academic experts, it is estimated that between 3 and 5 million acres are treated with 2,4-D for noxious weed/invasive plant control, with between 1 and 4 million pounds applied annually to these areas. The reduction in use compared to the previous report is likely due to the increase in availability of other active ingredients with improved effectiveness on target species in conjunction with the increase in targeted management of select areas, versus annual applications over large areas (e.g., roadsides). State and local staff responsible for treating noxious weeds/invasive plants are likely using other products or 2,4-D as a tank mixture to decrease cost of applications for noxious weeds, similar to pastures and rangeland areas. Therefore, when mixtures are used, application rates of 2,4-D are substantially less (0.25-0.75 lbs/A) compared when to when 2,4-D is used exclusively (1.0-2.0 lbs/A).

Loss of 2,4-D for noxious weed/invasive plant control would result in similar impacts as in pasture and rangeland areas. While increased cost would impact the ability to treat as much acreage, this impact would be much less than pastures and rangelands. This is due to the shift in management approaches for noxious weeds/invasive plants. Historically, large areas were annually treated with 2,4-D to control populations. Now most applications are to newly establishing populations that are potential sources for long-term spread. By using early detection and rapid response, the major expense for agency staff for managing noxious weeds/invasive plants is personnel, and not herbicide. Thus the impact from higher costs of a herbicide currently is not as detrimental as previously highlighted by Bovey (1993).

Summary

2,4-D use is still common across all three areas discussed in this chapter. While overall amount or acreage of 2,4-D applied did not dramatically change since 1992, the use pattern appears to be shifting. 2,4-D use alone is decreasing, but its use as a tank mix partner is increasing. While substantial acreage in pastures and rangelands are still treated only with 2,4-D (19% treated acres), nearly as many acres (18% treated acres) are treated with premixed products that include 2,4-D as a tank mixture. In contrast, the majority of 2,4-D is applied as a tank mixture in alfalfa and for noxious weed/invasive plant control. The low cost compared to other products and wide spectrum of broadleaf weed control are the major reasons that this herbicide is so widely used in these areas. Alternative products are available, effective and registered for use in these areas; however, these products are more expensive and will result in additional expenses to the consumer. Nonchemical alternatives are also available, but have been documented in most cases to be less effective and more costly than 2,4-D.

Nonchemical alternatives are also available, but have been documented in most cases to be less effective and more costly than 2,4-D. Thus 2,4-D continues to play an important role in weed, noxious weed, invasive plant management in pastures, rangelands, alfalfa termination and natural/wildland areas.

Thus 2,4-D continues to play an important role in weed, noxious weed, and invasive plant management in pastures, rangelands, alfalfa termination and natural/wildland areas.

LITERATURE CITED

Abaye, A.O., G. Scaglia, C. Teutsch. 1989. The Nutritive Value of Common Pasture Weeds and Their Relation to Livestock Nutrient Requirements. Blacksburg, VA: Virginia Polytechnic Institute and State University. Publication 418-150. 9p.

Ball, D.M., C.S. Hoveland, and G.D. Lacefield. 2007. Southern forages, modern concept for forage crop management. *IPIN: Norcross*

Bovey, R.W. 1993. 2,4-D Taskforce II: Chapter 5. Use of 2,4-D and other Phenoxy Herbicides on Pastureland, Rangeland, Alfalfa Forage, and Noxious Weeds in the United States. http://www.24d.org/abstracts/chapter5.pdf. Accessed: April 13, 2015

De Bruijn, S.L, and E.W. Bork. 2006. Biological control of Canada thistle in temperate pastures using high density rotational cattle grazing. Biological Control 36:305-15.

Duncan, C.L., J.J. Jachetta, M.L. Brown, V.F. Carrithers, J.K. Clark, J.M. DiTomaso, R.G. Lym, K.C., McDaniel, M.J. Renz, P.M. Rice. 2004. Assessing the economic, environmental and societal losses from invasive plants on rangeland and wildlands. Weed Technology 18:1411-16.

Celestine L. Duncan and Janet K. Clark. 2005. Invasive Plants of Range and Wildlands and Their Environmental, Economic, and Societal Impacts. Weeds Science Society of America.

Enloe, S.F., R.G. Lym, R. Wilson, P. Westra, S. Nissen, G. Beck, G. Moechnig, G. Peterson, R.A. Masters, M. Halstvedt. 2007. Canada thistle (Cirsium Arvense) control with Aminopyralid in range, pasture, and noncrop areas. Weed Technology 21: 890-4.

