



Legume Cover in Orchard Drive Alleys

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ABSTRACT

Orchardists in Washington State are interested in finding an alternative source of nitrogen to off-set the need for commercial fertilizer, which can be expensive, difficult to transport and apply, and may cause reductions in soil pH and fruit quality. Previous studies suggest legumes grown as drive alley cover may be able to supply up to 50% of the nitrogen requirements of an orchard, however a more extensive evaluation of legume species and varieties was necessary. An assessment of 25 different legumes was conducted in three apple orchards in the Yakima River Valley in south-central Washington. Legumes were planted in 100 ft long plots in drive alleys at each site and evaluated two to four times per year for three years. Measurements taken include percent establishment, percent cover, plant height, percent biomass nitrogen, and biomass and nitrogen production. An economic analysis was also conducted to determine the value of the nitrogen contribution in both organic and conventional orchards. Alfalfa varieties had higher percent cover (50 to 100%), more biomass (2,500 to 4,500 DM lb/ac/yr) and biomass nitrogen production (80 to 180 lb N/ac/yr) than the clover and other legume species. Alfalfa biomass nitrogen was significantly higher than clover biomass nitrogen in three out of four site x year combinations. Economic analysis showed after three years of production in an organic orchard, the alfalfa varieties, some white clover varieties, and 'Dominion' red clover had the potential to compensate for their establishment costs with the value of nitrogen they produced. Some alfalfa varieties also compensated for establishment costs in a conventional orchard.

INTRODUCTION

Organic and conventional orchardists in Washington rely on external sources of nitrogen, which can be expensive, labor intensive and sometimes result in lower soil pH or increased salinity and reduced fruit quality (Stamatiadis et al., 1999; Hoagland et al., 2008). Legumes grown in orchard drive alleys may provide a more sustainable, less expensive, on-farm source of nitrogen. In a previous study, a 4 foot wide legume strip in the drive alley was able to supply approximately 50% of the nitrogen required by the orchard, and increased levels of plant-available nitrogen were detected in the tree row following "mow and blow" management (Davenport and Granatstein, 2010). Four legumes were evaluated in that study; they include: kura clover (*Trifolium ambiguum* M. Bieb), 'Ladino' white clover (*Trifolium repens* L.), birdsfoot trefoil (*Lotus corniculatus* L.), and alfalfa (*Medicago sativa* L.). A more extensive screening of legumes was needed to determine the ideal species and cultivars that have the potential to supply nitrogen. The objective of this trial was to evaluate a broad spectrum of legume species and cultivars for their ability to thrive in an orchard environment and provide a significant nitrogen contribution.

MATERIALS AND METHODS

STUDY SITES, SEEDBED PREPARATION AND SEEDING METHODS

We planted this study at three orchards with various ages and architecture to evaluate the legumes in different environments. All study sites were located within the Yakima River Valley in south-central Washington, which is at approximately 1,100 feet elevation and receives an average of 9 inches of precipitation per year. Temperatures can range from near 0°F in the winter to over 100°F in the summer. Average yearly precipitation, average temperatures and extreme temperatures during the years of this study are listed in Table 1. Growing degree days (GDD) per growing season are listed in Table 2. (Data source: AgWeatherNet, 2015).

Table 1. Weather data from Washington State University AgWeatherNet station near Grandview, WA, 1 Sept 2012 – 31 Aug 2015.

Crop Year (1 Sept - 31 Aug)	Precipitation (in)	Air Temperature			
		Ave Daily High (°F)	Ave Daily Low (°F)	Extreme High (°F)	Extreme Low (°F)
2012 - 2013	8.37	64.7	40.7	101.5	16.2
2013 - 2014	4.5	64	39.6	103.9	2.3
2014 - 2015	6.08	67.2	42.2	105.6	9.6

Table 2. Growing degree day (GDD) data from Washington State University AgWeatherNet station near Grandview, WA, 2013 – 2015.

Growing Season (1 Apr - 31 Oct)	GDD (base 40°F)
2013	4794
2014	5078
2015	5237

Orchard Descriptions

Site 1) Orchard T, Grandview, WA

A new 'Gala'/M.9 apple orchard in a V-trellis system established in 2012 with conventional methods. The orchard has 12' between tree rows and a 3' in-row tree spacing. A 4' wide vegetation-free strip was maintained in the tree row with herbicide applications (during establishment) and cultivation. The predominant soil types are Warden silt loam and Warden fine sandy loam. Micro-sprinklers were used for orchard establishment, and the orchard was converted to drip irrigation in 2013. Micro-sprinklers were still used occasionally to irrigate the drive-row vegetation, as were overhead cooling sprinklers in 2014 and 2015. The seedbed was prepared by rototilling. All legume plots were seeded on September 11, 2012 with a 5' Brillion® broadcast seeder (Landoll Corporation, Marysville, KS). The seedbed had no weeds and the ideal amount of loose soil for covering the seed. The orchard was converted to organic management in 2013.

Site 2) Orchard A, Prosser, WA

A mature organic 'Golden Delicious' apple orchard on Esquatzal silt loam soil irrigated with micro-sprinklers. The orchard has 14' between tree rows and 7' in-row tree spacing. A 3' wide vegetation free strip was periodically created in the tree row with cultivation. The orchard had a previous drive alley cover of grass and white Dutch clover. To prepare the seedbed, drive alley vegetation was rototilled. Plots were roller packed with two passes, and were seeded with a 7' Aitchison Grassfarmer® tine drill (SimTech-Aitchison, Suffolk, UK) with 6" spacing. All plots were seeded on September 12, 2012. The seedbed was moist and uneven (Figure 1). The orchard succumbed to an outbreak of fire blight in 2013, and all trees were heavily pruned to prevent disease spread.

Site 3) Orchard B, Zillah, WA

A new organic almond orchard established in 2011 on Warden silt loam soil irrigated with overhead sprinklers. The orchard had 14' between tree rows and 10' in-row spacing, and had a previous drive alley cover of grass and white Dutch clover. Little in-row weed control was performed. To prepare the seedbed, drive alley vegetation was rotovated two times. Plots were roller packed two times, and were seeded with a 7' Aitchison Grassfarmer® tine drill (SimTech-Aitchison, Suffolk, UK) with 6" spacing. All plots were seeded on September 13, 2012. The seedbed was moist and uneven. We collected establishment data in 2012 and percent cover and biomass data in 2013. In 2014, the orchard was sold to a new owner who discontinued the study.



Figure 1. Seedbed before planting at Orchard A, September 2012.

LEGUME SELECTION AND SEEDING

We selected legumes for this study based on their commercial availability, their potential to withstand traffic and frequent mowing, and their ability to tolerate shade. We obtained multiple varieties of white clovers and alfalfas, which are species considered to have high performance potential, having been bred for intensive grazing systems or hay production. Below are brief descriptions of the legumes

we evaluated (Description sources: Ogle et al., 2012; USDA PLANTS, 2015 and the seed supplier websites). Species with no variety are listed as Variety Not Specified (VNS) which is a term used for “common” seed. Table 3, below, lists the criteria for determining seeding rates. Table 4 lists the average seeds per pound of the legumes and mixes and the Pure Live Seed (PLS) seeding rates in the study.

Perennials

1. **VNS white Dutch clover** (*Trifolium repens* L.) is a standard, medium-leaf clover commonly planted with grasses in orchard drive alleys and pastures. It is drought and shade tolerant, competitive with grasses and weeds, and requires little maintenance.
2. **‘Jumbo Ladino’ white clover** (*Trifolium repens* L.) is a fast growing, vigorous perennial white clover characterized by its large leaf size. It grows well with perennial ryegrass, orchard grass and tall fescue.
3. **‘Alice’ white clover** (*Trifolium repens* L.) has large leaves and vigorous tall growth. It is very winter hardy and performs well under grazing management. It grows well with perennial ryegrass, orchardgrass and tall fescue.
4. **‘Kopu II’ white clover** (*Trifolium repens* L.) was bred for stolon density, persistence under grazing, high yield and large leaf size (3” diameter). Parent stock was selected from plants in cattle grazing systems in the northern U.S. and sheep grazing systems in New Zealand. It performs well in mixtures with orchard grass, perennial ryegrass and tall fescue.
5. **VNS birdsfoot trefoil** (*Lotus corniculatus* L.) is a moderately long-lived legume grown for hay, pasture and wildlife plantings.
6. **‘Antelope’ white prairie clover** (*Dalea candida* Michx. Ex Willd.) is a tested class release from North Dakota and Montana. It is native to the northern Great Plains, and grows in small clumps 2 to 3 feet tall.
7. **‘Dominion’ red clover** (*Trifolium pretense* L.) is medium-leaf red clover selected for grazing and animal trampling tolerance after two years of intensive cattle grazing in the southeastern U.S. It is grown throughout the northeastern U.S. and some areas in the Pacific Northwest for forage production and soil improvement.
8. **‘Lutana’ cicer milkvetch** (*Astragalus cicer* L.) is a long-lived legume that spreads by creeping roots and rhizomes. It rapidly regrows after being grazed, however it regrows more slowly after cutting for hay.
9. **‘FSG229CR’ creeping alfalfa** (*Medicago sativa* L.) is a rhizomatous alfalfa selected for resistance to multiple diseases. It is very winter-hardy and is intended for hay and pasture in the North Central, Great Plains and East Central areas of the U.S.
10. **VNS falcata alfalfa** (*Medicago sativa* ssp. *falcata* (L.) Arcang) is a drought-tolerant, yellow-flowered alfalfa that produces higher yields than standard alfalfas in dryland areas with low rainfall.

11. **'Upper Edge' alfalfa** (*Medicago sativa* L.) is a standard alfalfa selected for resistance to multiple diseases and high feed value. It is intended for hay and pasture in the North Central, East Central, Great Plains, and Intermountain areas of the U.S.
12. **'Maxigraze GT' alfalfa** (*Medicago sativa* L.) is a standard alfalfa developed for grazing and hay production.
13. **'Vernema' alfalfa** (*Medicago sativa* L.) is an older variety of alfalfa known for its winter-hardiness, disease and nematode resistance, and high palatability, protein content, and production.
14. **'Perfect' alfalfa** (*Medicago sativa* L.) is a standard alfalfa developed to produce high quality forage and increased yields. It is extra leafy, very winter hardy and has excellent disease resistance.
15. **'Artisan II' alfalfa** (*Medicago sativa* L.) is a standard alfalfa developed for grazing and hay production.
16. **VNS kura clover** (*Trifolium ambiguum* M. Bieb.) is a slow-to-establish but long-lived, hardy clover that has shown potential for orchard drive alley cover in previous studies.
17. **'Delaney' sainfoin** (*Onobrychis viciiflora* Scop.) is a legume grown alone or in mixes for hay and pasture. Early season cuttings often yield higher than alfalfa, but lower in later season.

Annuals

1. **VNS crimson clover** (*Trifolium incarnatum* L.) is a red-flowered winter annual clover grown for pasture, hay, silage mixes, pollinator habitat, soil protection or green manure.
2. **VNS subterranean clover** (*Trifolium subterraneum* L.) is a low-growing annual clover that flowers and produces seed underground. It provides good cover but does not produce large amounts of biomass.
3. **VNS hairy vetch** (*Vicia villosa* Roth) is a trailing or climbing, cool season biennial or annual legume with a shallow root system that produces large amounts of biomass.
4. **'Lana' woollypod vetch** (*Vicia villosa* ssp. *varia* (Host) Corb.) is a trailing and climbing cool season legume. It matures two weeks earlier than other vetches.
5. **VNS Austrian winter pea** (*Pisum sativum* L.) is a winter-hardy pea often planted as an over-wintering cover crop or green manure.

Table 3. Seeding rates used in this study based on the number of seeds per pound.

Seeds/lb	PLS/sq ft
> 500,000	100
100,000 - 500,000	50
10,000 - 100,000	30
<10,000	10

Table 4. Perennial and annual legumes evaluated, with average seeds per pound and Pure Live Seed (PLS) seeding rate used in the study. Species with VNS are Variety Not Specified, also known as common seed. All legumes were evaluated in all orchards except the entries with a particular orchard listed.

Perennials	Seeds/lb	Pure Live Seed (PLS) lb/ac Seeding Rate
VNS white Dutch clover	712,000	6
'Jumbo Ladino' white clover	712,000	6
'Alice' white clover	712,000	6
'Kopu II' white clover	712,000	6
VNS birdsfoot trefoil	375,000	6
'Antelope' white prairie clover	278,000	8
'Artisan II' alfalfa + white Dutch clover (Orchard T)	456,000	5
'Perfect' alfalfa + white Dutch clover (Orchards A and B)	456,000	5
'Dominion' red clover	272,000	8
'Lutana' cicer milkvetch	130,000	17
'FSG229CR' creeping alfalfa	200,000	11
VNS falcata alfalfa	200,000	11
'Upper Edge' alfalfa (Tudor)	200,000	11
'Maxigraze GT' alfalfa (Tudor)	200,000	11
'Vernema' alfalfa	200,000	11
'Perfect' alfalfa	200,000	11
'Artisan II' alfalfa + kura clover (Orchard T)	176,000	12
'Vernema' alfalfa + kura clover (Orchards A and B)	176,000	12
VNS kura clover	152,000	14
'Delaney' sainfoin	30,000	44
Annuals		
VNS crimson clover	150,000	15
VNS subterranean clover	54,000	24
VNS hairy vetch	16,300	80
'Lana' woolypod vetch	11,360	115
VNS Austrian winter pea	3,800	115

We planted 100' foot long plots of legumes in the drive alleys of each orchard. The seed of 'Artisan II' alfalfa, 'Upper Edge' alfalfa and 'Maxigraze GT' alfalfa was treated with fungicide, so we did not plant these varieties at Orchards A and B because they were certified organic. At these orchards we substituted the untreated alfalfa varieties 'Perfect' and 'Vernema' in mixes. We calibrated the drills on-site for each entry and removed seed from the drill with a vacuum before planting the next plot (Figure 2). We adjusted the depth of the tine drill as necessary, with a depth of 0.25" for small-seeded species to 1.5" for large-seeded species. Most of the clover and alfalfa seed was pre-inoculated. We inoculated the remainder of the seed the day before planting with a slurry method and the appropriate *Rhizobium* bacteria. The inoculum we used for birdsfoot trefoil was past its expiration date, and we used a general "garden" inoculum for sainfoin and cicer milkvetch.



Figure 2. Vacuuming seed out of the Aitchison tine drill between legume plantings at Orchard A, September 2012.

LEGUME MANAGEMENT

Mowing drive alley vegetation is necessary in orchard floor management to provide access for pruning, spraying, harvesting and other operations. Timing of mowing in this study was planned to occur as soon as possible after sampling to accurately assess total biomass produced during the growing season. However in 2013, Orchards B and T mowed on April 15 and May 1, respectively, prior to our first data sampling, and Orchard A mowed in early July, prior to our second data sampling. The remaining mowing operations in 2014 and 2015 occurred soon after data collection.

In addition, alterations in irrigation water management caused reductions in potential legume growth at Orchard A in 2014 and Orchards A and T in 2015. In 2015 Orchard A mowed their drive alley cover after data collection in mid-July through the remainder of the growing season to reduce water use and Orchard T mowed their drive alley cover late June through the end of August.

ESTABLISHMENT

We evaluated establishment 6 weeks after planting by using techniques appropriate for each planting method. At Orchard T, where the plots were broadcast seeded, we placed a 1 sq yd subplot frame at 25', 50' and 75' into each plot and estimated percent seedling cover, then averaged the three subplots. At Orchards A and B, where the plots were seeded within a tine drill, we placed a 1 sq yd subplot frame at 25', 50' and 75' into each plot and estimated percent seedling cover within each of the five drill rows in the frame, then averaged the subplots.

CANOPY COVER

We evaluated percent cover before each biomass sampling. We used a point-intercept method, in which we stretched a 100 ft cable with 2 ft tape marks diagonally across the length of the plot and recorded the vegetation type below each point. Vegetation types included: planted legume, grass, weed, bare ground, residue, and previously-planted legume.

PLANT CANOPY HEIGHT

At the time of biomass sampling, we measured canopy height at three representative points in the plot, then averaged the heights.

PLANT GROWTH STAGE, NITROGEN FIXATION, INSECT DAMAGE AND RODENT DAMAGE

At the same time as measuring height, we noted flowering stage, and any visible damage to the plants caused by insects or rodents. We also examined legume roots for presence of nodules and cut into the nodules to determine active nitrogen fixation (indicated by red or pink tissue).

BIOMASS PRODUCTION

In 2013, we selected three representative areas within each plot and cut all of the plant material in a 5.4 ft² frame to a 2 inch height to mimic mowing. We weighed the biomass separately in bags and averaged the values for pounds per acre calculations. We combined the biomass and obtained a 0.5 lb composite sample for drying. In 2014 and 2015, we selected one 40 ft² representative area within each plot and cut the plant material with a modified Black and Decker hedge trimmer (Stanley Black and Decker, New Britain, CT) (Figure 3) or a Swift forage harvester (Swift Machine and Welding, Ltd., Swift Current, SK) (Figure 4) to a 2 inch height. We weighed and mixed the sample then obtained a 0.5 lb composite sample for drying. In all years, we weighed the composite samples in the field then dried them in a lab drying oven for 4 days at 55°C. We re-weighed the samples to calculate percent dry matter (DM) and dry matter biomass production. We calculated DM biomass per acre with the following equation: wet biomass (lb/ac) x % DM x 50% (orchard floor covered by legume).



Figure 3. Harvesting alfalfa biomass with a modified hedge trimmer at Orchard T near Grandview, WA, May 2014.



Figure 4. Harvesting legume biomass with the Swift forage harvester at Orchard T near Grandview, WA, September 2015.

PERCENT NITROGEN

We determined biomass percent nitrogen by grinding the dried composite samples with a Wiley mill (Thomas Scientific, Swedesboro, NJ) and processing the material with a LECO® dry combustion analyzer (LECO Corporation, St. Joseph, MO).

NITROGEN PRODUCTION

We calculated biomass nitrogen per acre with the following equation: Wet biomass (lb/ac) x % DM x 50% (orchard floor covered by legume) x % N.

To determine if nitrogen production of alfalfa varieties was significantly higher than clover varieties, we used the varieties as replications, and ran an Analysis of Variance (AOV) on the site x year x legume interaction. The interaction was significant, so we conducted a LSD All-Pairwise-Comparison test.

ECONOMIC ANALYSIS

We developed a partial budget economic analysis to estimate cost of planting each legume and compared it with the estimated value of the nitrogen delivered to the tree row. Legume establishment costs were based on: seedbed preparation (tractor + rotovator), \$25.93/ac (Wahl et al., 2014); seeding (tractor + drill), \$13.77/ac (Siegel et al., 2010); seed cost (price per pound from 2015 catalogs, and seeding rate used in the study). An average value was calculated for the alfalfas and the white clovers. Value of legume nitrogen contribution was estimated by multiplying the three year total biomass N contribution per treatment by 40% to estimate plant-available N provided (Mullinix and Granatstein, 2011). We then multiplied this value by either \$0.65 per pound for urea fertilizer (conventional, price as of November 2015), or \$2.00 per pound for chicken manure compost (organic, price as of November 2015).

