# A MAYWEED CHAMOMILE GROWING DEGREE DAY MODEL FOR THE INLAND PACIFIC NORTHWEST

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## Abstract

Mayweed chamomile (*Anthemis cotula* L.) is a problematic weed in agronomic production systems in the inland Pacific Northwest (iPNW), primarily in higher rainfall zones. Emerging issues that impact successful management of mayweed chamomile are herbicide resistance and the possibility of increased range expansion resulting from warmer and wetter springs and summers due to climate change. For this reason, growers need a resource that identifies the critical window for mayweed chamomile management in varied environments and crop production systems to mitigate current and future infestations. Therefore, a mayweed chamomile specific growing degree day model has been developed for the pulse and grain production regions of the iPNW and integrates mayweed chamomile growth stage, cumulative growing degree days, seed set, and herbicide application.

## Introduction

Mayweed chamomile (*Anthemis cotula* L.) is an invasive weed and significant crop pest in the cereal and pulse production systems located in high rainfall zones of the iPNW. Also known as dogfennel, mayweed chamomile is primarily found in regions where annual precipitation exceeds 18 inches (Gealy et al. 1994). Climate prediction models for the iPNW suggest the likelihood of increased summer annual temperatures accompanied by increased spring precipitation, both of which are favorable conditions for mayweed chamomile establishment, survival, and range expansion. Mayweed chamomile impacts crops directly through competition for resources during the growing season and indirectly through prolific seed production, persistence in the seed bank, variable seed germination and emergence in the fall and spring, and genetic diversity through outcrossing. Mayweed chamomile has also evolved resistance to commonly used herbicides including the ALS-inhibiting herbicides chlorsulfuron, imazethapyr, thifensulfuron, tribenuron, and chloransulam (Lyon et al. 2017). Effective management of mayweed chamomile requires a standard metric for identifying critical growth stages, from emergence through seed set, for timing of management inputs like herbicide applications and timing of likely growth stages during the growing season.

Phyllochron, the time that elapses between the emergence of new leaves on the main stem of a plant, is associated with cumulative growing degree days (GDD), or thermal time (Bonhomme 2000).

Likewise, GDD are closely associated with plant development stage and routinely used to estimate crop development, predict harvest date, and to determine herbicide application timing. However, unlike crops, which are bred for developmental uniformity, weeds, including mayweed chamomile, display a high degree of developmental variability and do not necessarily respond to GDD in the same way as the crops that they are growing alongside of. For this reason, effective management of mayweed chamomile requires a mayweed chamomile-specific GDD model.

A new developmental prediction tool based on mayweed chamomile plant development accurately predicts vegetative and reproductive growth stages, flowering time, and mature seed set in regions across the iPNW.

## Mayweed Chamomile Growth Stage Classification

Seedling emergence and developmental parameters including number of leaves, plant height, flowering, seed development, and seed set were measured and photographed twice a week from growth chambers and field locations at the Washington State University Cook Agricultural Research Farm in Pullman, WA in 2013 and 2015. Mayweed chamomile developmental stages were designated based on those previously described for sunflower according to Schneiter and Miller (1981). Vegetative stages (V) occur before primary inflorescence formation and include: emergence (VE), appearance of first true leaves (V1), secondary true leaves from rosette and seedlings less than an inch (in) tall (V2), and vertical growth and branching (V3). Reproductive stages (R) occur from primary bud formation through mature seed set and include: primary bud formation (R1), primary bud opening and the presence of immature disk flowers, for example, small yellow flowers that cover the center of the head (R2), disk flower maturation and the presence of immature ray flowers, for example, white flowers around the outside margin of the head (R3.1), elongation of ray flowers on primary buds and secondary bud opening (R3.2), maturation of ray flowers (R3.3), pollen grain formation on disk flowers (R3.4), disk flowers become cone shaped (R3.5), drying down or senescence of ray flowers (R3.6), and mature dry seed (R4). Images and description of mayweed chamomile vegetative and reproductive stages are detailed in Figure 1 and Table 1.