Evans, E.A. 2003. Economic Dimensions of Invasive Species. CHOICES. http://www.choicesmagazine.org/archives/2003/q2/2003-2-02.htm . Accessed: April 13, 2015.

Grekul, C.W., E.W. Bork. 2004. Herbage yield losses in perennial pasture due to Canada thistle (Cirsium arvense). Weed Technology 18:784-94.

Gurda, A. 2014. Mob Grazing, from People to Pastures: Weed Biology, Pasture Productivity and Farmer Perception and Adoption. MS Thesis. Madison, WI: University of Wisconsin-Madison. 65 p.

Marten, G.C. and R.N. Andersen. 1975. Forage nutritive value and palatability of 12 common weeds. Crop Sci. 15:821-827.

Marten, G.C., C.C. Sheaffer, D.L. Wyse. 1987. Forage Nutritive-Value and Palatability of

Perennial Weeds. Agronomy Journal 79:980-6.

Oates, L.G., D.J. Undersander, C. Gratton, M.M. Bell, R.D. Jackson. 2011. Management-Intensive Rotational Grazing Enhances Forage Production and Quality of Subhumid Cool-Season Pastures. Crop Science 51:892-901.

Renz, M.J. 2012. Removal of RR Alfalfa in No-Till Systems. Pages 86-87 in Proceedings from the 2012 Wisconsin Crop Management Conference. Madison, WI.

Sather, B.C., R.L. Kallenbach, W.J. Sexten, K.W. Bradley. 2013. Evaluation of Cattle Grazing Distribution in Response to Weed and Legume Removal in Mixed Tall Fescue (Schedonorus phoenix) and Legume Pastures. Weed Technology 27: 101-7.

Scifres, C.J., J.R. Scifres, and M.M. Kothman. 1983. Differential grazing use of herbicide-treated areas by cattle. J. of Range Management 36: 65-69

Seefeldt, S.S., J.M.C. Stephens, M.L. Verkaaik, A. Rahman. 2005. Quantifying the Impact of a Weed in a Perennial Ryegrass-White Clover Pasture. Weed Science: 53:113-20

Sleugh, B.B., K.J. Moore, E.C. Brummer, A.D. Knapp, J. Russell, and L. Gibson. 2001. Forage nutritive value of various amaranth species at different harvest dates. *Crop Science*, *41*(2), pp.466-472.

Stone, W.W. 2013. Estimated annual agricultural pesticide use for counties of the conterminous United States, 1992-2009: Washington, DC: US Geological Survey Data Series 752.

Tolson, J.A., J.D. Green, W.W. Witt, G.J. Schwab, J.A. Omielan. 2012. Integrated Management Strategies Reduced Tall Ironweed (Vernonia altissima) Populations and Weed Biomass and Improved Tall Fescue Pasture Productivity. Weed Science 60:106-12.

[USDA] US Department of Agriculture Forest Service. 2004. National Report of Pesticide Use on National Forest System Lands Fiscal Year 2004. http://www.fs.fed.us/foresthealth/pesticide/docs/2004pesticideuse_report.doc. Accessed April 13, 2015.

US Department of Agriculture National Agricultural Statistics Service. 2007. Census of Agriculture. http://www.nass.usda.gov/Statistics_by_State/Wisconsin/index.asp . Accessed: April 13, 2015.

US Department of Agriculture Economic Research Service. 2012. Major Land Uses - Grassland pasture and range (non-cropland and non-forest), by region and States, United States, 1945-2012. https://www.ers.usda.gov/webdocs/DataFiles/52096/pasture_and_range_19452012_by_state.xls?v=0. Accessed: August 28, 2018.

Vallentine, J.F. 2000. Grazing Management. Elsevier Science. ISBN 9780080532592

Mark Renz is an Associate Professor/ Extension Weed Specialist at the University of Wisconsin. His research interests include weed management in alfalfa and pastures. He is also involved in the development of control methods for invasive plants in natural areas and assists in development of early detection and rapid response networks in the Great Lakes region.

Byron Sleugh is a Senior Research Scientist at Corteva Agriscience, Agriculture Division of DowDuPont. His experience spans academia and industry in teaching, research and farmer/rancher/land manager educational activities related to pasture/rangeland management, forage production, quality and utilization as well as the management of weeds and brush in pastures and rangeland and other non-crop sites.