RESULTS AND DISCUSSION

Data were collected over three full growing seasons. Biomass results from 2013 were for an establishment year and some stands may have not reached peak production. Drought in 2015 led to changes in management in response to water interruptions that reduced legume production for the season. Data from 2014 represent the most typical growing season of the three years, with three mowing operations at Orchard A and four mowing operations at Orchard T. Detailed tables and figures are included in the Appendix, and are denoted by an “A” before the number when mentioned in this section.

ESTABLISHMENT

Annuals

The vetch varieties had the best initial establishment among annual legumes at all three orchards, with 86 to 93% establishment for ‘Lana’ woollypod vetch (Figure 5) and 68 to 81% establishment for VNS hairy vetch. VNS crimson clover had good establishment (71 to 72%) at Orchards T and A, but poor establishment (27%) at Orchard B (Figure 6).



Figure 5. 'Lana' woolypod vetch establishment at Orchard T near Grandview, WA, in October 2012, six weeks after planting.

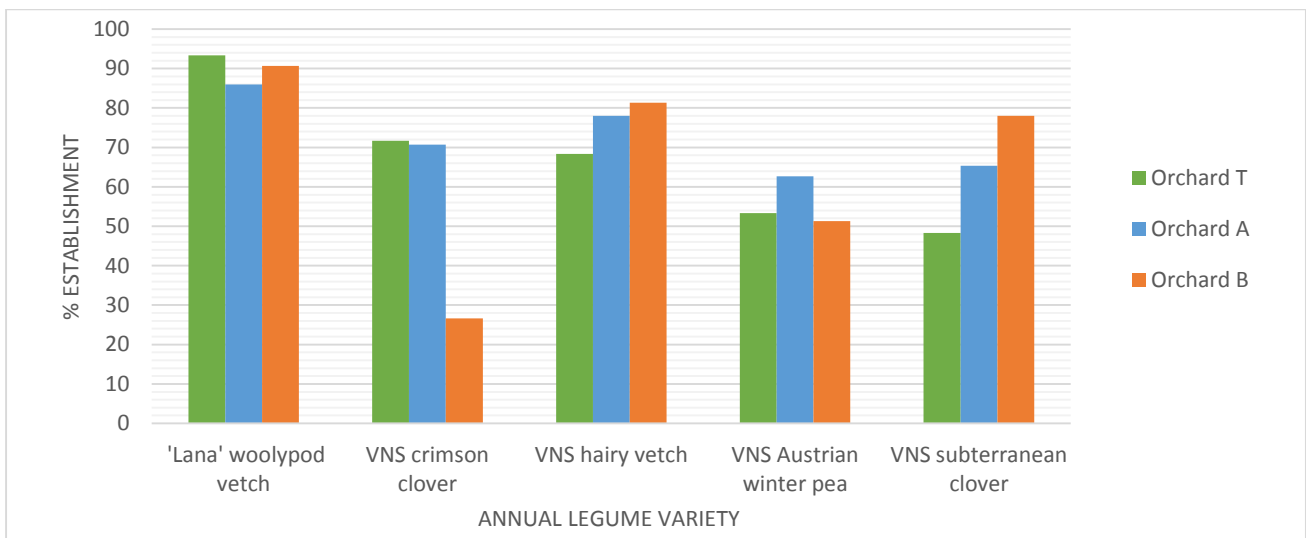


Figure 6. Percent establishment of annual legumes 6 weeks after planting, 31 October 2012 at Orchard T near Grandview, WA; Orchard A near Prosser, WA; and Orchard B near Zillah, WA.

Alfalfas

Most of the alfalfa varieties had over 50% establishment at all orchards, except 'Vernema' which had 25% or less establishment at all orchards (Figure 7).

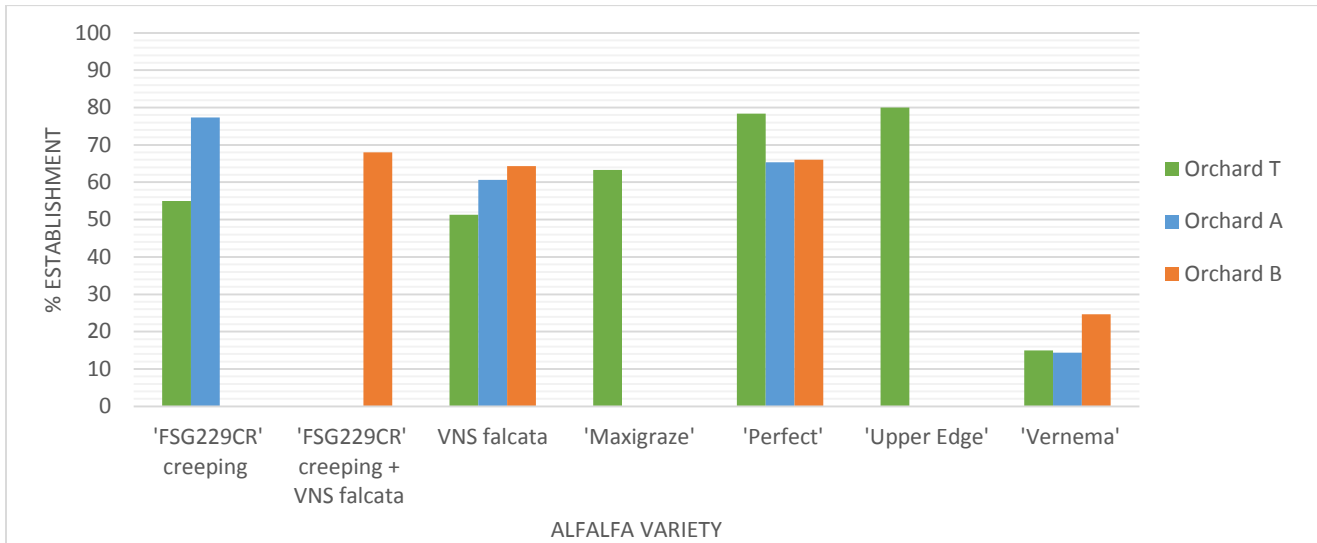


Figure 7. Percent establishment of alfalfa varieties 6 weeks after planting, 31 October 2012 at Orchard T near Grandview, WA; Orchard A near Prosser, WA; and Orchard B near Zillah, WA.

Clovers

At Orchard T, establishment and growth of clovers was spotty due to uneven micro-sprinkler irrigation patterns. Clover establishment at Orchard T was only measured in areas receiving irrigation. In these areas, establishment of all varieties was high (over 73%) except for kura clover, which had 23% establishment at Orchard T (Figure 8). At Orchards A and B, clover establishment was variable, with 'Kopu II' white clover and 'Dominion' red clover having the most reliable establishment. Kura clover also established poorly at Orchards A and B.

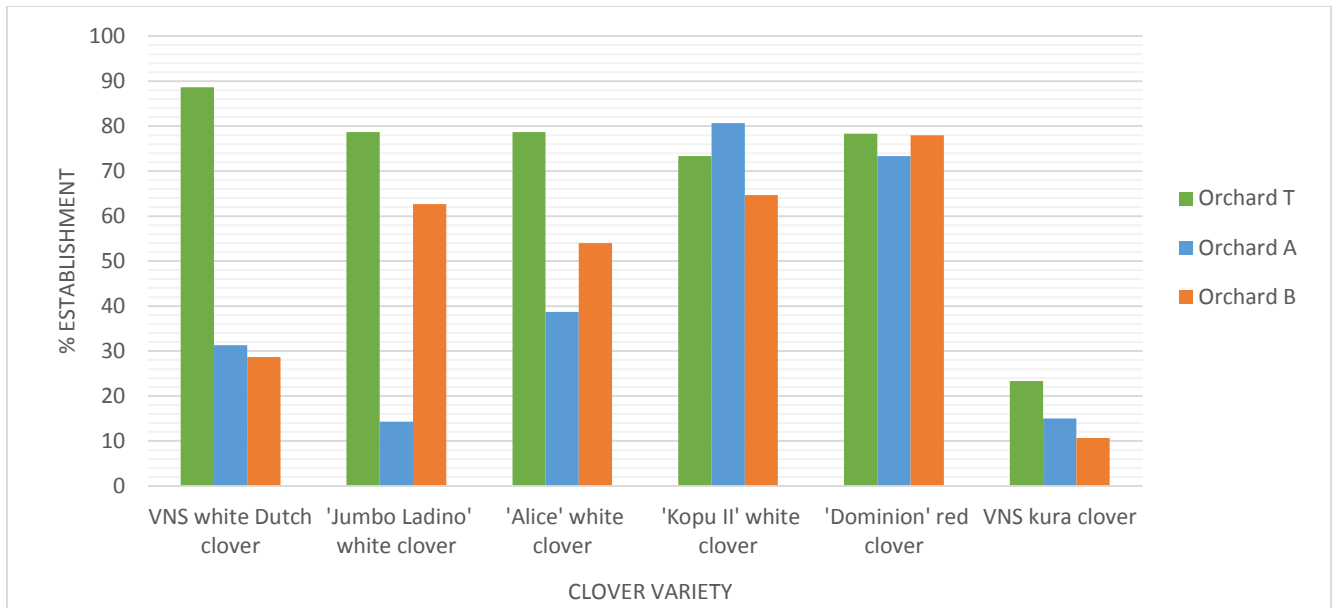


Figure 8. Percent establishment of clover varieties 6 weeks after planting, 31 October 2012 at Orchard T near Grandview, WA; Orchard A near Prosser, WA; and Orchard B near Zillah, WA.

Other Legumes

Most of the other legumes and mixes exhibited poor establishment at all Orchards. Varieties or mixes with over 50% establishment six weeks after planting were 'Delaney' sainfoin and 'Artisan II' alfalfa + VNS white Dutch clover at Orchard T, and 'Perfect' alfalfa + white Dutch clover at Orchards A and B (Figure 9).

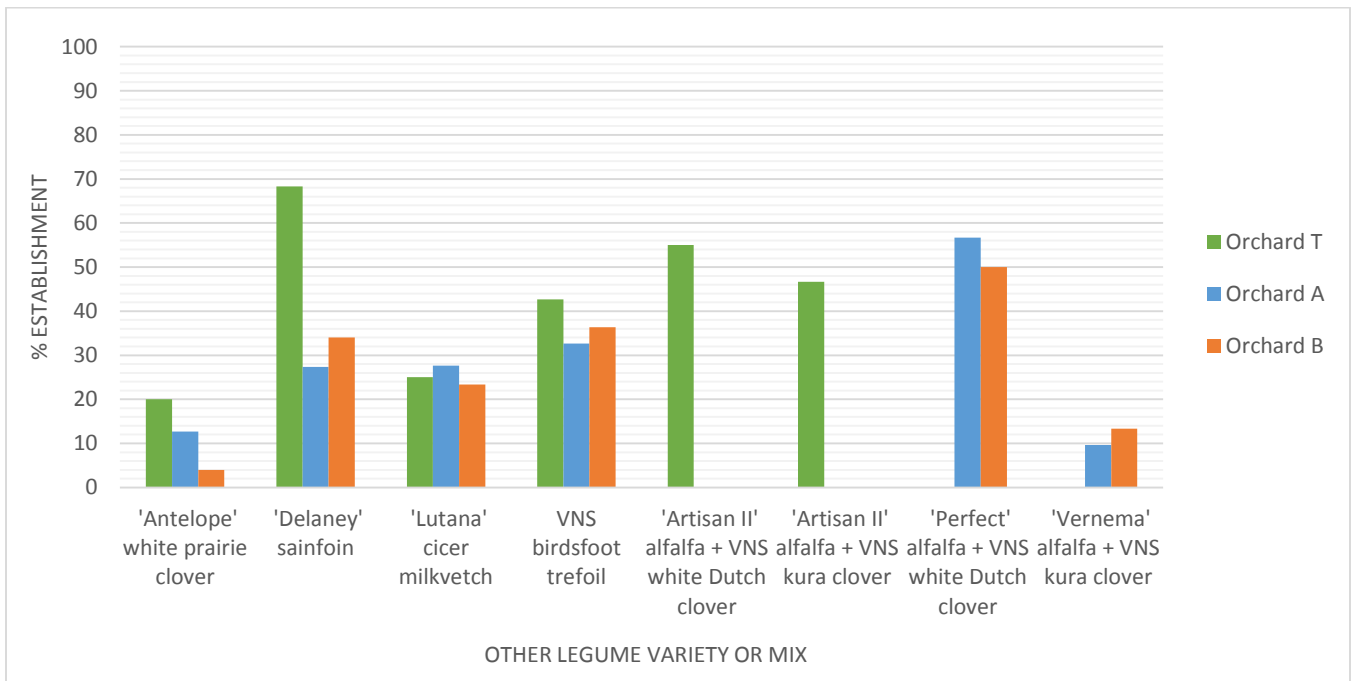


Figure 9. Percent establishment of other legume varieties and mixes 6 weeks after planting, 31 October 2012 at Orchard T near Grandview, WA; Orchard A near Prosser, WA; and Orchard B near Zillah, WA.

CANOPY COVER

Annuals

All annual legumes survived the winter, however some may have been damaged by frost, resulting in lower percent cover in spring. 'Lana' woollypod vetch had the most rapid establishment of all annual legumes but had lower percent cover than VNS hairy vetch in May 2013 (Figure 10). VNS hairy vetch had the highest percent cover among all annual legume varieties in May 2013 at both Orchard A and Orchard B, with 87.5% and 65% cover, respectively. 'Lana' woollypod vetch, VNS subterranean clover, and VNS crimson clover had over 50% canopy cover at Orchard A, but canopy cover of VNS Austrian winter pea was 30%.

Plots at Orchard B were mowed one month prior to sampling, therefore canopy measurements were of regrowth or matted, unmowed growth. We did not measure canopy cover of annual legumes at Orchard T because plots were mowed two weeks prior to sampling and no measurable regrowth had occurred. The plots at Orchards A and B were mowed in late May, and percent cover of all annuals declined to 0% with negligible regrowth throughout the remaining growing season.

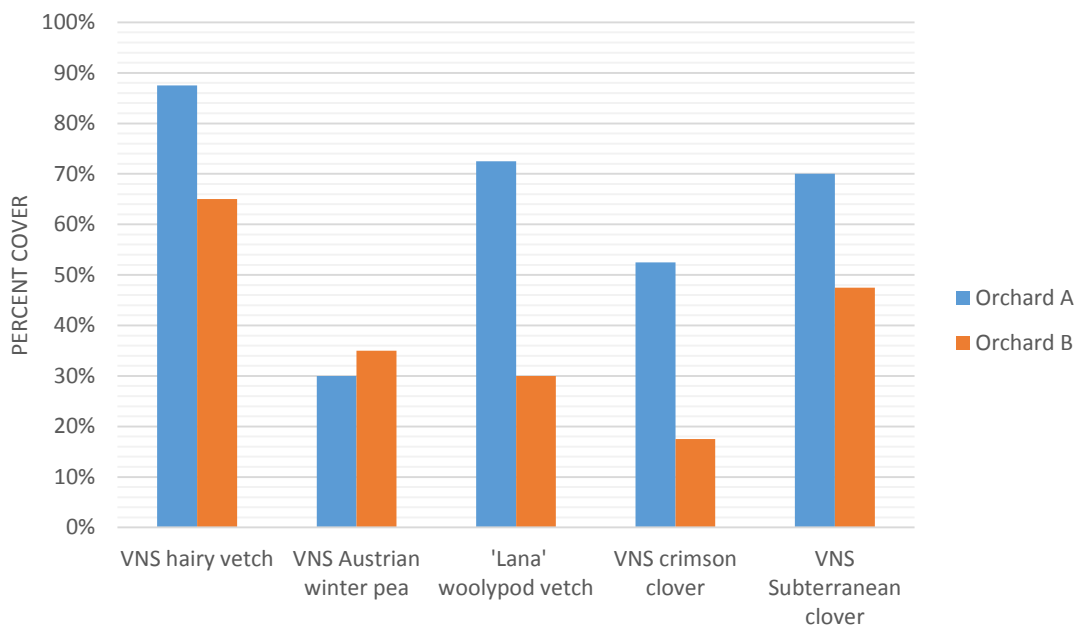


Figure 10. Percent cover of annual legume varieties in May 2013 at Orchard A near Prosser, WA and Orchard B near Zillah, WA. Orchard B values represent matted unmowed growth or regrowth since plots were mowed one month prior to sampling.

Alfalfas

Alfalfa varieties generally had 50 to 100% percent cover during the periods of measurement (Figures 11, 12, and 13). Alfalfa percent cover was low in May 2013 at Orchards T and B because the plots had been mowed prior to sampling. The alfalfa varieties with consistently high percent canopy cover at all orchards and in all years were 'FSG229CR', VNS falcata, and 'Perfect'. 'Vernema' typically had lower percent cover, as did 'Maxigraze' and 'Upper Edge', which were only planted at Orchard T.

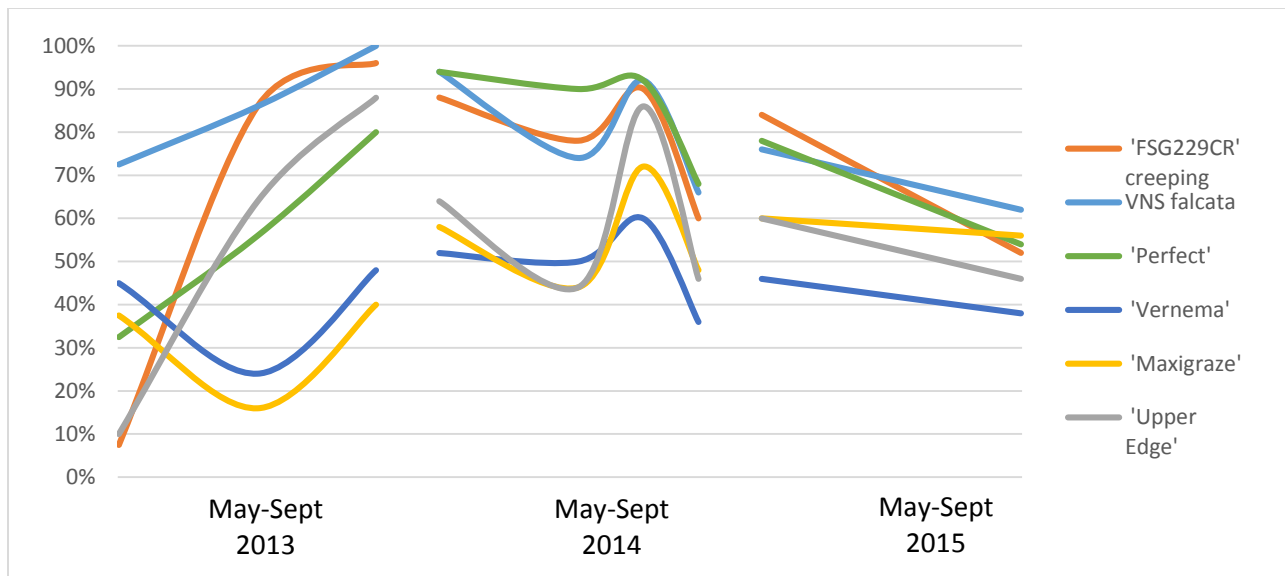


Figure 11. Percent cover of alfalfa varieties during periods of observation 2013 - 2015 at Orchard T near Grandview, WA. Plots were mowed 2 weeks prior to measurement in May 2013.