Table 1. Mayweed chamomile growth stages adopted from sunflower (Schneiter and Miller 1981, reprinted in 2013). Designations of “V” and “R” indicated vegetative and reproductive stages.

| Developmental Stage | Description |
|---|---|
| **VE** | Cotyledon emergence |
| **V1** | Appearance of true leaves |
| **V2** | Rosette formation; seedlings less than an inch tall |
| **V3** | Vertical plant growth and branching |
| **R1** | Primary bud formation |
| **R2** | Primary bud opening; immature disk flowers are visible |
| **R3.1** | Development of immature ray flowers; mature disk flowers |
| **R3.2** | Elongation of ray flowers on the primary bud; secondary buds open |
| **R3.3** | Mature ray flowers |
| **R3.4** | Pollen grain formation on disk flowers |
| **R3.5** | Disk flowers become cone shaped; initiation of senescence |
| **R3.6** | Ray flowers dry down |
| **R4** | Mature dry seed |

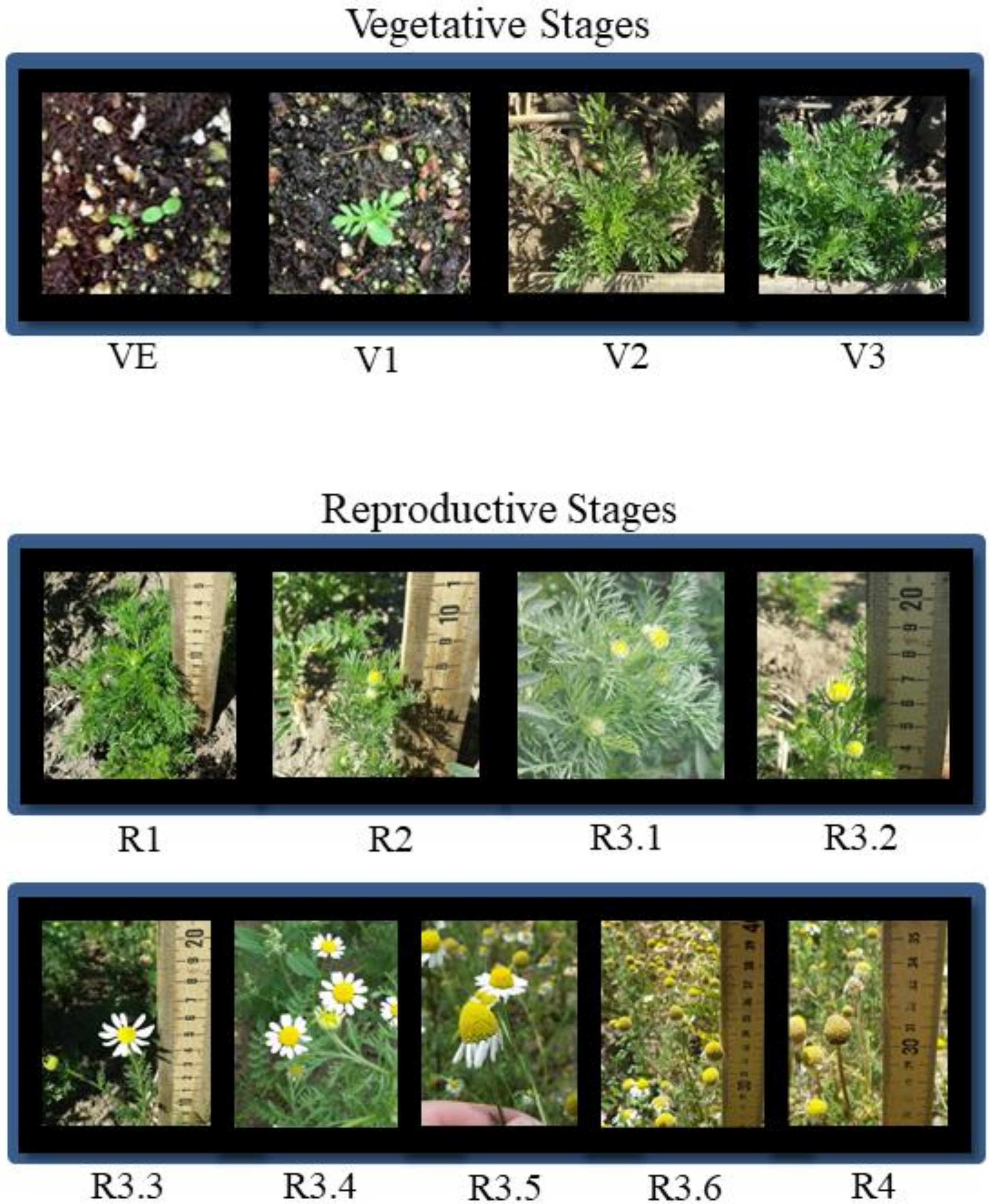


Figure 1. Images of four vegetative and nine reproductive developmental growth stages of mayweed chamomile adopted from sunflower (Schneiter and Miller 1981, reprinted May 2013).

## Predicting Mayweed Chamomile Development with a GDD Model

A mayweed chamomile growing degree day model (Table 2) was developed using the formula GDD = daily maximum temperature [C] + daily minimum temperature [C])/2, with a base temperature of 39°F (4°C) (Ball et al. 2004). GDD were calculated using daily maximum and minimum air temperature data acquired from the Cook Farm weather station in 2013 and 2015 beginning from January 1 (Washington State University AgweatherNet; weather.wsu.edu) (Ball et al. 2004). Cumulative GDD were compared across years in spring wheat and chickpea trials beginning with emergence (VE), capturing the transition between the final stage of vegetative growth (V3) and the first stages of reproductive growth; also included in GDD were flower bud formation (R1 and R2), proceeding through pollen grain