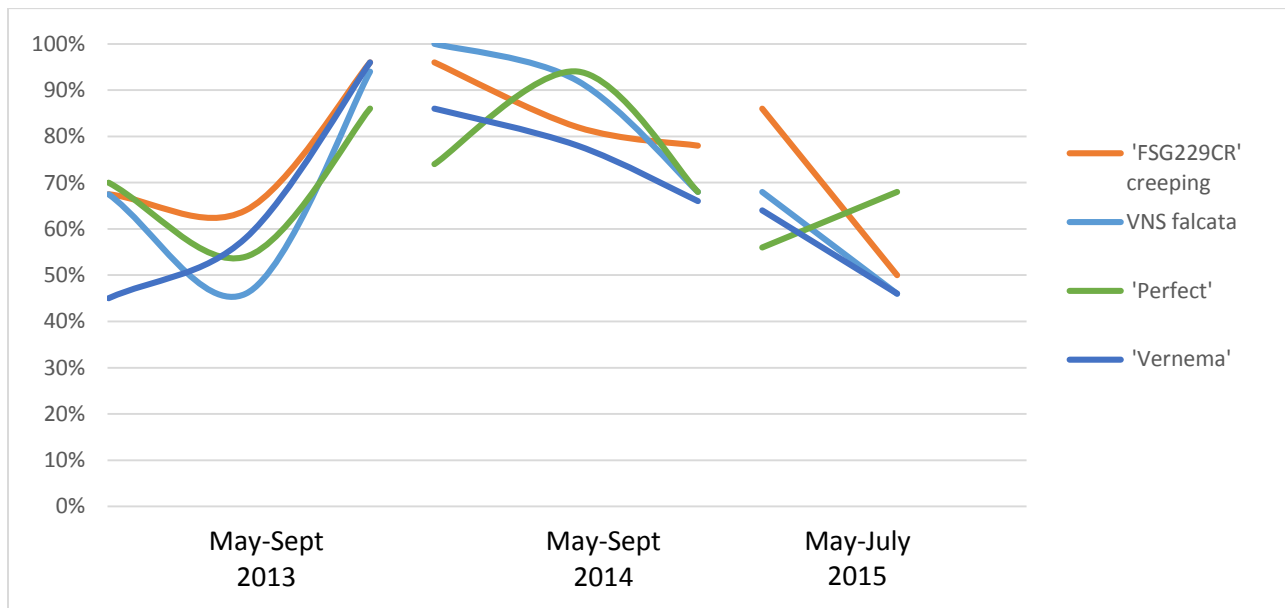


Figure 12. Percent cover of alfalfa varieties during periods of observation 2013 - 2015 at Orchard A near Prosser, WA.

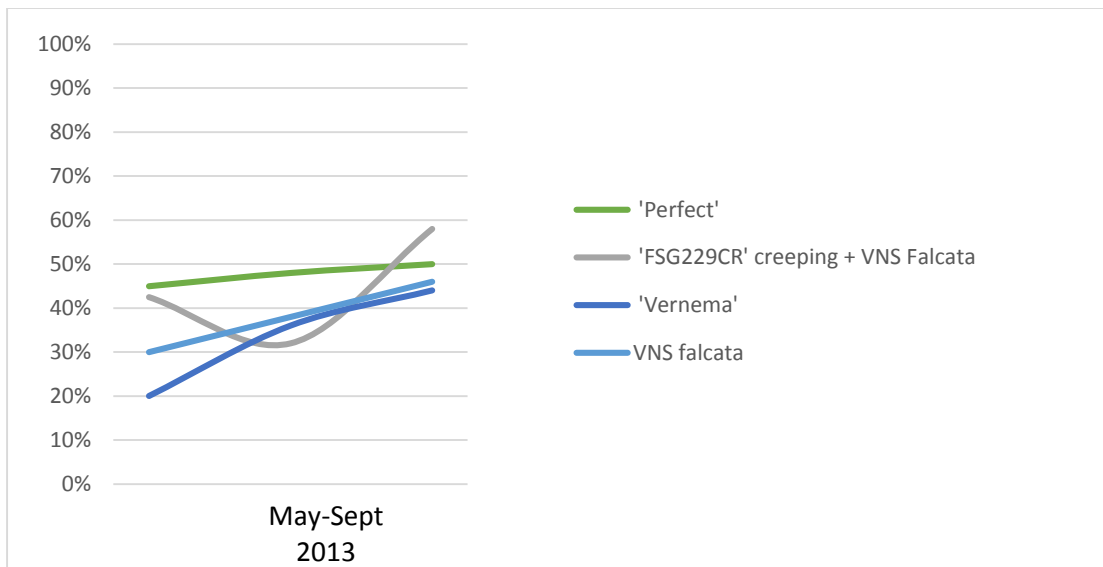


Figure 13. Percent cover of alfalfa varieties during the period of observation in 2013 at Orchard B near Zillah, WA. May values represent regrowth since plots were mowed 1 month prior to first measurement.

Clovers

Clover canopy cover was variable among orchards, which is likely a result of different irrigation systems at each site. At Orchard T, establishment and growth of clovers was spotty due to micro-sprinkler irrigation patterns. By Year 3, some clover varieties appeared to fill in a few gaps, however percent cover never exceeded 65% for any variety except for Kopu II white clover in 2013 (Figure 14). Orchards A and B had more uniform irrigation, and as a result, more uniform clover establishment and growth (Figures 15 and 16). In 2013, all clover varieties except kura clover had about 60 to 100% cover at Orchards A and B. Clover percent cover at Orchard A declined over time, which is typical of clovers, being short-lived perennials. Kura clover is known to establish very slowly and increase in density over time, which occurred at Orchard T. 'Kopu II' white clover consistently had high canopy cover at all orchards (Figure 17).

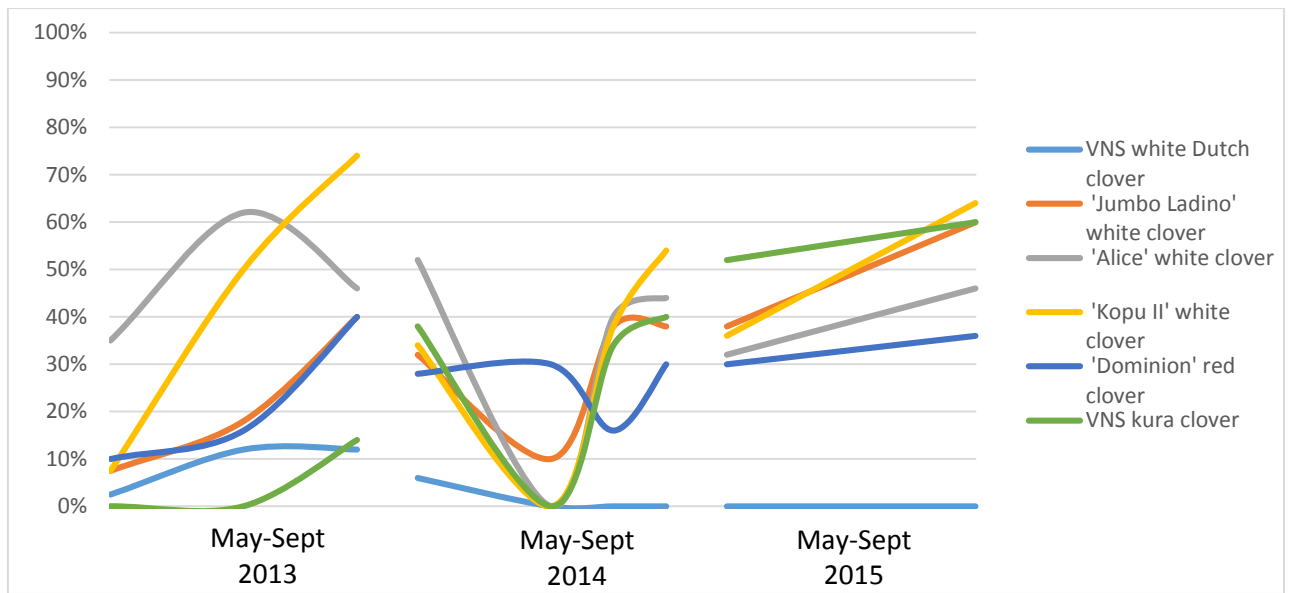


Figure 14. Percent cover of clover varieties during periods of observation 2013 - 2015 at Orchard T near Grandview, WA. Plots were mowed 2 weeks prior to measuring in May 2013.

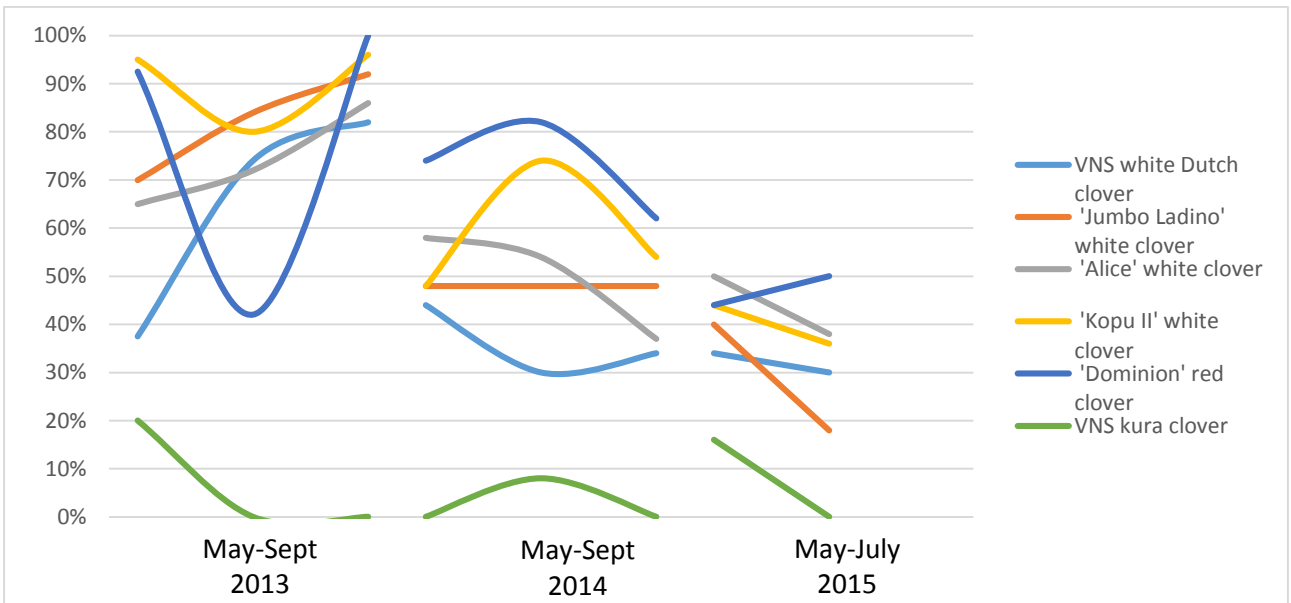


Figure 15. Percent cover of clover varieties during periods of observation 2013 - 2015 at Orchard A near Prosser, WA.

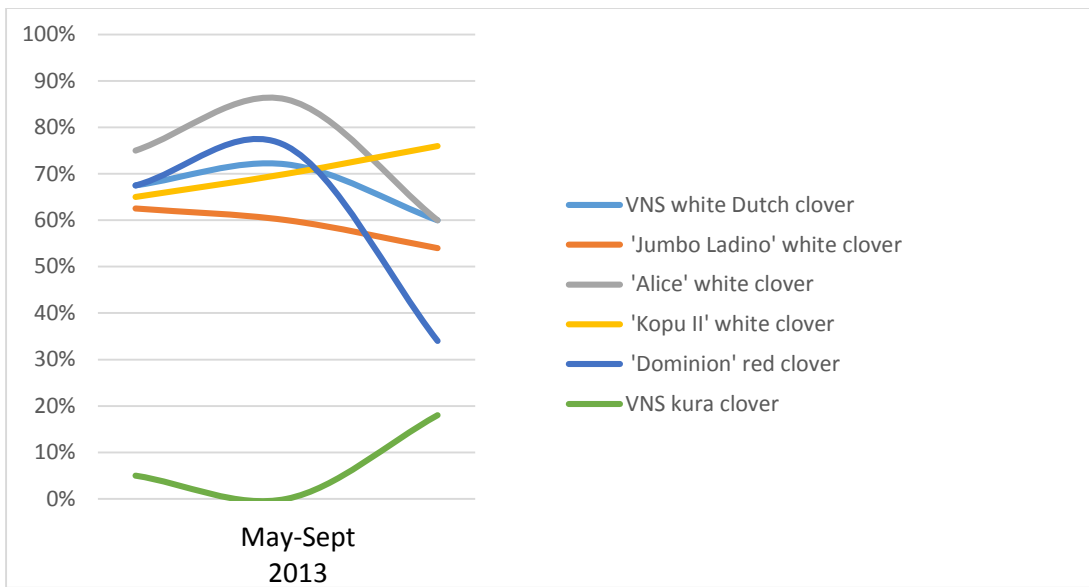


Figure 16. Percent cover of clover varieties during the period of observation in 2013 at Orchard B near Zillah, WA. May values represent regrowth since plots were mowed 1 month prior to first measurement.



Figure 17. 'Kopu II' white clover at Orchard A near Prosser, WA, May 2013.

Other Legumes and Mixes

Among the other legumes and mixes of alfalfa and clovers, the mixes had the highest percent cover at all three sites and in all three years (Figures 18, 19 and 20). One exception to this was the mix 'Artisan II' alfalfa and white Dutch clover; it was slow to establish at Orchard T. 'Delaney' sainfoin and 'Lutana' cicer milkvetch performed well at Orchard T (Figure 21) but not at Orchards A or B. VNS birdsfoot trefoil had lower percent cover than the sainfoin and cicer milkvetch at Orchard T, but higher percent cover at Orchards A and B. 'Antelope' white prairie clover did not establish at any site.

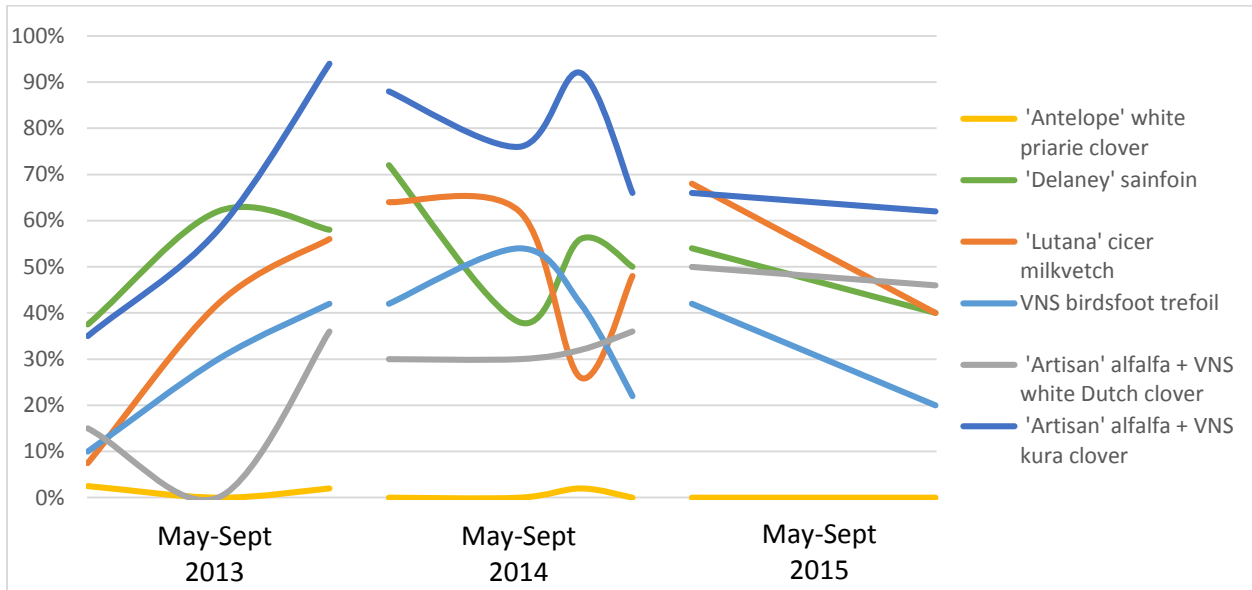


Figure 18. Percent cover of other legume varieties and mixes during periods of observation 2013 - 2015 at Orchard T near Grandview, WA. Plots were mowed 2 weeks prior to measurement in May 2013.

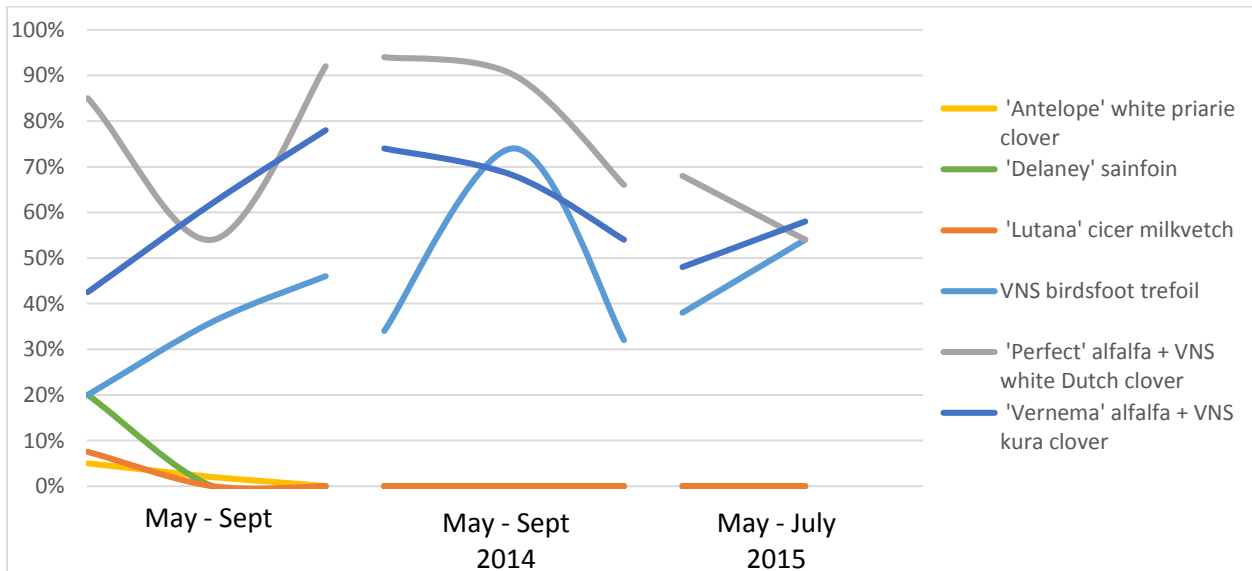


Figure 19. Percent cover of other legume varieties and mixes during periods of observation 2013 - 2015 at Orchard A near Prosser, WA.

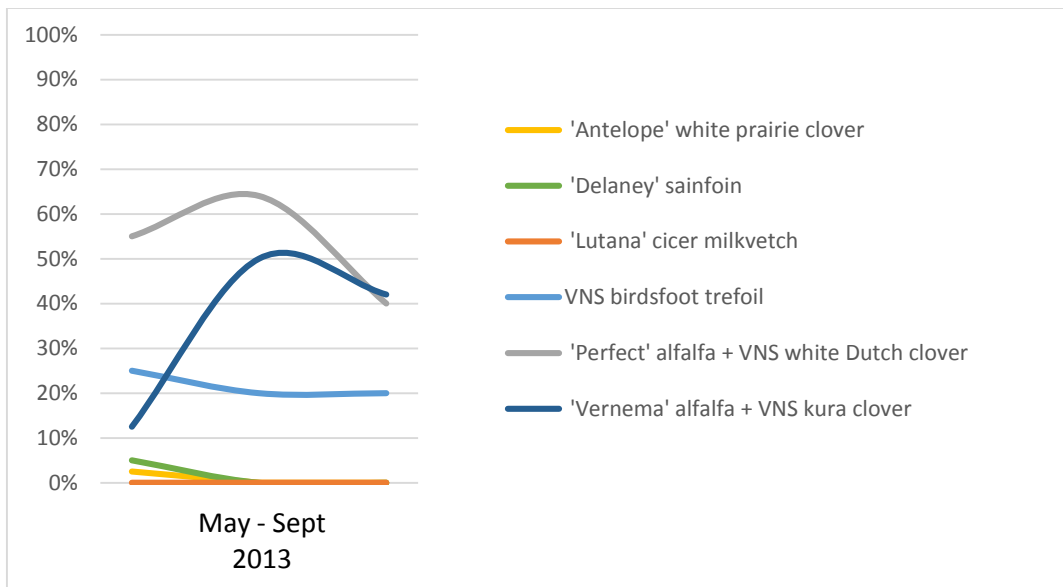


Figure 20. Percent cover of other legume varieties during the period of observation in 2013 at Orchard B near Zillah, WA. May values represent regrowth since plots were mowed 1 month prior to first measurement.



Figure 21. Cicer milkvetch roots at Orchard T near Grandview, WA, May 2014.

Weeds and Grass

Decline in legume percent cover at Orchards A and T from 2013 to 2015 coincided with increase in grass and broadleaf weed percent cover. At Orchard A, grass was more prevalent than broadleaf weeds due to the regrowth of previous vegetation. Grass percent cover ranged from 0 to 32% in September 2013, and 0 to 76% in July 2015 (data not presented). There was a slight increase in broadleaf weed cover from 2013 to 2015 at Orchard A, with 0 to 20% in September 2013 to 0 to 28% in July 2015. At Orchard T, there was no previous vegetation, but grass from neighboring orchard drive alleys established along with broadleaf weeds. In September 2013, grass percent cover ranged from 0 to 10%, and in September 2015, 4 to 74%. Broadleaf weed percent cover at Orchard T ranged from 0 to 62% in September 2013, and 4 to 50% in September 2015.

PLANT HEIGHT

The average height of alfalfa varieties 'FSG229CR', VNS falcata, 'Perfect' and 'Vernema' was about 18 inches, and for the remaining alfalfa varieties, 'Maxigraze' and 'Upper Edge', the average height was lower; about 14 and 16 inches, respectively (Table A2). The mix of 'FSG229CR' and VNS falcata alfalfas had the lowest height of all alfalfas, about 13 inches. Alfalfa varieties were generally taller than clover varieties, which had average heights of about 7 to 9 inches (Table A3). The exception to the clovers was 'Dominion' red clover, which had an average height of about 16 inches. The alfalfa-clover mixes had heights similar to the alfalfa varieties; about 16 to 21 inches (Table A4). VNS birdsfoot trefoil, 'Lutana' cicer milkvetch, and 'Delaney' sainfoin had heights of about 11, 13, and 18 inches, respectively.

PLANT GROWTH STAGE, NITROGEN FIXATION, INSECT DAMAGE AND RODENT DAMAGE

Most legumes were near or at flowering stage at the time of sampling, which is the ideal growth stage for optimum nitrogen production. Most root nodules we sampled were red or pink, indicating active fixation activity (Lindemann and Glover, 2013). Occasionally the nodules were white, which is a sign the nodules were producing little or no nitrogen. This may have been the result nodules being newly formed or inhabited by an inefficient rhizobia strain, poor plant nutrition, diversion of resources to seed production, or environmental stress (Lindemann and Glover, 2013). When root nodules were not present, this may have indicated the soil nitrate (NO₃) level was above a certain threshold (Doughtton et al., 1993; Voisin et al., 2002). We observed some insect feeding on the legumes, but not excessive levels. We also observed frequent evidence of the presence of voles, but no evidence of damage to orchard trees.

BIOMASS

Annuals

The 2013 data presented here represent partial biomass production during that growing season (an estimated 60 to 75% of the total produced). Biomass samples at Orchard A were from unmowed plots, and samples at Orchard B were from plots mowed one month prior to sampling. At Orchard A, the two vetches, 'Lana' woolypod vetch and VNS hairy vetch, produced the most biomass, with 1553 and 1409 lb DM/ac, respectively (Figure 22). Subterranean clover produced the least amount of above-ground biomass, 180 lb DM/ac.

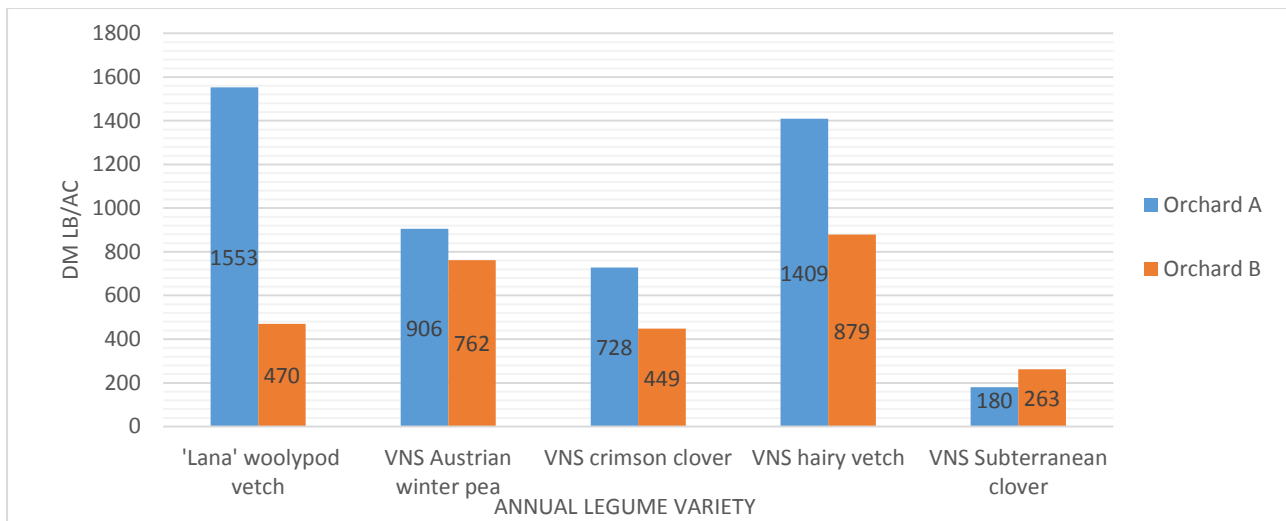


Figure 22. Annual legume biomass (DM lb/ac) production in 2013 at Orchard A and B near Prosser, WA, and Zillah, WA, respectively.

Alfalfas

Alfalfa varieties generally produced 300 to 2,000 lb DM/ac per cutting at all three orchards, and cuttings early in the year typically had more biomass than mid- or late-season cuttings (Figures A1, A2 and A3). Cumulative biomass production per year varied among orchards and years, and was likely dependent on the number of cuttings and water availability. In 2014, 'Perfect' alfalfa produced the most biomass of all varieties among all years and sites with a cumulative total of 4,719 lb DM/ac (Figure 23). 'FSG229CR' and VNS falcata produced more biomass than other varieties at Orchard T in 2014 and 2015, however at Orchards A and B, all varieties produced about the same amount of biomass each year.

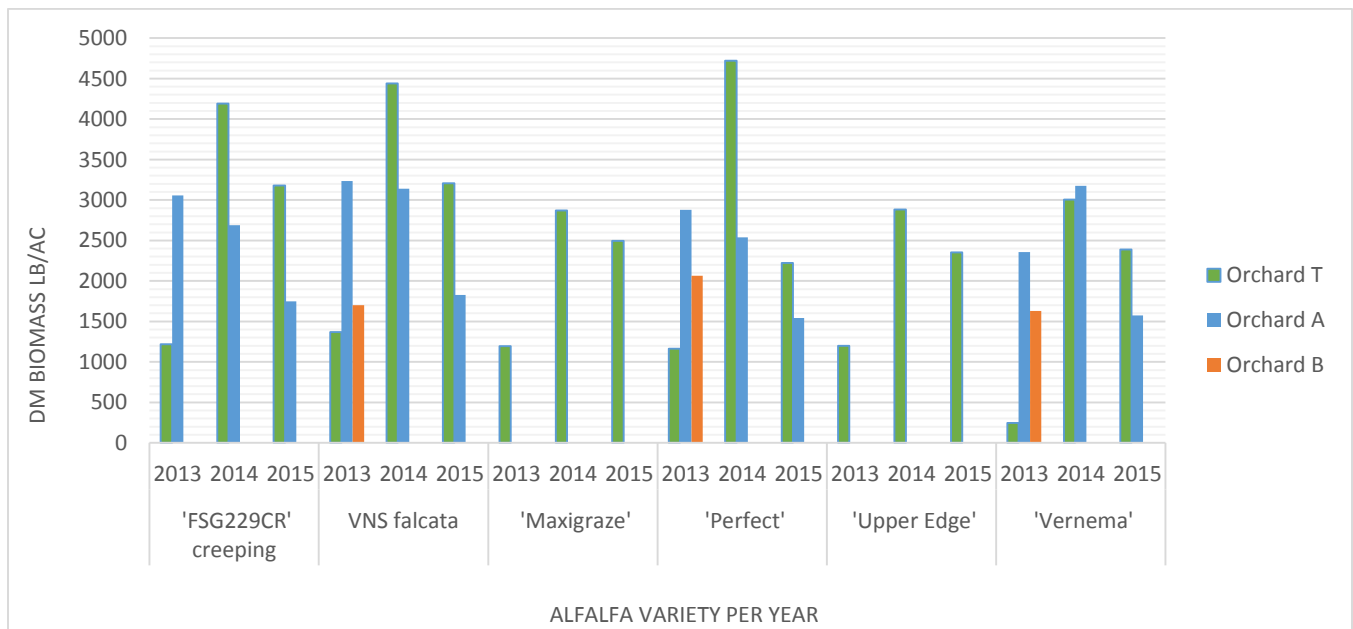


Figure 23. Cumulative biomass production (DM lb/ac) of alfalfa varieties in 2013 – 2015 at all three orchards per year. At Orchard T near Grandview, WA, biomass was sampled two times in 2013: 22 July and 19 September; four times in 2014: 7

May, 14 July, 15 August, and 11 September; and two times in 2015: 11 May and 14 September. At Orchard A near Prosser, WA, biomass was sampled three times in 2013: 15 May, 20 July and 19 September; three times in 2014: 7 May, 15 July, and 11 September; and two times in 2015: 11 May and 15 July. At Orchard B near Zillah, WA, biomass was sampled three times in 2013: 16 May, 23 July, and 18 September.

Clovers

Clover varieties produced less biomass than the alfalfa varieties, with 0 to approximately 1600 lb DM/ac per cutting at all three orchards in all years (Figures A4, A5, and A6). ‘Dominion’ red clover produced the most biomass of all clover varieties, with 4,031 lb DM/ac at Orchard A in 2014 and about 1,500 to 2,500 lb DM/ac at Orchards A and T in 2014 and 2015 (Figures 24 and 25). Many of the *Trifolium* clover varieties in this trial are short-lived species, as evidenced by the declining pattern of biomass production at Orchard A (the orchard with the most accurate data sampling).

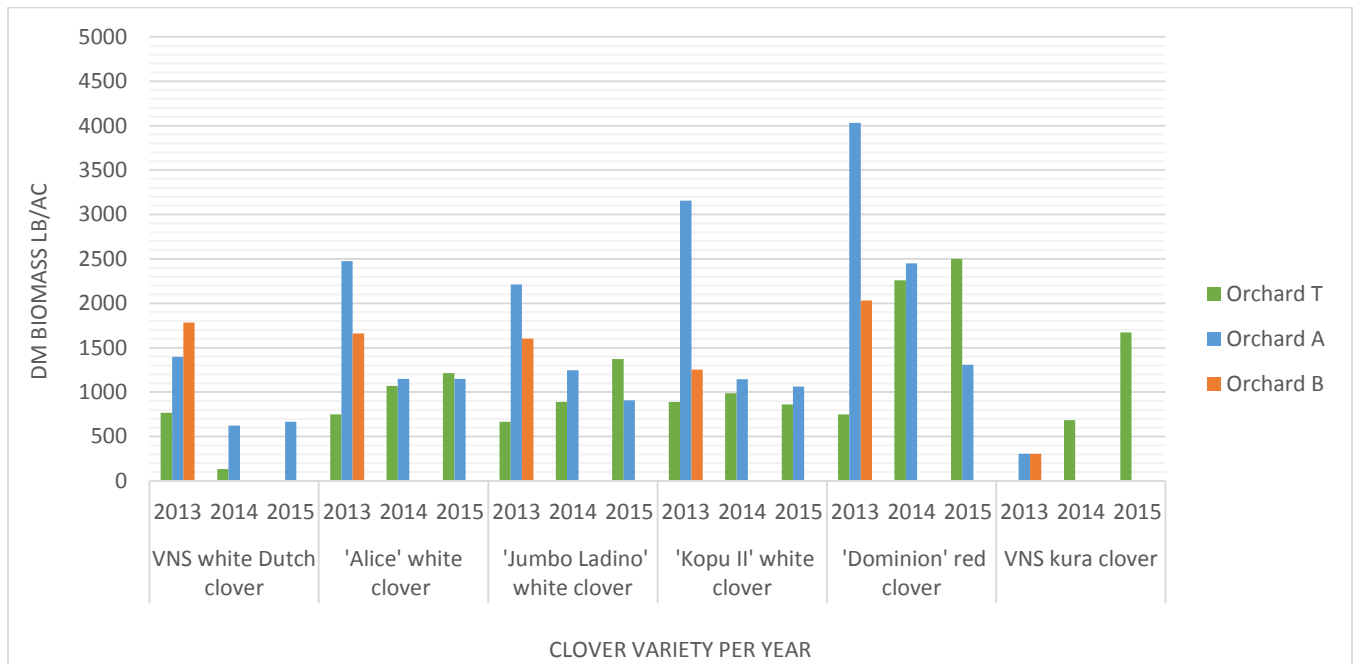


Figure 24. Cumulative biomass production (DM lb/ac) of clover varieties in 2013 – 2015 at all three orchards per year. At Orchard T near Grandview, WA, biomass was sampled two times in 2013: 22 July and 19 September; four times in 2014: 7 May, 14 July, 15 August, and 11 September; and two times in 2015: 11 May and 14 September. At Orchard A near Prosser, WA, biomass was sampled three times in 2013: 15 May, 20 July and 19 September; three times in 2014: 7 May, 15 July, and 11 September; and two times in 2015: 11 May and 15 July. At Orchard B near Zillah, WA, biomass was sampled three times in 2013: 16 May, 23 July, and 18 September.



Figure 25. 'Dominion' red clover at Orchard A near Prosser, WA, September 2013.

Other Legumes and Mixes

'Delaney' sainfoin and 'Lutana' cicer milkvetch produced relatively high amounts of cumulative biomass at Orchard T in 2014 and 2015, with over 3,000 cumulative lb DM/ac each year (Figure A7). However, the two varieties performed poorly at Orchards A and B, which likely was a result of poor establishment at these two sites (Figures A8 and A9). The alfalfa and clover mixes produced about 1,000 to 2,500 cumulative lb DM/ac in 2014 and 2015 at Orchards T and A (Figure 26), which is less than the biomass production of the alfalfa varieties alone.

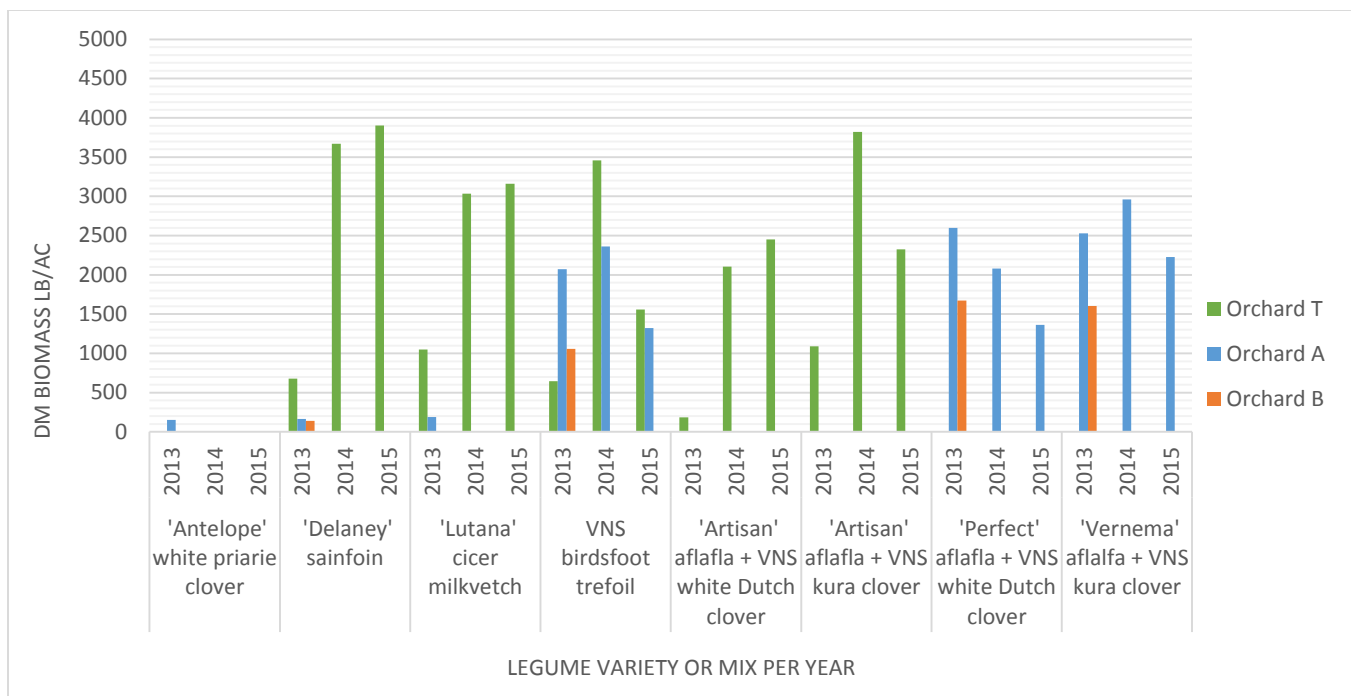


Figure 26. Cumulative biomass production (DM lb/ac) of other legume varieties and mixes in 2013 – 2015 at all three orchards per year. At Orchard T near Grandview, WA, biomass was sampled two times in 2013: 22 July and 19 September; four times in 2014: 7 May, 14 July, 15 August, and 11 September; and two times in 2015: 11 May and 14 September. At Orchard A near Prosser, WA, biomass was sampled three times in 2013: 15 May, 20 July and 19 September; three times in 2014: 7 May, 15 July, and 11 September; and two times in 2015: 11 May and 15 July. At Orchard B near Zillah, WA, biomass was sampled three times in 2013: 16 May, 23 July, and 18 September.