formation (R3.4), and ending at the initiation of senescence (R3.5) (Table 1). In 2015, mayweed chamomile spring emergence and the progression through to senescence occurred earlier in spring wheat than in garbanzo beans, and earlier than mayweed chamomile populations in spring wheat from 2013. Emergence (VE), the transition from vegetative to reproductive growth (V3 through R1), pollen grain formation (R3.4), and the beginning of senescence (R3.5) occurred within the ranges of 165 to 540 GDD, 421 to 801 GDD, 801 to 1206 GDD, and 828 to 1321 GDD respectively (Table 2). Local field conditions, moisture availability, existing mayweed seed banks, and crop competition are likely to have contributed to variability across plots, trials, and field seasons.

Table 2. Mayweed chamomile cumulative GDD (base temperature 39°F [4°C]) and developmental stages at Washington State University Cook farm field in 2013 and 2015.

| Spring Wheat 2013 | | | Spring Wheat 2015 | | | Chickpea 2015 | | |
|---|---|---|---|---|---|---|---|---|
| **Date** | **Cumulative [a]GDD** | **DS** | **Date** | **Cumulative GDD** | **DS** | **Date** | **Cumulative GDD** | **DS** |
| May 2 | 165 | VE | April 28 | 288 | VE | May 26 | 540 | VE |
| May 10 | 265 | V1 | May 3 | 334 | V1 | May 31 | 609 | V1 |
| May 15 | 320 | V2 | May 9 | 474 | V2 | June 6 | 676 | V2 |
| May 31 | 421 | V3 | May 14 | 419 | V3 | June 12 | 773 | V3 |
| June 15 | 574 | R1 | May 20 | 474 | R1 | June 15 | 801 | R1 |
| June 30 | 747 | R2 | May 26 | 540 | R2 | June 17 | 828 | R2 |
| [1]- | - | R3.1 | June 6 | 676 | R3.1 | June 22 | 915 | R3.1 |
| - | - | R3.2 | June 12 | 773 | R3.2 | June 24 | 949 | R3.2 |
| - | - | R3.3 | June 14 | 789 | R3.3 | July 1 | 1092 | R3.3 |
| - | - | R3.4 | June 15 | 801 | R3.4 | July 9 | 1206 | R3.4 |
| - | - | R3.5 | June 17 | 828 | R3.5 | July 13 | 1321 | R3.5 |
| - | - | R3.6 | - | - | R3.6 | July 16 | 1405 | R3.6 |
| - | - | R4 | - | - | R4 | July 21 | 1433 | R4 |