PERCENT NITROGEN

Percent nitrogen in the annual legume biomass ranged from 2.2 to 4.9% (Table 5). The vetches had the highest average percent nitrogen, with 3.7% in 'Lana' woollypod vetch and 4.2% in VNS hairy vetch.

Table 5. Average and range percent nitrogen of biomass samples from annual legume plots at Prosser, WA, and Zillah, WA, in 2013.

Legume Type	Variety	Average ----- % N -----	Range	# observations
Woollypod vetch	'Lana'	3.7	3.2-4.2	2
Hairy vetch	VNS	4.2	3.5-4.9	2
Austrian winter pea	VNS	3.3	2.8-3.8	2
Crimson clover	VNS	2.5	2.3-2.6	2
Subterranean clover	VNS	2.3	2.2-2.4	2

Percent nitrogen in the perennial legume biomass ranged from 1.7 to 5.0, and was likely influenced by percent grass or non-legume broadleaf weed in the biomass sample (Table 6), the maturity of the legume and the different cutting methods. For the three year period, alfalfa average percent nitrogen ranged from 3.5 to 4.1, and clover average percent nitrogen ranged from 3.4 to 3.9 (not including kura clover, which established poorly) (Tables A4, A5 and A6). The alfalfa-clover mixes had average percent nitrogen of 3.2 to 3.9, and the other legumes had a range of 1.9 to 3.6 average percent nitrogen. We

found no consistent pattern of increase or decrease in percent nitrogen of legume biomass throughout each growing season or the trial period.

Table 6. Average and range percent nitrogen of biomass samples from perennial legume plots at all three locations near Grandview, Prosser, and Zillah, WA, 2013 – 2015.

Legume Type	Variety	3-yr average ----- % N -----	Range	# observations
Alfalfa	Average all alfalfa varieties	3.8	2.5-5.0	91
	'FSG229CR' creeping	3.9	2.9-4.8	16
	VNS falcata	3.8	2.5-4.9	19
	'Perfect'	3.8	2.6-4.8	19
	'Vernema'	3.6	2.4-4.7	18
	'Maxigraze'	3.8	3.0-4.4	8
	'Upper Edge'	4.1	3.0-5.0	8
	'FSG229CR' creeping + VNS falcata	3.5	3.4-3.6	3
White clover	Average all white clover varieties	3.7	2.2-4.9	67
	VNS white Dutch	3.5	2.5-4.4	13
	'Jumbo Ladino'	3.8	2.2-4.9	18
	'Alice'	3.7	2.6-5.1	18
	'Kopu II'	3.9	2.9-4.8	18
Red clover	'Dominion'	3.4	2.6-4.5	19
Kura clover	VNS	3	1.7-3.9	6
Birdsfoot trefoil	VNS	3.4	2.2-4.5	18
Sainfoin	'Delaney'	2.7	2.0-3.8	8
Cicer milkvetch	'Lutana'	3.6	2.6-4.4	7
Mix	'Artisan II' alfalfa + VNS white Dutch clover	3.9	3.0-4.8	7
	'Artisan II' alfalfa + VNS kura clover	3.9	2.6-5.1	8
	'Perfect' alfalfa + VNS white Dutch clover	3.6	2.9-4.7	11
	'Vernema' alfalfa + VNS kura clover	3.2	2.0-4.2	11

BIOMASS NITROGEN

Annuals

VNS hairy vetch and 'Lana' woollypod vetch produced the most biomass nitrogen among annual legumes at Orchard A with 50 and 49 lb N/ac, respectively, followed by VNS Austrian winter pea with 25 lb N/ac, VNS crimson clover with 17 lb N/ac and VNS subterranean clover with 4 lb N/ac (Figure 27). Measurements at Orchard B were not an accurate representation of total biomass since the plots had been mowed, but they followed a similar pattern.

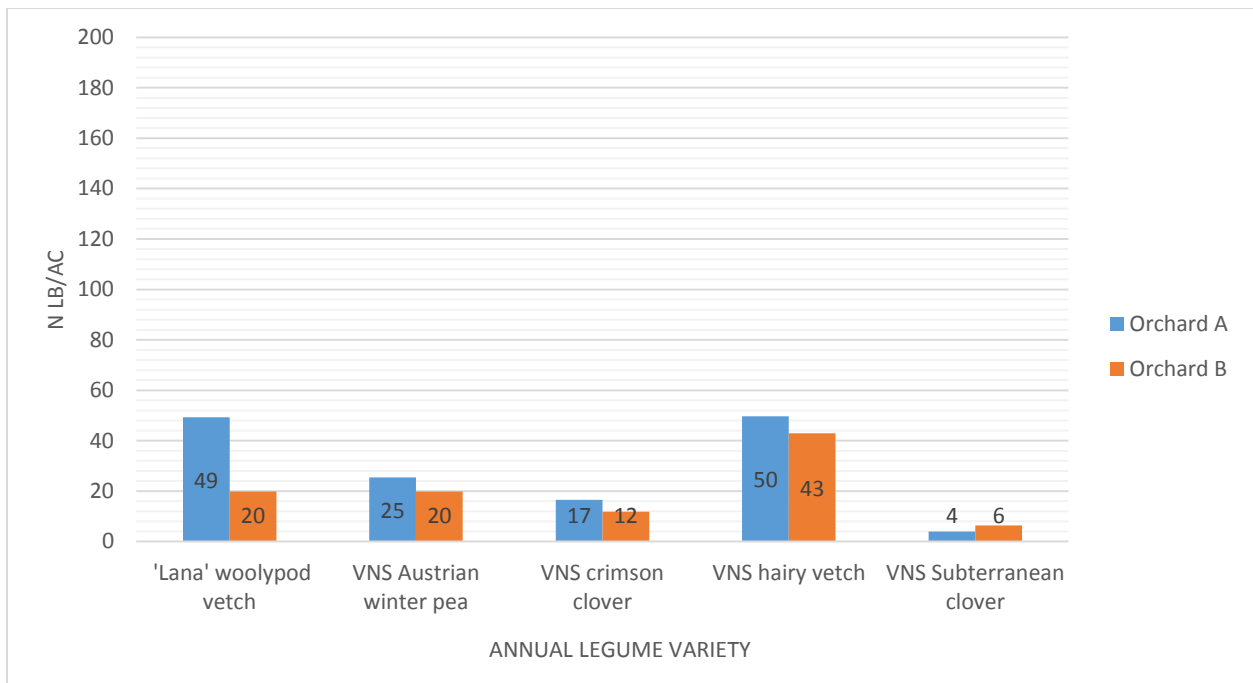


Figure 27. Biomass nitrogen production (N lb/ac) of annual legumes in 2013 at Orchard A near Prosser, WA, and Orchard B near Zillah, WA.

Alfalfas

Biomass nitrogen per cutting of alfalfa typically ranged from about 15 to 80 lb N/ac at each site and in each year (Figures A10, A11 and A12). The highest cumulative amounts of nitrogen were of VNS falcata, 'FSG229CR' creeping and 'Perfect' alfalfa varieties at Orchard T, ranging from about 120 to 190 lb N/ac (Figures 28 and 29). At Orchards A and B, biomass nitrogen production was about the same for all varieties, ranging from about 60 to 120 lb N/ac. During the most representative year (2014) every alfalfa at Orchards T and A produced over 100 lb N/ac. Among all years, only 'FSG229CR' creeping alfalfa produced over 100 lb N/ac. Biomass N appears to be more influenced by biomass dry matter production, as percent nitrogen levels were less variable on a given date across the treatments.

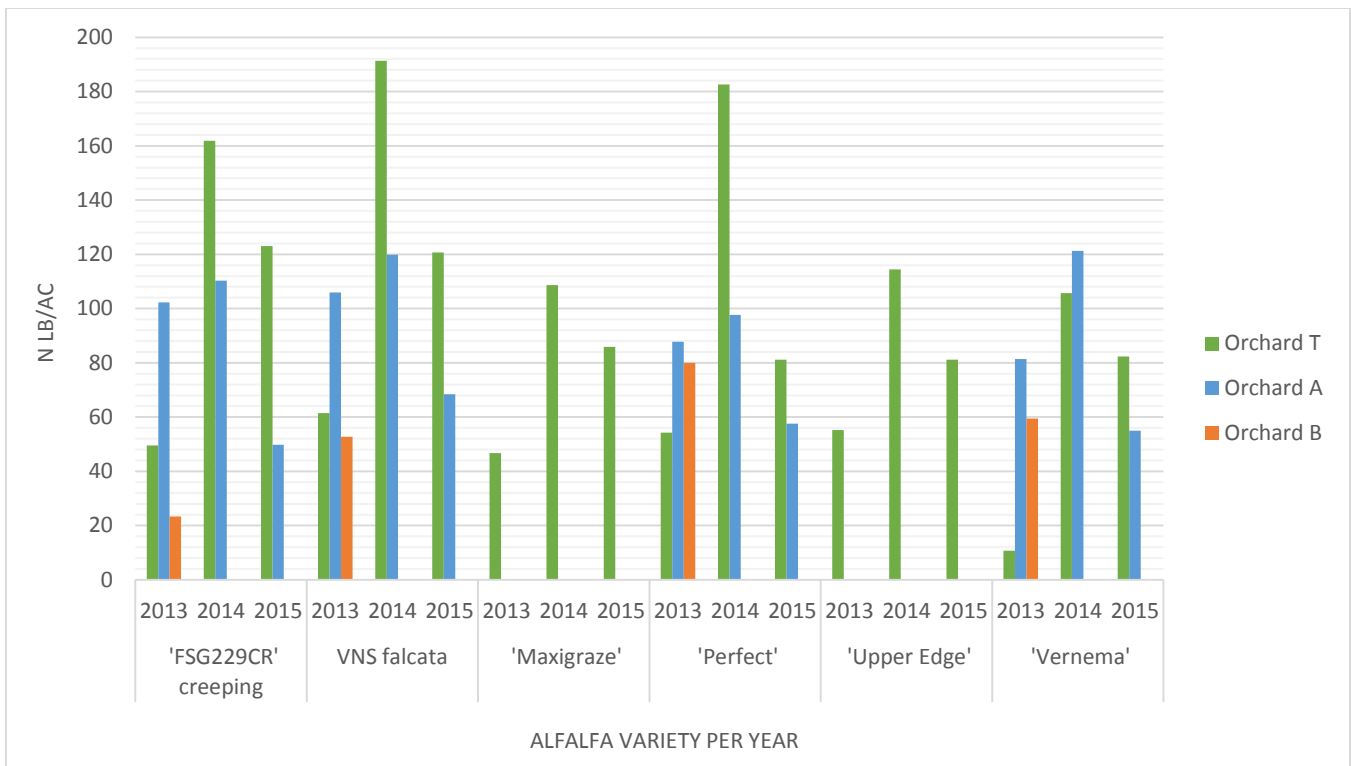


Figure 28. Cumulative biomass nitrogen production (N lb/ac) of alfalfa varieties in 2013 – 2015 at all three orchards per year. At Orchard T near Grandview, WA, biomass was sampled two times in 2013: 22 July and 19 September; four times in 2014: 7 May, 14 July, 15 August, and 11 September; and two times in 2015: 11 May and 14 September. At Orchard A near Prosser, WA, biomass was sampled three times in 2013: 15 May, 20 July and 19 September; three times in 2014: 7 May, 15 July, and 11 September; and two times in 2015: 11 May and 15 July. At Orchard B near Zillah, WA, biomass was sampled three times in 2013: 16 May, 23 July, and 18 September.



Figure 29. 'Perfect' alfalfa at Orchard A near Prosser, WA, May 2014.

Clovers

'Dominion' red clover produced the most biomass nitrogen among all clover varieties at Orchards T and A in all years, with about 44 to 120 cumulative lb N/ac (Figures A13, A14 and A15). 'Kopu II' produced the most biomass nitrogen in 2013 compared to the other white clover varieties, with a cumulative 97.5 lb N/ac at Orchard A and 92 lb N/ac at Orchard B (Figure 30). Clover biomass nitrogen production was generally lower than alfalfa biomass nitrogen production at Orchard T, but more similar to alfalfa biomass nitrogen production at Orchards A and B.

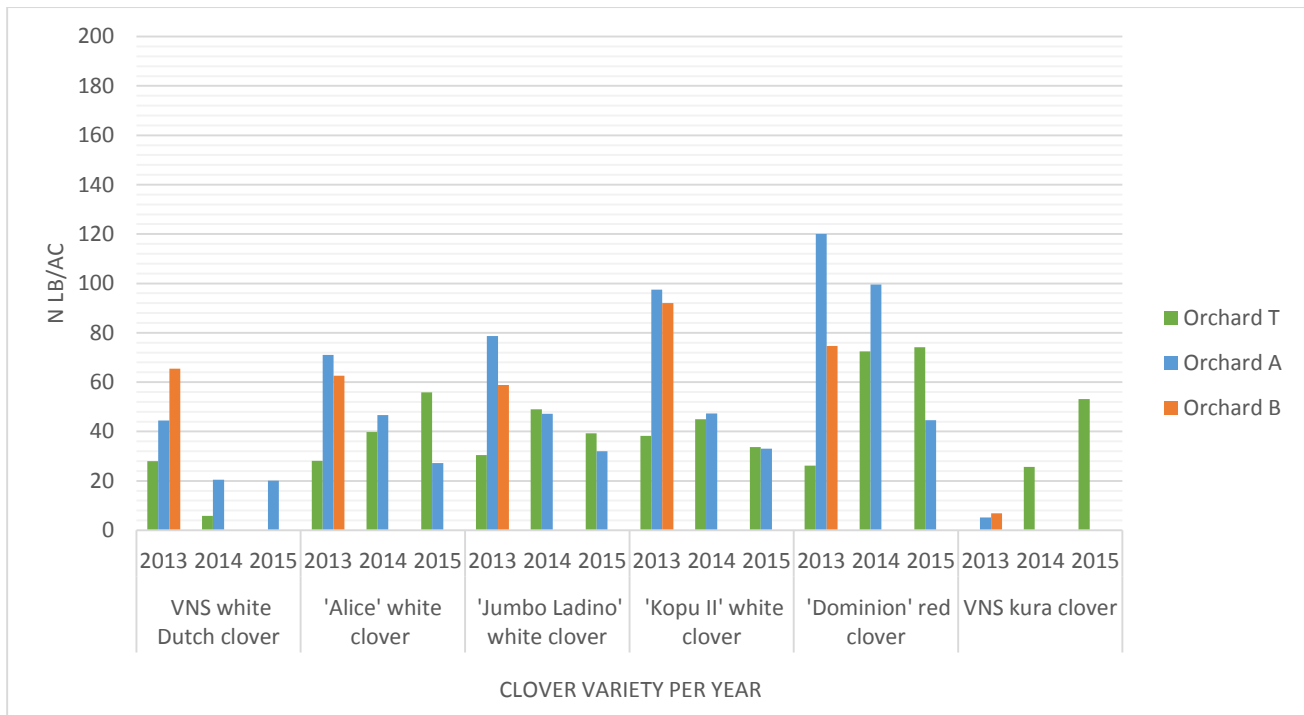


Figure 30. Cumulative biomass nitrogen production (N lb/ac) of clover varieties in 2013 – 2015 at all three orchards per year. At Orchard T near Grandview, WA, biomass was sampled two times in 2013: 22 July and 19 September; four times in 2014: 7 May, 14 July, 15 August, and 11 September; and two times in 2015: 11 May and 14 September. At Orchard A near Prosser, WA, biomass was sampled three times in 2013: 15 May, 20 July and 19 September; three times in 2014: 7 May, 15 July, and 11 September; and two times in 2015: 11 May and 15 July. At Orchard B near Zillah, WA, biomass was sampled three times in 2013: 16 May, 23 July, and 18 September.

Other Legumes and Mixes

The alfalfa and clover mixes generally produced 80 lb N/ac/yr or more at all sites (Figures 31, A16, A17 and A18). 'Delaney' sainfoin and 'Lutana' cicer milkvetch also produced about 80 lb N/ac/yr, but only at Orchard T; at Orchards A and B, they performed poorly. VNS birdsfoot trefoil produced over 80 lb N/ac in 2014 at Orchards T and A, but production declined in 2015. 'Antelope' white prairie clover did not establish well, and did not produce any biomass.

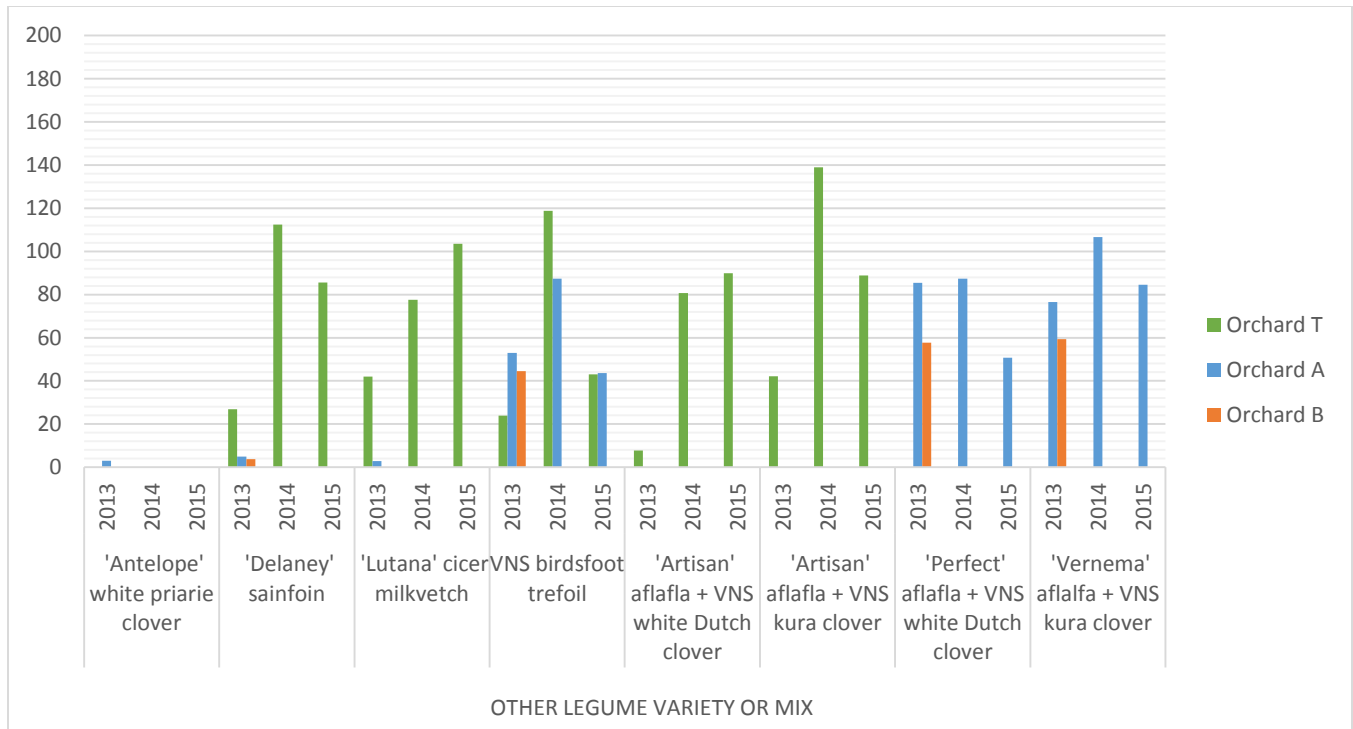


Figure 31. Cumulative biomass nitrogen production (N lb/ac) of other legume varieties and mixes in 2013 – 2015 at all three orchards per year. At Orchard T near Grandview, WA, biomass was sampled two times in 2013: 22 July and 19 September; four times in 2014: 7 May, 14 July, 15 August, and 11 September; and two times in 2015: 11 May and 14 September. At Orchard A near Prosser, WA, biomass was sampled three times in 2013: 15 May, 20 July and 19 September; three times in 2014: 7 May, 15 July, and 11 September; and two times in 2015: 11 May and 15 July. At Orchard B near Zillah, WA, biomass was sampled three times in 2013: 16 May, 23 July, and 18 September.

Alfalfa Varieties vs. Clover Varieties

Alfalfa varieties produced significantly more biomass nitrogen than the clover varieties across most sites and years ($p < .05$) (Figure 32). Biomass N of alfalfas at Orchard A in 2015 was not significantly higher than clovers at Orchard T in 2014 and 2015 or at Orchard A in 2014, but was significantly higher than clovers in 2015.

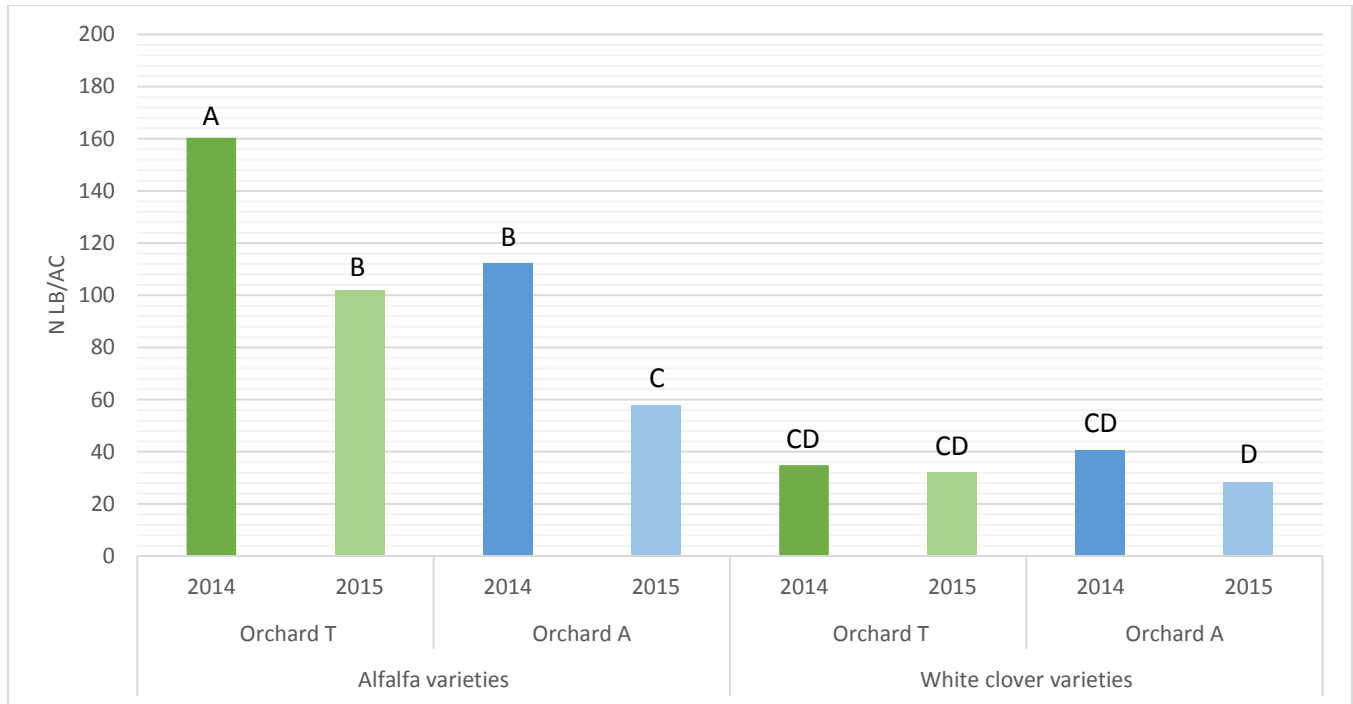


Figure 32. Cumulative biomass nitrogen production (N lb/ac) of grouped alfalfa and clover varieties in 2014 and 2015 at Orchard T near Grandview, WA and Orchard A near Prosser, WA. Alfalfa varieties include ‘FSG229CR’ creeping, VNS falcata, ‘Perfect’ and ‘Vernema’. White clover varieties include VNS white Dutch, ‘Alice’, ‘Jumbo Ladino’ and ‘Kopu II’. Plots were sampled four times at Orchard T in 2014: 7 May, 14 July, 15 August, and 11 September; and two times in 2015: 11 May and 14 September. Plots were sampled three times at Orchard A in 2014: 7 May, 15 July, and 11 September; and two times in 2015: 11 May and 15 July. Means with the same letter above the bar are not significantly different in LSD all-pairwise comparison test ($\alpha = 0.05$).

Managing Legume Nitrogen Contribution in the Orchard

The data presented here suggest monitoring of potential N contribution may be needed with a legume ‘mow and blow’ system to avoid excess nitrogen at the wrong time (Goh et al. 1995; Marsh et al., 1996). Tissue nitrogen content in alfalfa varied as much as 30% above the average value given in Table 6. With some alfalfa cultivars producing 180 lb biomass N/ac in a year, an excess of N could be delivered to trees that may only require 50-60 lb available N/ac for a typical crop. Few studies have examined nitrogen release and tree uptake for a ‘mow and blow’ type system. Vigil and Kissel (1991) reported 40% and 50% N mineralization at 28 days and 70 days, respectively, for a vetch cover crop incorporated in soil with 3-4% residue N content. In an orchard study in central Washington, about 43% of the N in legume residue cut from the alley and placed on the soil surface in the tree row was found as nitrate in the soil after 3 weeks (Mullinix and Granatstein, 2011). In a California study, subterranean clover grown in the tree-row was found as effective as 90 kg N/ha applications of compost + native vegetation for establishment of young peach trees at only a fraction of the cost

(Meyer et al., 2006). Ideally, larger inputs of N would occur in spring and near or just after harvest. Growers can manage the N contribution by mowing the legume in place, where available N would be largely be recycled in the growth of the legume. Based on the results in this study, estimating the dry matter present in the legume prior to mowing would allow for this sort of decision to be made. Estimates of the percent dry matter in various wet legume samples are needed, along with the %N content of the dry matter as presented here, to allow for real-time decision making.

ECONOMIC ANALYSIS

Estimates of the cost of establishing legumes compared to the potential nitrogen value they deliver are provided in Table 7. Standard costs from enterprise budgets were used for seedbed preparation and seeding, and will vary with the equipment on an individual farm. Seed costs were based on 2015 catalogue prices from several companies that offer a wide range of legume seeds. Most were conventional seed prices; organic seed prices, when available, were often 50-100% higher. The potential value of nitrogen contribution was based on 40% mineralization during the current growing season, and no value was assigned to carryover nitrogen from the legume residue. The comparisons in Table 7 are intended to provide a coarse analysis of whether planting legumes in orchard alleys might be a cost-effective practice based on the nitrogen contribution alone. The N value is summed over three years for perennials and only for one year for annuals.

Based on the field data, alfalfa varieties have the potential to provide over 100 lb N/ac per year (of which approximately 40% becomes plant-available N) (Mullinix and Granatstein, 2011) from an alley planting that covers 50% of the orchard floor (7' in this study). With an average establishment cost of \$93/ac, the N value of alfalfa based on urea fertilizer substitution generally does not cover costs, but in organic systems, it would. The same is true for 'Dominion' red clover. The white clover varieties 'Jumbo Ladino' and 'Kopu II', and VNS birdsfoot trefoil, would cover establishment costs occasionally in organic orchards. Clover production may decline over time, reducing the possibility of covering establishment costs. Annual legumes were not economically viable, as they had only one season of nitrogen production, and did not cover establishment costs.

Table 7. Estimated establishment costs for legume drive-row cover and the economic value of the plant available nitrogen for three years (using the price of urea or chicken manure compost that would be replaced).

Legume Type	Establishment Cost \$/ac	Urea N Value -----\$/ac/3yr-----	Organic	Top Performing Varieties
			Fertilizer N Value	
alfalfa varieties	93	58-108	178-334	VNS falcata, 'FSG229CR' creeping
'Dominion' red clover	54	45-68	138-211	
VNS birdsfoot trefoil	59	1-48	4-148	
white clover varieties	60	8-46	68-142	'Jumbo Ladino', 'Kopu II'
VNS kura clover	194	1-20	4-63	
'Lutana' cicer milkvetch	118	1-58	2-178	
'Delaney' sanfoin	118	48-58	147-180	
annual legumes ^{1/}	87	1-12	3-40	VNS hairy vetch, 'Lana' woolypod vetch

1/ data for one year only; other data is cumulative for 3 years

OTHER CONSIDERATIONS

Further refinement of the use of legumes as an N source in orchards is needed. The release of N from cut biomass and its uptake by trees is not well defined. Impacts of entire block plantings to alley legumes on potential pest insects and rodents have not been evaluated. Interactions between tree roots and the legumes are unclear and likely vary depending on tree and legume species, and age of the trees. Research on peach and trefoil in Utah found positive effects relative to a standard grass alley (Culumber, 2016). Additional benefits may accrue to the orchards from a 'mow and blow' system that creates a mulch in the tree row, such as water conservation, increased tree growth, higher fruit yield, and larger fruit size (Nielsen et al., 2003; Atucha et al., 2011; Granatstein et al., 2014). In addition, this study was planted in mid-September which would not be feasible for certain apple cultivars. Results from a spring-planted legume need to be examined (e.g. Granatstein et al., 2013) for this situation.

CONCLUSIONS

The trials described here were conducted in grower orchards at field scale which often adds to the variability of the results. However, under such conditions, meaningful differences that emerge are typically more robust as they reflect the issues faced in normal farm management. Alfalfas have the potential to deliver 100 to 120 lb N/ac/yr or more biomass N (of which an estimated 40 to 48 lb becomes plant-available N), which is close to the 50-60 lb N/ac/yr nitrogen needs of many modern orchards. 'Dominion' red clover was the next highest in N contribution. 'Kopu II' white clover, the best of the white clover group, VNS birdsfoot trefoil, 'Delaney' sainfoin, and 'Lutana' cicer milkvetch all produced 80 lb N/ac/yr biomass N. None of the annual legumes achieved the annual N contribution of the perennials, but the vetches could deliver 50 lb N/ac biomass N from one cutting which may be useful to some growers. However, annual planting and soil disturbance is not desirable. Based on estimated costs for establishment and the potential N value of the legume biomass, the alfalfas showed the most potential to be cost effective as a replacement for organic fertilizer sources, and only marginally for synthetic sources.

Durability of these legumes over time in an orchard alley remains to be determined, and would impact the economic estimates presented here. The different alfalfa cultivars and types exhibited potential for selection of traits more suitable to the orchard setting, and mixtures could offer benefits in terms of durability. Research suggests birdsfoot trefoil can persist 6 years or more as an open field forage crop (Macadam and Griggs, 2006) and thus may have durability over time in orchards as well. Letting trefoil set seed every year may be a strategy for extending stand life (Undersander et al., 1993). Kura clover is known to persist 15-20 years but as evidenced in this study and others (Albrecht, undated; Kramer and Kussman, 2011), it is very difficult and expensive to establish. Mixtures of alfalfa and clover did not lead to greater biomass N but did show some potential for faster canopy development after planting that could be beneficial for weed suppression.

Use of legumes to supply nitrogen to orchards is feasible and may make economic sense in some cases, especially for organic growers.

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APPENDIX

PLANT HEIGHT

Table A1. Average stand height (in) of annual legume varieties at the time of biomass sampling at Orchard A near Prosser, WA; and Orchard B near Zillah, WA.

Orchard	'Lana' woolypod vetch	VNS crimson clover	VNS hairy vetch	VNS Austrian winter pea	VNS subterranean clover
	in				
A	17.2	13.1	20.6	20.1	4.7
B	10.5	9.4	10	15.4	3.8

Table A2. Average stand height (in) of alfalfa varieties at the time of biomass sampling at Orchard T near Grandview, WA; Orchard A near Prosser, WA; and Orchard B near Zillah, WA.

Orchard	Year	Month	'FSG229CR'	VNS falcata	'Perfect'	'Vernema'	'Maxigraze'	'Upper Edge'	'FSG229CR' creeping + VNS falcata	
			creeping							
-----in-----										
T	2013	July	22.3	21.0	19.7	N/A	15.7	18.4	^	
		Sept	13.9	11.4	14.2	9.8	11.5	13.9	^	
	2014	May	25.7	22.4	21.3	22.3	14.4	13.1	^	
		July	19.7	18.5	15.6	11.2	10.8	10.9	^	
		Aug	13.8	20.2	13.8	19.8	16.8	19.3	^	
	2015	Sept	21.4	20.6	20.3	21.4	17.1	18.5	^	
		May	11.5	21.1	22.6	36.7	16.9	20.1	^	
		Sept	17.8	17.2	18.0	15.0	13.8	18.8	^	
	A	2013	May	14.4	17.1	18.9	13.6	^	^	^
			July	18.4	16.4	17.1	21.0	^	^	^
Sept			14.4	14.7	13.4	12.1	^	^	^	
2014		May	22.4	22.8	20.1	25.1	^	^	^	
		July	16.3	17.7	16.8	14.6	^	^	^	
		Sept	18.0	17.7	23.4	19.4	^	^	^	
2015		May	20.3	24.7	21.1	23.8	^	^	^	
		July	30.3	31.2	24.3	25.1	^	^	^	
B	2013	May	^1/	10.9	11.3	7.3	^	^	12.1	
		July	^	15.1	19.0	18.4	^	^	15.7	
		Sept	^	9.2	11.5	11.8	^	^	11.0	
AVE			18.8	18.4	18.0	18.2	14.6	16.6	12.9	

1/ ^ Indicates the variety was not planted at the site.

Table A3. Average stand height (in) of clover varieties at the time of biomass sampling at Orchard T near Grandview, WA; Orchard A near Prosser, WA; and Orchard B near Zillah, WA.

Orchard	Year	Month	'Jumbo					VNS kura clover
			VNS white Dutch clover	Ladino' white clover	'Alice' white clover	'Kopu II' white clover	'Dominion' red clover	
-----in-----								
T	2013	July	7.0	9.2	12.5	10.5	17.7	*
		Sept	7.3	6.4	5.7	8.9	9.1	*
	2014	May	4.6	6.2	7.6	7.7	16.5	6.3
		July	* ^{1/}	*	*	*	16.0	*
		Aug	*	7.9	8.7	9.3	14.2	10.1
		Sept	*	11.5	11.0	9.7	13.4	8.9
		May	*	11.3	8.8	6.4	18.0	13.8
	2015	Sept	*	8.9	9.7	9.1	21.1	16.0
		May	7.2	8.8	11.5	13.0	18.0	7.1
	A	2013	July	12.5	12.5	10.5	12.7	22.3
Sept			9.7	10.5	10.0	11.8	15.7	*
May			4.9	7.1	10.0	8.1	13.4	*
2014		July	6.0	8.3	9.8	9.6	21.7	*
		Sept	*	8.9	11.5	11.2	16.4	*
		May	5.9	8.0	8.7	8.9	18.1	*
2015		July	10.0	8.0	10.1	10.6	18.0	*
		May	7.5	8.5	8.5	10.1	10.1	8.9
B	2013	July	10.5	11.8	11.2	10.5	16.4	*
		Sept	8.1	7.6	7.2	9.7	9.6	*
	AVE		7.8	9.0	9.6	9.9	16.1	10.2

1/ * Indicates height was not measured because legume percent cover was less than 20%.

Table A4. Average stand height (in) of other legume varieties and mixes at the time of biomass sampling at Orchard T near Grandview, WA; Orchard A near Prosser, WA; and Orchard B near Zillah, WA.

Orchard	Year	Month	'Antelope'	VNS	'Delaney'	'Lutana'	'Artisan II'	'Artisan II'	'Perfect'	'Vernema'	
			white prairie clover	birdsfoot trefoil	sainfoin	cicer milkvetch	alfalfa + VNS white Dutch clover	alfalfa + VNS kura clover	alfalfa + VNS white Dutch clover	alfalfa + VNS kura clover	
T	2013	July	* ^{1/}	9.3	17.7	17.7	*	23.0	^	^	
		Sept	*	4.2	8.7	6.6	14.2	15.1	^	^	
	2014	May	*	11.3	24.9	16.0	14.6	21.7	^	^	
		July	*	14.3	31.5	14.0	20.9	19.4	^	^	
		Aug	*	10.8	18.4	12.7	20.3	25.7	^	^	
	2015	Sept	*	9.8	24.8	12.1	18.4	20.3	^	^	
		May	*	12.1	31.9	16.5	22.8	24.5	^	^	
		Sept	*	8.0	10.2	20.9	16.4	18.8	^	^	
	A	2013	May	*	7.7	3.1	1.0	^ ^{2/}	^	15.0	11.8
			July	*	15.1	*	*	^	^	15.1	15.7
Sept			*	11.5	*	*	^	^	13.6	13.1	
2014		May	*	12.6	*	*	^	^	24.1	24.7	
		July	*	17.8	*	*	^	^	28.1	18.0	
		Sept	*	11.8	*	*	^	^	16.4	26.2	
2015		May	*	13.5	*	*	^	^	23.0	24.9	
		July	*	13.9	*	*	^	^	18.0	24.5	
B		2013	May	*	6.6	8.3	*	^	^	7.1	9.4
			July	*	15.7	*	*	^	^	12.5	13.1
	Sept		*	*	*	*	^	^	7.3	12.1	
AVE			*	11.5	18.0	13.1	18.2	21.1	16.4	17.6	

1/ * Indicates height was not measured because legume percent cover was less than 20%. 2/ ^ Indicates the variety was not planted at the site.