[a]Abbreviations; GDD: growing degree days; DS: developmental stage.

[1]An (-) indicates no measurement was recorded.

Mayweed chamomile developmental stages that are most responsive to herbicide applications are highlighted in grey.

## Mayweed Chamomile Development Varies Across Production Zone and GDD

Mayweed seed germination is very sensitive to moisture availability. Regional and geographical expansions are thought to be tightly regulated by annual precipitation and stored soil moisture (Gealy et al. 1985). To explore the possibility of regional expansion of mayweed chamomile into varied rainfall zones and to validate our GDD model, developmental parameters were assessed across a north-to-south transect of Washington and Idaho, capturing field locations with average annual precipitation ranges of 12 to 26 inches a year. Northern field sites were: Green Bluff A, Site 1; Green Bluff B, Site 2; Spokane Valley, Site 3; and Coeur D'Alene, Site 4; with average annual precipitation ranges of 22 to 26 inches. Southern field sites were: Walla Walla, Site 5; Waitsburg, Site 6; and Leland, Site 7; with average annual precipitation ranges of 12 to 16 inches. Results were compared to the data from the Cook Farm Research Station from 2015, which receives average annual precipitation rates of 16 to 18 inches per year (Figure 2; weather.wsu.edu). The north-to-south transect study was important for determining if there is an association between accumulation of GDD and the progression of plant growth stage regardless of environmental variability. In other words, we would expect that most plants at locations with more accumulated GDD to be further along in development than those with fewer GDD. Sites 1 through 4 were visited on June 30, 2015, sites 5 and 6 were visited on July 2, 2015, and site 7 was visited on July 8, 2015 (Figure 2 and Figure 3).