BIOMASS PER CUTTING AT EACH ORCHARD

Alfalfas

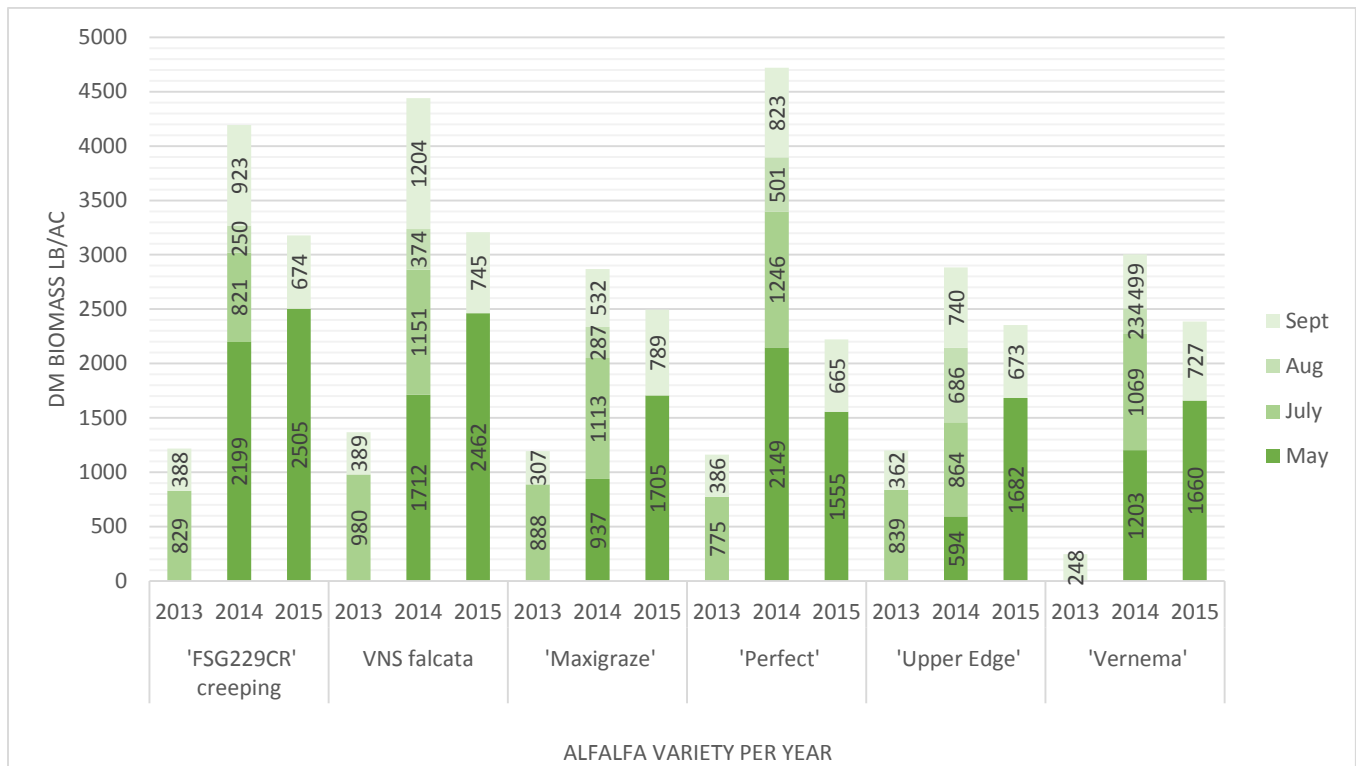


Figure A1. Biomass production (DM lb/ac) of alfalfa varieties at Orchard T near Grandview, WA. Biomass was sampled two times in 2013: 22 July and 19 September; four times in 2014: 7 May, 14 July, 15 August, and 11 September; and two times in 2015: 11 May and 14 September.

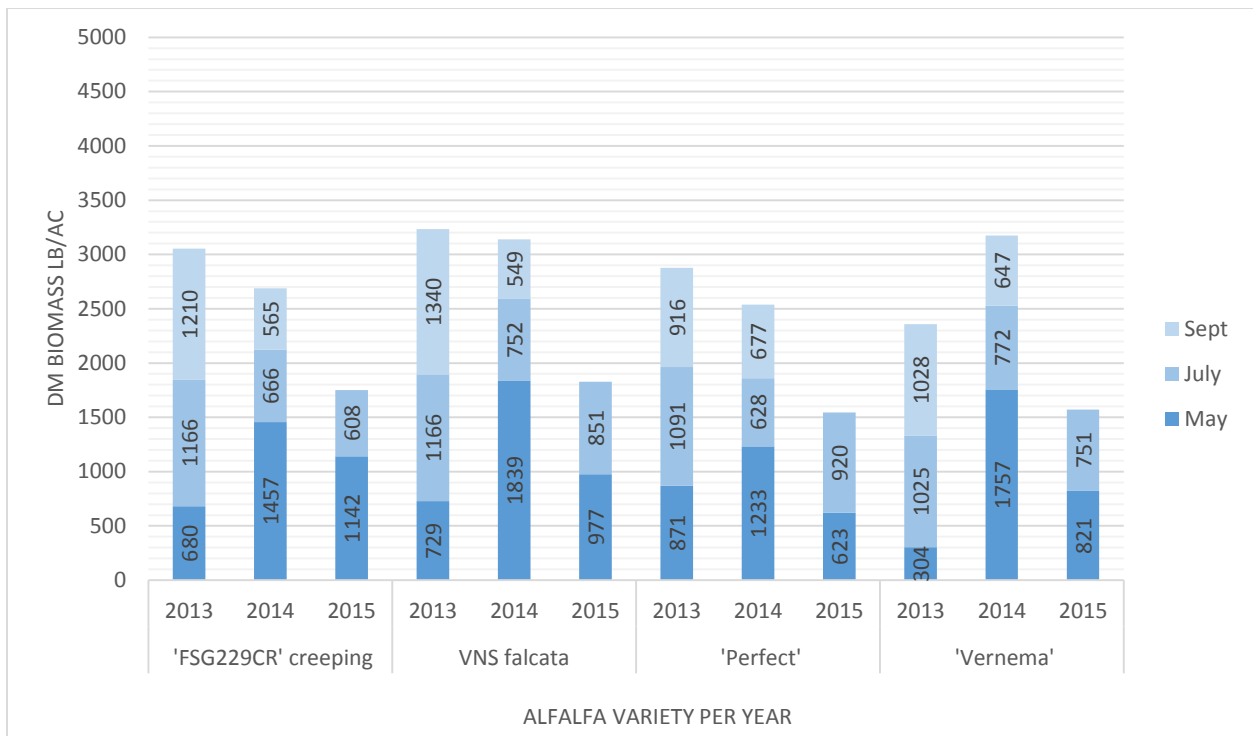


Figure A2. Biomass production (DM lb/ac) of alfalfa varieties at Orchard A near Prosser, WA. Biomass was sampled three times in 2013: 15 May, 20 July and 19 September; three times in 2014: 7 May, 15 July, and 11 September; and two times in 2015: 11 May and 15 July.

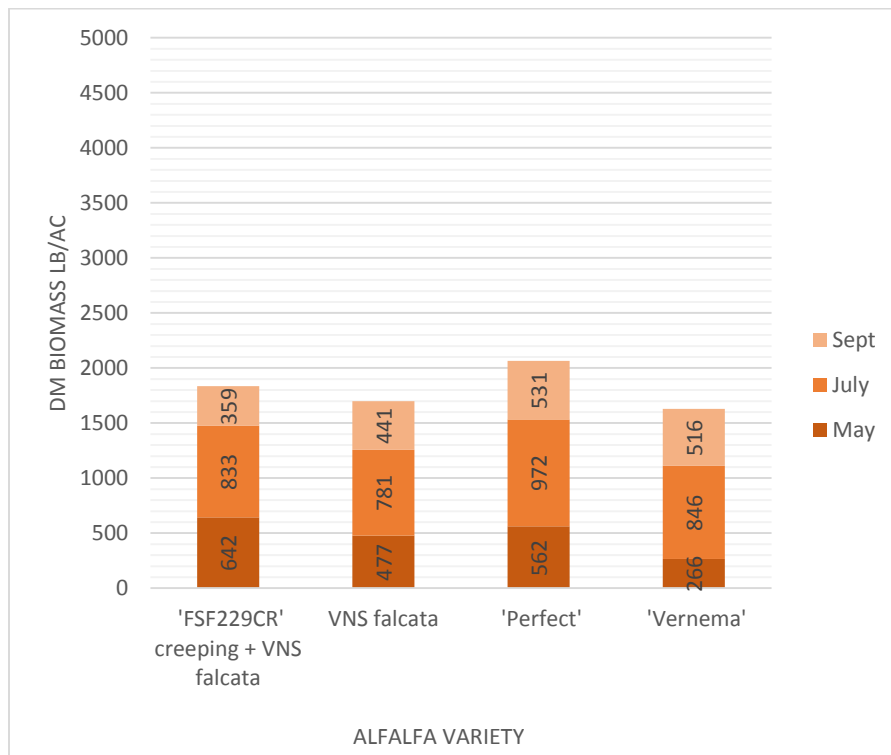


Figure A3. Biomass production (DM lb/ac) of alfalfa varieties in 2013 at Orchard B near Zillah, WA. Biomass was sampled three times: 16 May, 23 July, and 18 September.

Clovers

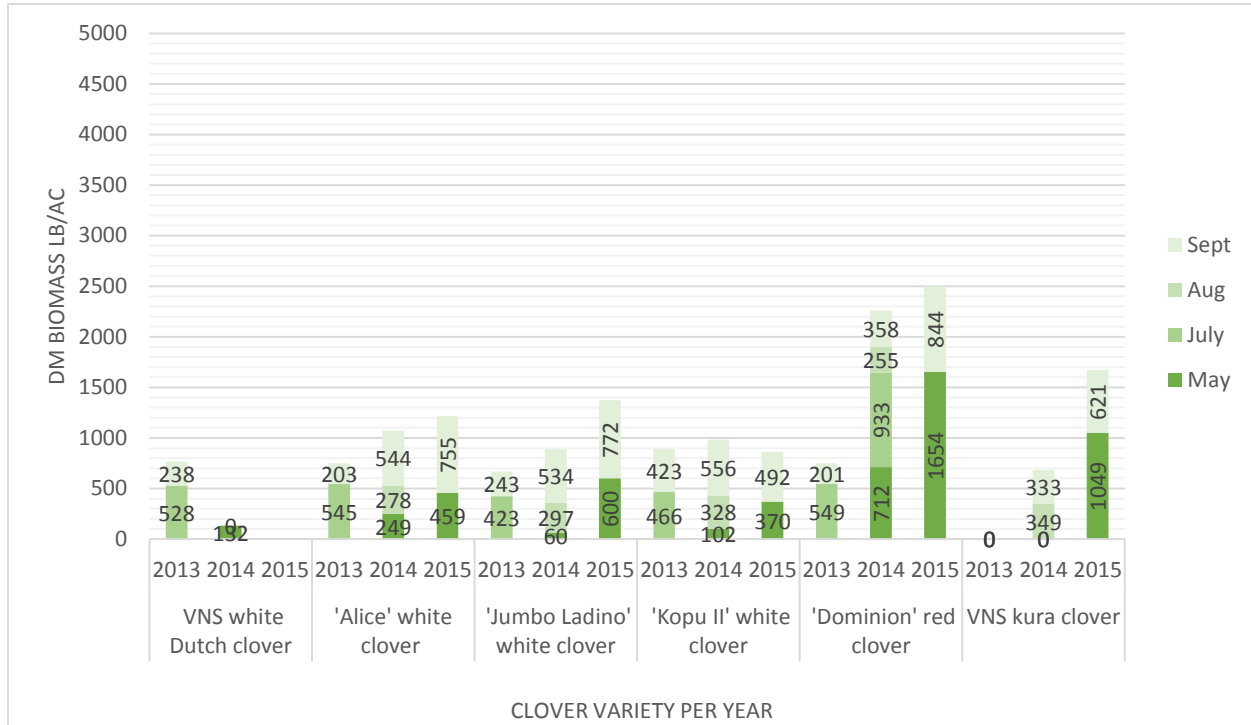


Figure A4. Biomass production (DM lb/ac) of clover varieties at Orchard T near Grandview, WA. Biomass was sampled two times in 2013: 22 July and 19 September; four times in 2014: 7 May, 14 July, 15 August, and 11 September; and two times in 2015: 11 May and 14 September.

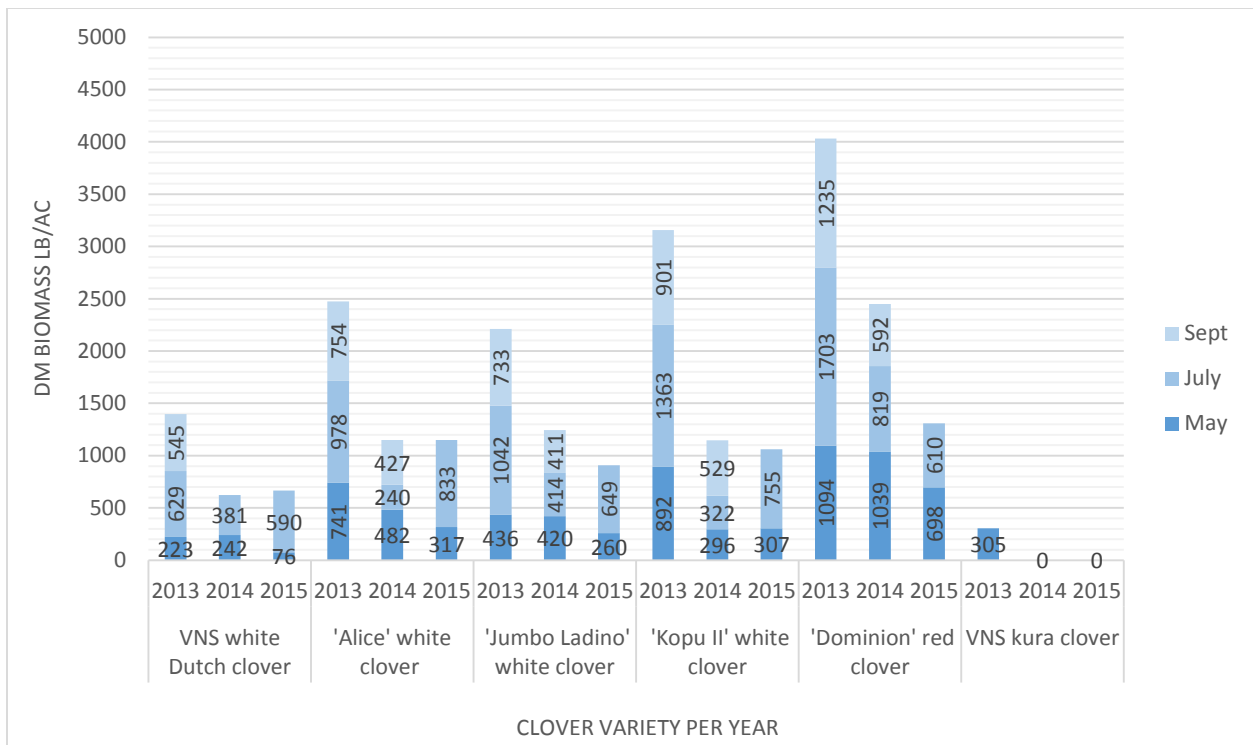


Figure A5. Biomass production (DM lb/ac) of clover varieties at Orchard A near Prosser, WA. Biomass was sampled three times in 2013: 15 May, 20 July and 19 September; three times in 2014: 7 May, 15 July, and 11 September; and two times in 2015: 11 May and 15 July.

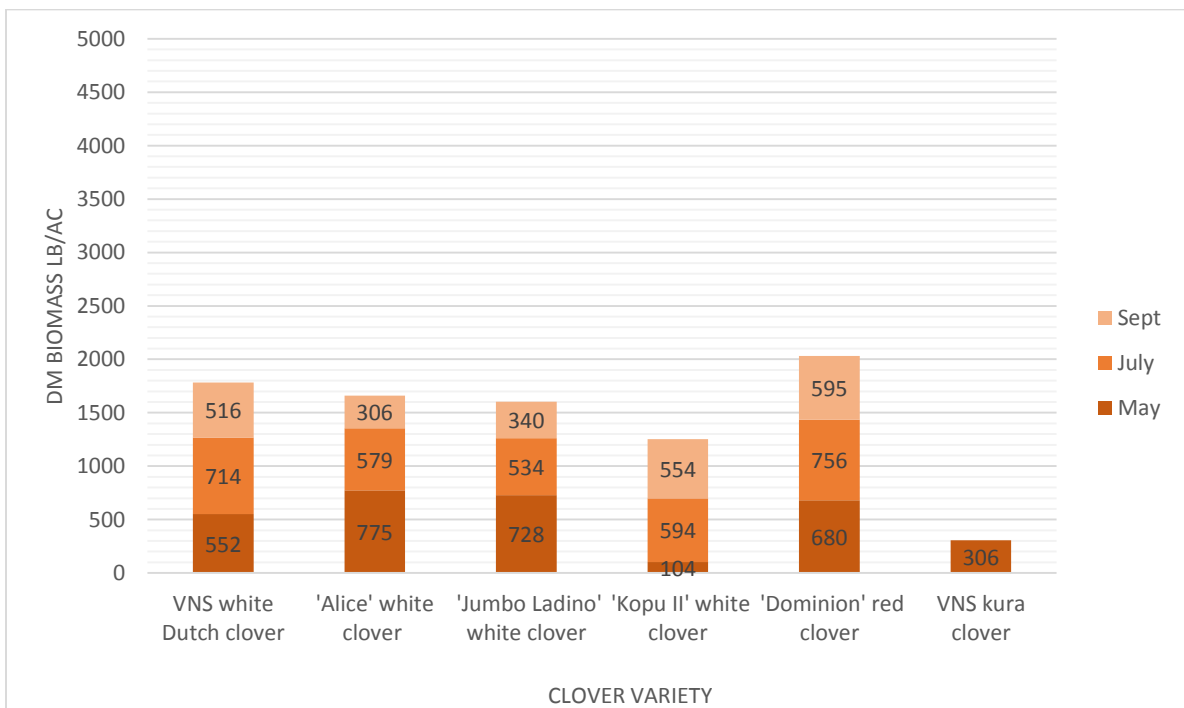


Figure A6. Biomass production (DM lb/ac) of clover varieties in 2013 at Orchard B near Zillah, WA. Biomass was sampled three times: 16 May, 23 July, and 18 September.