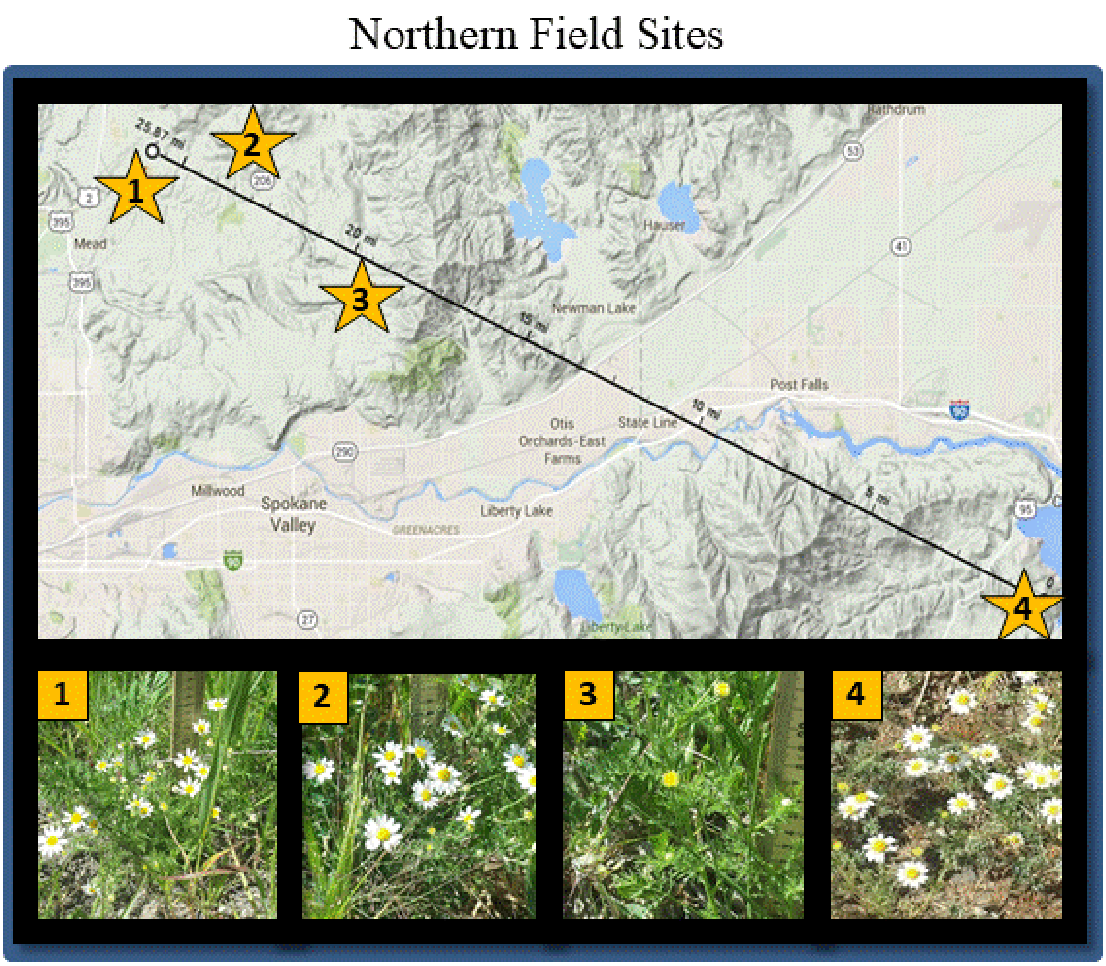


Figure 2. Mayweed Chamomile development was rated at four northern field locations in eastern Washington and Idaho to assess GDD accumulation on plant development. Orange stars indicate specific field locations: (1) Greenbluff, WA, 1; (2) Greenbluff, WA, 2; (3) Spokane Valley, WA; (4) Coeur d' Alene, ID. Ratings occurred on June 30, 2015 and accumulated GDD for all four locations was 1175. The developmental stage at Sites 1 and 2 was R3.3, whereas developmental stages ranged from R3.2 to R3.3 at Site 3, and from R3.3 to R3.4 at Site 4. Images: Kyle Race.

Developmental variation consistent with what was observed at the Cook Farm field trials occurred across northern or southern site locations. However, despite observed variation, the association between accumulated GDD and plant development was clear. Accumulated GDD for sites 1 through 4 was 1175 on June 30, 2015 and developmental stages ranged from R3.3 (mature ray flower formation) to R3.4 (pollen formation). On July 1, 2015, the accumulated GDD at Cook Farm were 1098 with a corresponding developmental stage of R3.3 (mature ray flower formation). On July 2, 2015, the accumulated GDD at southern sites 5 and 6 ranged from 1520 to 1570, and were accompanied by more advanced stages of mayweed chamomile plant development with stages between R3.5 (initiation of senescence) and R4 (mature dry seed). With fewer accumulated GDD, overall plant development at Cook Farm progressed more slowly than those at the northern field sites 1 through 4, and the southern field sites 5 and 6. Mayweed chamomile plant development at southern site 7 was the slowest to progress compared to all other sites. On July 8, 2015, accumulated GDD for site 7 were 1024, with developmental stages ranging between R3.1 (formation of immature ray flowers; mature disk flower formation) and R3.2 (elongation of ray flowers on the primary bud; secondary bud opening). In contrast, on July 9, 2015, the accumulated GDD for Cook Farm were 1205, and mayweed chamomile plant development was at R3.4 (pollen grain formation). North-to-south transect comparisons demonstrate that while mayweed chamomile development varies from site to site, earlier developmental stages occurred with fewer accumulated GDD, and later stages of developmental occurred with more accumulated GDD. Thus, GDD appears to be a good predictor of mayweed chamomile plant developmental stage across the region.

Southern Field Sites

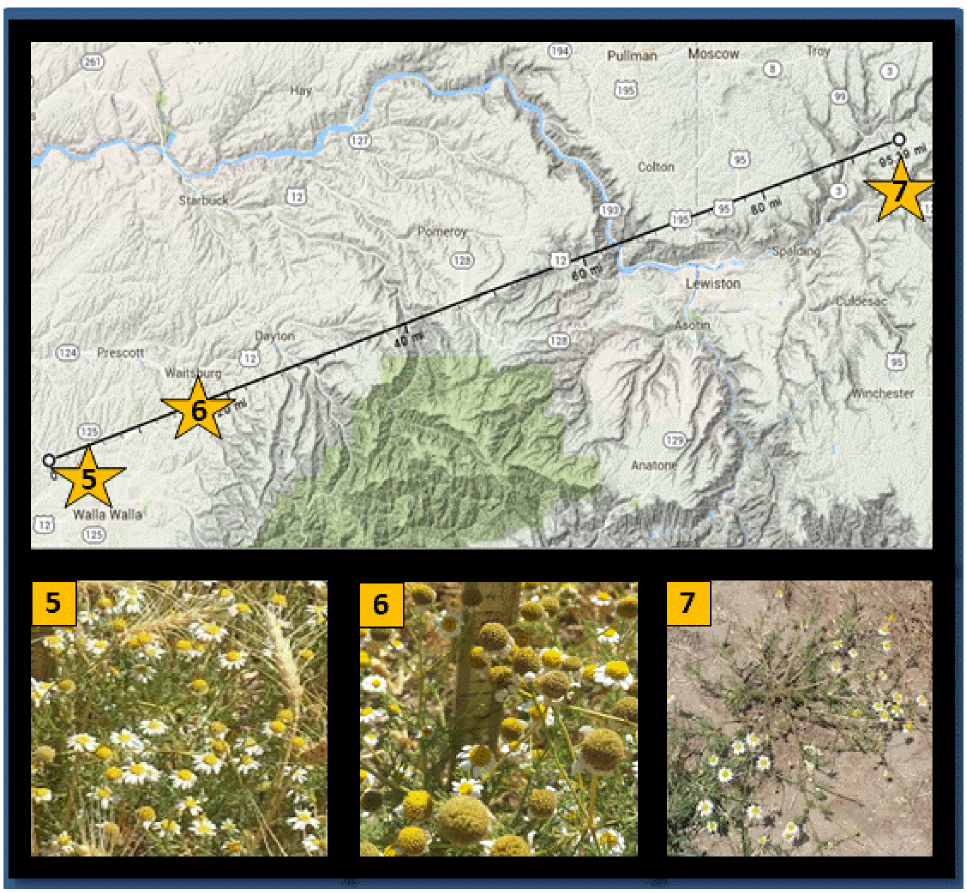


Figure 3. Mayweed chamomile development was rated at three southern field locations in eastern Washington and Idaho to assess GDD on plant development. Orange stars indicate specific field locations: (5) Walla Walla, WA; (6) Waitsburg, WA; (7) Leland, ID. Sites 5 and 6 were measured on July 8, 2016. Accumulated GDD were 1570, 1520, and 1024 for Sites 5, 6, and 7, respectively. Developmental stages ranged from R3.5 to R4 at Sites 5 and 6, and R3.1 to R3.2 at Site 7. Images: Kyle Race.

## Regional Management Implications

Integrated weed management systems for mayweed chamomile management should incorporate plant developmental stages and explanations for how these stages are associated with GDD. Ideally, herbicide applications should be timed to prevent new seed dispersal while minimizing injury risk to crops. The timing for postemergence herbicide applications for mayweed chamomile management is based on both the size of the weed and the crop, and applications should never fall outside of the labeled timing for the crop (Figure 4) (Lyon et al. 2017). With the aforementioned considerations in mind, the best time to treat mayweed chamomile is just after emergence starting between V1 and V2 stages (402 to 490 GDD) through to stage R3.1 (800 GDD). Comparisons across field locations north and south of the Cook Farm field site in Pullman, WA indicate that the growth stage is strongly correlated to an increase in GDD, and the critical mayweed chamomile management window typically occurs from May through the end of June (Figure 4). Although growth parameters vary to some degree from year to year, and between mayweed populations, likely due to genetic diversity and environmental factors (temperature and moisture availability), the mayweed-specific GDD model developed for the iPNW will be a useful tool implementing selective management regimes.

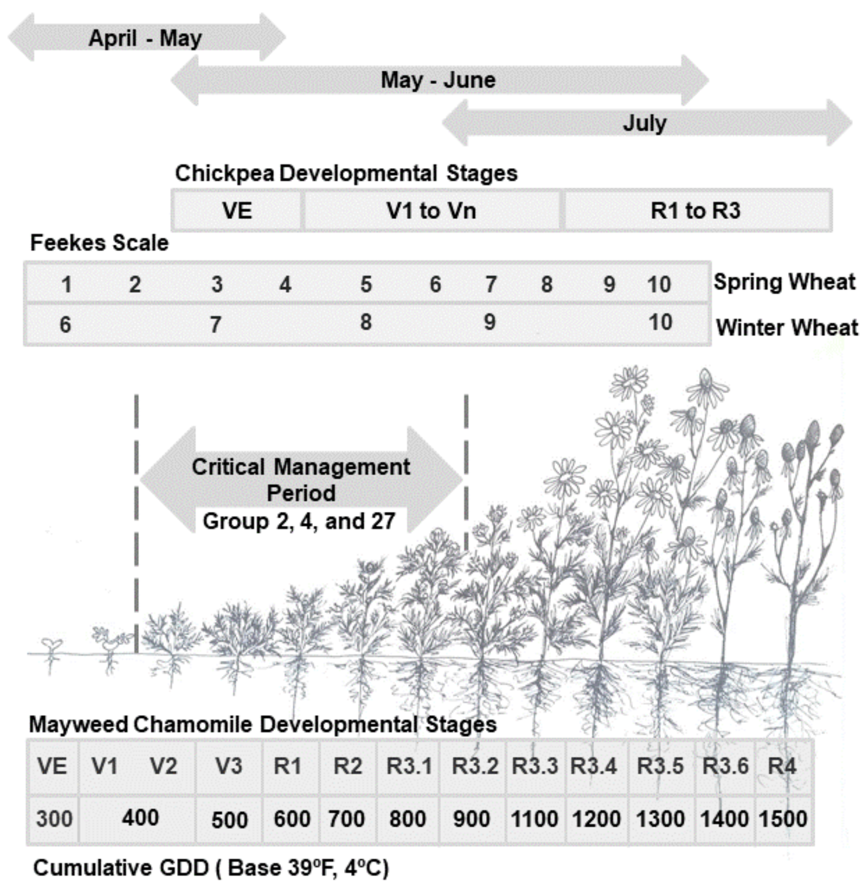


Figure 4. The critical management period for mayweed chamomile occurs between stages V1 and R3.1 (GDD 400 and 800), prior to flowering when seedlings are small and rapidly growing, and according to post-emergent application recommendations for Group 2,4, and 27 herbicides (Lyon et al. 2017). The corresponding developmental stages of spring and winter wheat (Feekes units), and chickpea (VE; emergence, V1 to Vn; unfolding of the first through last multifoliate leaves, and R1 to R3; formation of the first flower to early pod formation (Meicenheimer and Muehlbauer 1982; Gan et al. 2006) are included as a way to compare mayweed chamomile development and management with cereals and pulses. Artist rendering of mayweed chamomile developmental stages courtesy of Lindsay Koby.

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