Other Legumes and Mixes

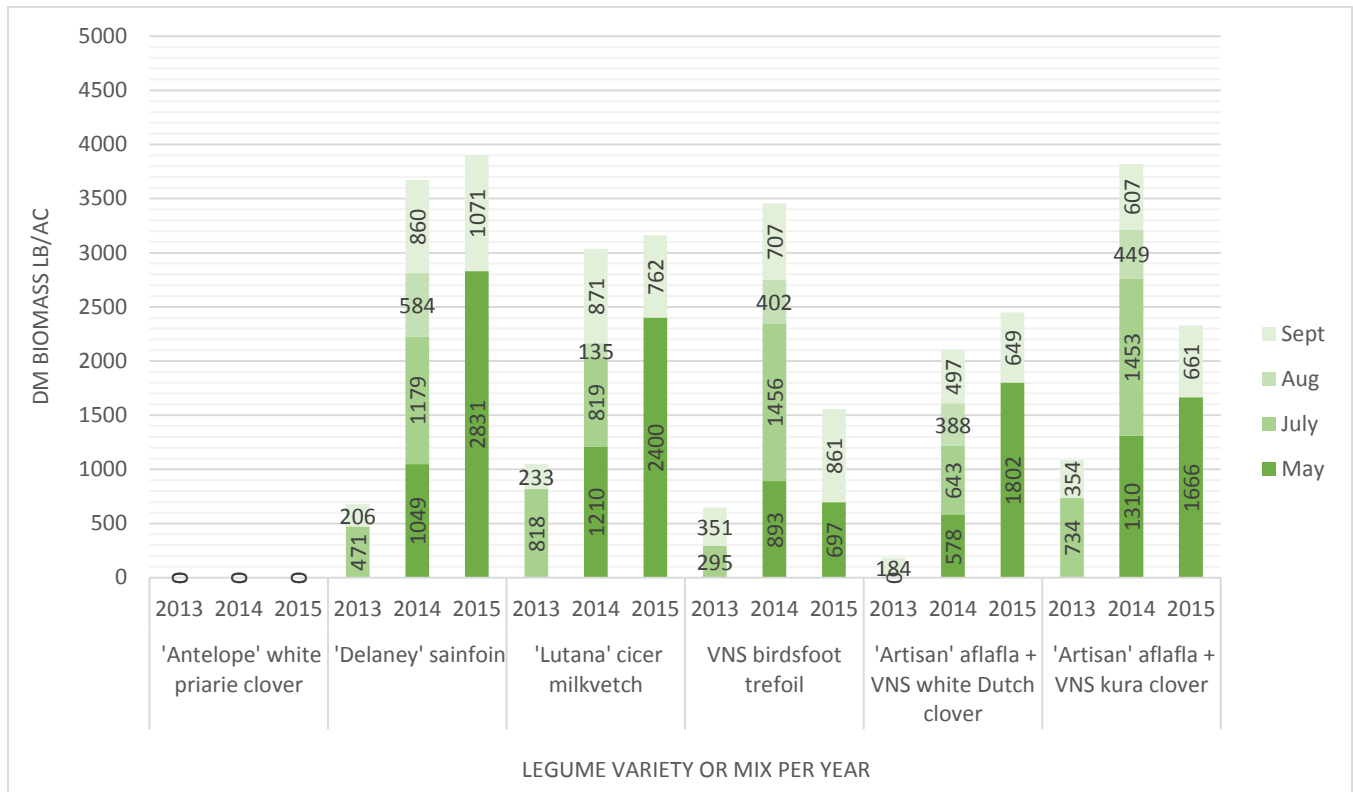


Figure A7. Biomass production (DM lb/ac) of other legume varieties at Orchard T near Grandview, WA. Biomass was sampled two times in 2013: 22 July and 19 September; four times in 2014: 7 May, 14 July, 15 August, and 11 September; and two times in 2015: 11 May and 14 September.

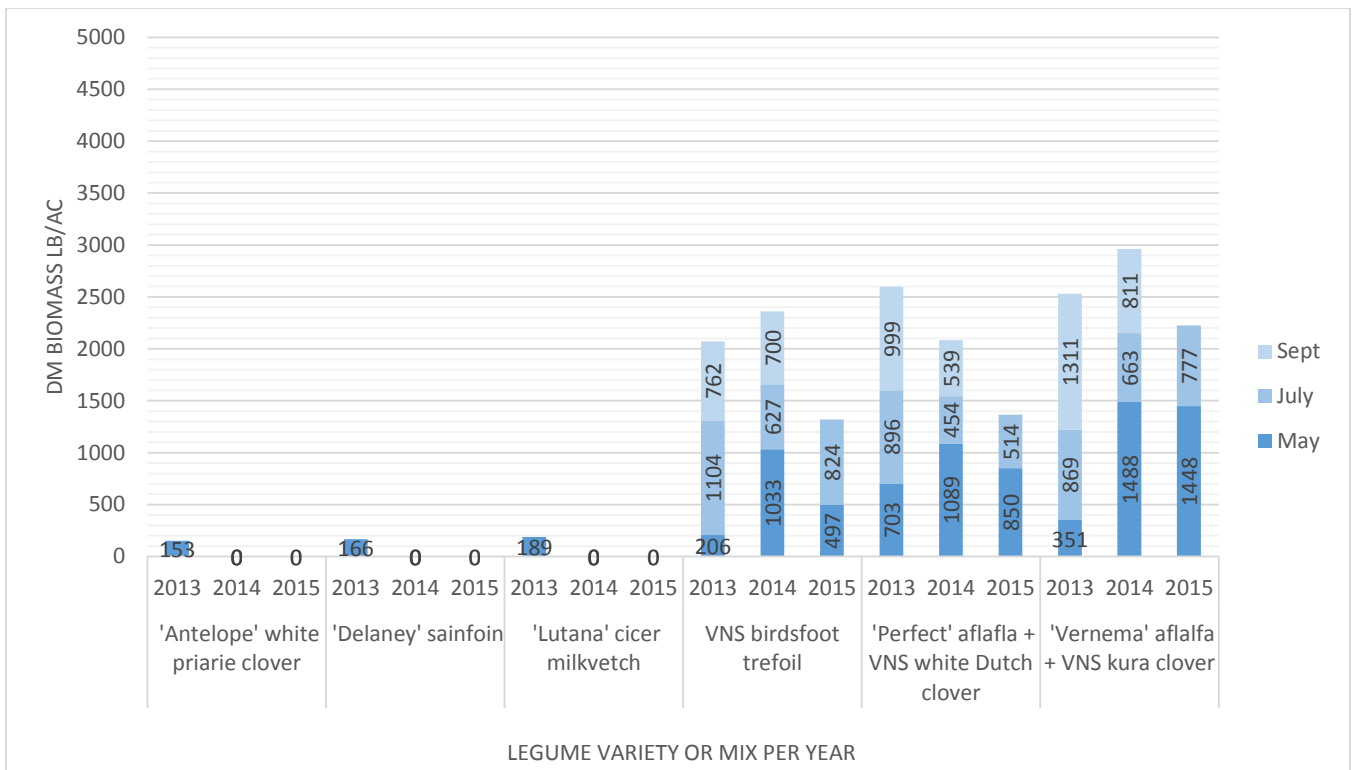


Figure A8. Biomass production (DM lb/ac) of other legume varieties and mixes at Orchard A near Prosser, WA. Biomass was sampled three times in 2013: 15 May, 20 July and 19 September; three times in 2014: 7 May, 15 July, and 11 September; and two times in 2015: 11 May and 15 July.

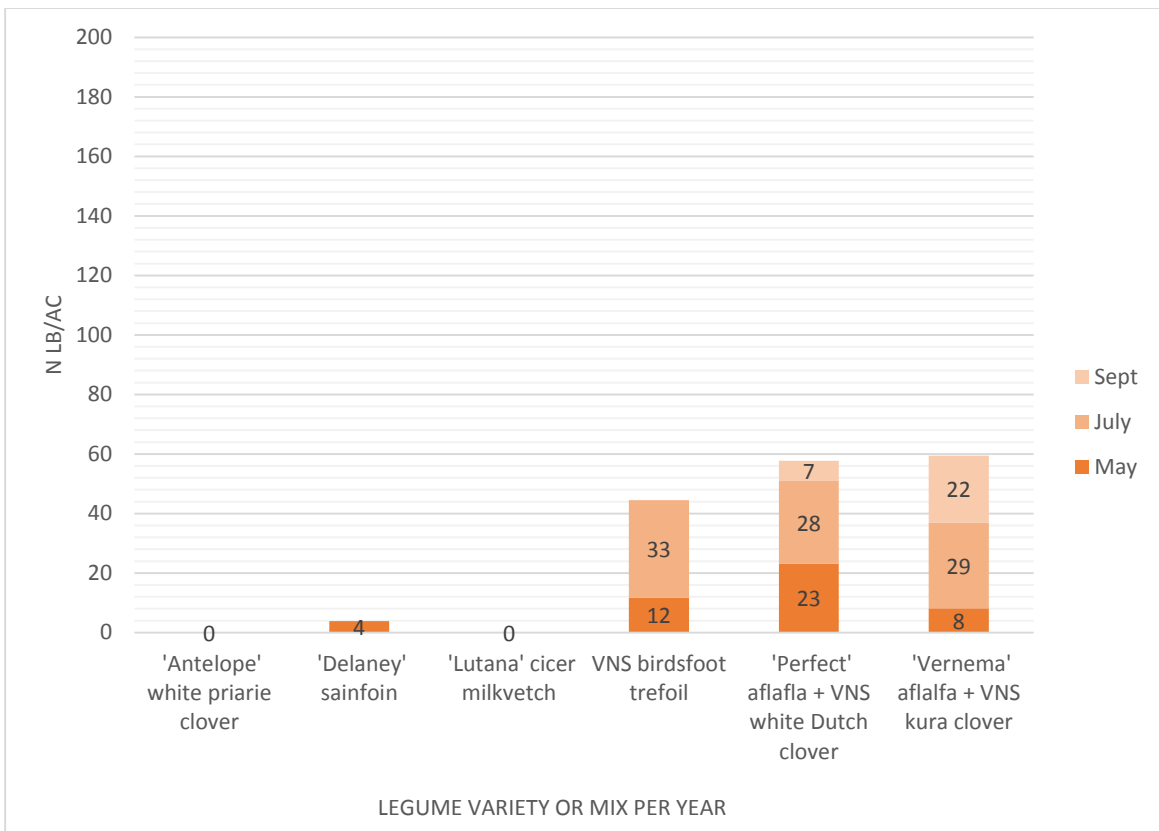


Figure A9. Biomass production (DM lb/ac) of other legume varieties and mixes in 2013 at Orchard B near Zillah, WA. Biomass was sampled three times: 16 May, 23 July, and 18 September.

PERCENT NITROGEN

Table A5. Percent nitrogen of annual legume biomass at Orchard A near Prosser, WA, and Orchard B near Zillah, WA.

Orchard	'Lana' woolypod vetch	VNS crimson clover	VNS hairy vetch	VNS Austrian winter pea	VNS subterranean clover
	% N				
A	3.2	2.3	3.5	2.8	2.2
B	4.2	2.6	4.9	3.8	2.4

Table A6. Percent nitrogen of alfalfa plot biomass at Orchard T near Grandview, WA; Orchard A near Prosser, WA; and Orchard B near Zillah, WA.

Orchard	Year	Month	% N					'Upper Edge'	'FSG229CR' creeping + VNS falcata
			'FSG229CR' creeping	VNS falcata	'Perfect'	'Vernema'	'Maxigraze'		
T	2013	July	3.9	4.3	4.6		3.7	4.5	^
		Sept	4.3	4.9	4.8	4.3	4.4	4.8	^
	2014	May	3.7	4.3	3.8	3.6	4.4	4.0	^
		July	3.3	3.7	3.0	2.6	3.0	3.0	^
		Aug	3.9	4.5	4.6	4.7	4.3	4.1	^
	2015	Sept	4.8	4.8	4.8	4.7	4.0	5.0	^
		May	3.8	3.9	3.6	3.6	3.4	3.3	^
		Sept	4.2	3.4	3.9	3.2	3.5	3.8	^
		May	2.9	2.9	3.3	2.4	^	^	^
	A	2013	July	2.9	2.5	2.6	2.9	^	^
Sept			3.7	4.2	3.3	3.9	^	^	^
May			4.1	4.0	4.1	3.9	^	^	^
2014		July	4.3	3.5	3.6	3.8	^	^	^
		Sept	3.8	3.8	3.6	3.7	^	^	^
2015		May	4.4	4.2	4.1	3.9	^	^	^
		July	3.8	3.2	3.5	3.0	^	^	^
B	2013	May	^1/	3.2	4.1	3.1	^	^	3.4
		July	^	3.7	3.6	3.4	^	^	3.6
		Sept	^	3.4	4.1	4.3	^	^	3.6
AVE			3.9	3.8	3.8	3.6	3.8	4.1	3.5

1/ ^ Indicates the variety was not planted at the site.

Table A7. Percent nitrogen of clover plot biomass at Orchard T near Grandview, WA; Orchard A near Prosser, WA; and Orchard B near Zillah, WA.

Orchard	Year	Month	'Jumbo					VNS kura clover
			VNS white Dutch clover	Ladino' white clover	'Alice' white clover	'Kopu II' white clover	'Dominion' red clover	
			----- % N -----					
T	2013	July	3.6	4.3	4.1	4.4	3.4	*
		Sept	3.9	4.2	3.9	4.2	3.6	*
	2014	May	4.4	4.3	3.9	4.4	3.6	*
		July	* ^{1/}	*	*	*	2.7	*
		Aug	*	3.7	4.2	4.2	3.5	3.9
		Sept	*	4.9	5.1	4.8	3.5	3.7
		May	*	3.9	4.2	3.7	2.9	2.9
	2015	Sept	*	4.2	2.7	4.0	3.1	3.6
		May	2.5	2.2	3.0	3.2	3.3	1.7
	A	2013	July	2.8	3.0	2.7	2.9	2.7
Sept			3.9	4.1	4.0	3.2	3.1	*
May			3.4	3.9	4.3	4.2	4.1	*
2014		July	3.2	3.3	3.9	3.8	4.0	*
		Sept	*	4.0	4.1	4.3	4.0	*
2015		May	2.7	2.8	3.2	3.4	3.4	*
		July	3.1	3.1	2.6	3.0	3.4	*
B		2013	May	4.0	3.5	3.0	4.0	3.8
	July		4.3	4.9	4.2	4.7	4.5	*
	Sept		3.6	3.3	3.6	4.1	2.6	*
AVE			3.5	3.8	3.7	3.9	3.4	3.0

1/ * Indicates biomass percent nitrogen was not measured because legume percent cover was less than 20%

Table A8. Percent nitrogen of other legume and mix plot biomass at Orchard T near Grandview, WA; Orchard A near Prosser, WA; and Orchard B near Zillah, WA.

Orchard	Year	Month	'Antelope'	VNS	'Delaney'	'Lutana'	'Artisan II'	'Artisan II'	'Perfect'	'Vernema'	
			white prairie clover	birdsfoot trefoil	sainfoin	cicer milkvetch	alfalfa + VNS white Dutch clover	alfalfa + VNS kura clover	alfalfa + VNS white Dutch clover	alfalfa + VNS kura clover	
			----- % N -----								
T	2013	July	* ^{1/}	3.9	*	3.9	*	3.8	^	^	
		Sept	*	3.6	*	4.4	4.2	4.0	^	^	
	2014	May	*	3.5	2.2	4.2	3.5	3.9	^	^	
		July	*	2.9	3.1	3.3	3.0	2.6	^	^	
		Aug	*	4.0	3.8	*	4.4	4.2	^	^	
	2015	Sept	*	4.1	3.6	*	4.8	5.1	^	^	
		May	*	2.8	2.0	3.2	3.6	3.8	^	^	
	A	2013	Sept	*	2.8	2.8	3.7	3.8	3.9	^	^
			May	1.9	2.2	1.7	2.6	^ ^{2/}	^	3.6	2.0
		2014	July	*	2.3	*	*	^	^	2.9	2.3
Sept			*	3.1	*	*	^	^	3.4	3.8	
May			*	4.4	*	*	^	^	4.7	3.9	
2015		July	*	3.0	*	*	^	^	3.8	3.3	
		Sept	*	3.4	*	*	^	^	3.5	3.3	
B		2013	May	*	3.4	*	*	^	^	3.8	4.2
			July	*	3.3	*	*	^	^	3.6	3.1
		2014	May	*	3.6	2.7	*	^	^	3.0	3.0
	July		*	4.5	*	*	^	^	3.9	3.4	
2015	Sept	*	*	*	*	^	^	3.6	3.0		
	AVE		1.9	3.4	2.7	3.6	3.9	3.9	3.6	3.2	

1/ * Indicates biomass percent nitrogen was not measured because legume percent cover was less than 20%. 2/ ^ Indicates the variety was not planted at the site.

BIOMASS NITROGEN PRODUCTION
Alfalfas

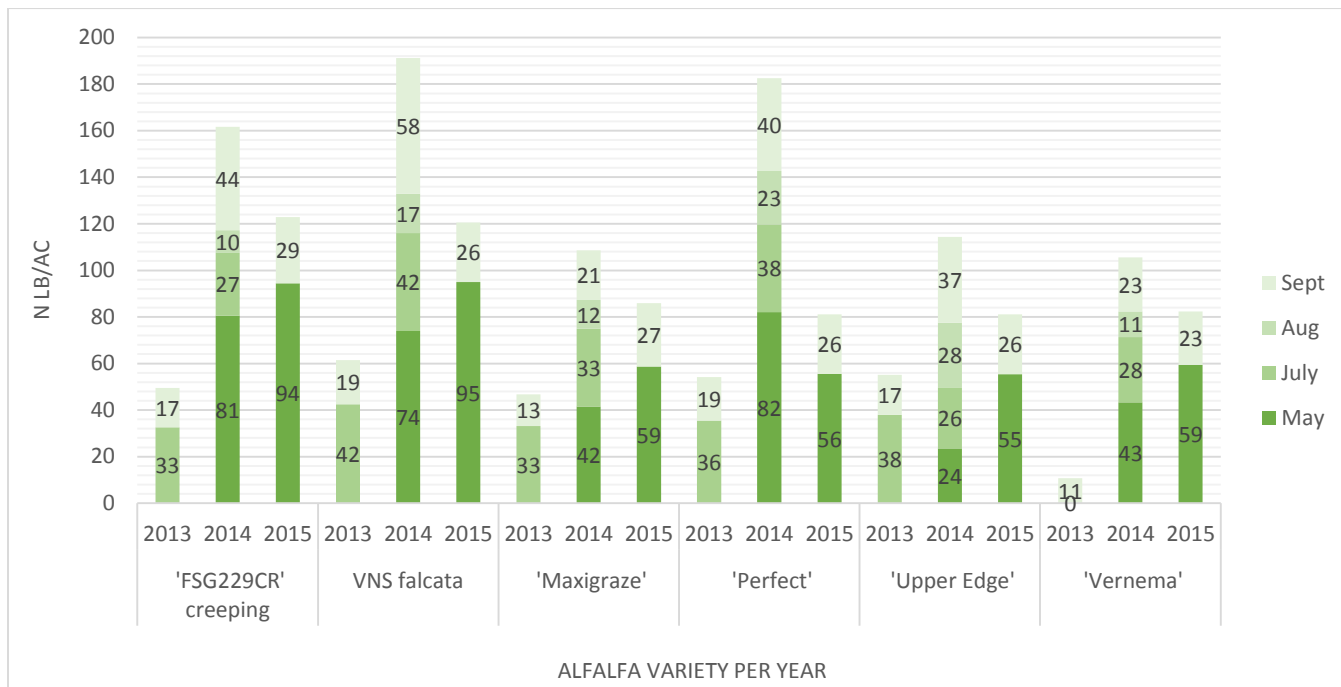


Figure A10. Biomass nitrogen production (N lb/ac) of alfalfa varieties at Orchard T near Grandview, WA. Biomass was sampled two times in 2013: 22 July and 19 September; four times in 2014: 7 May, 14 July, 15 August, and 11 September; and two times in 2015: 11 May and 14 September.

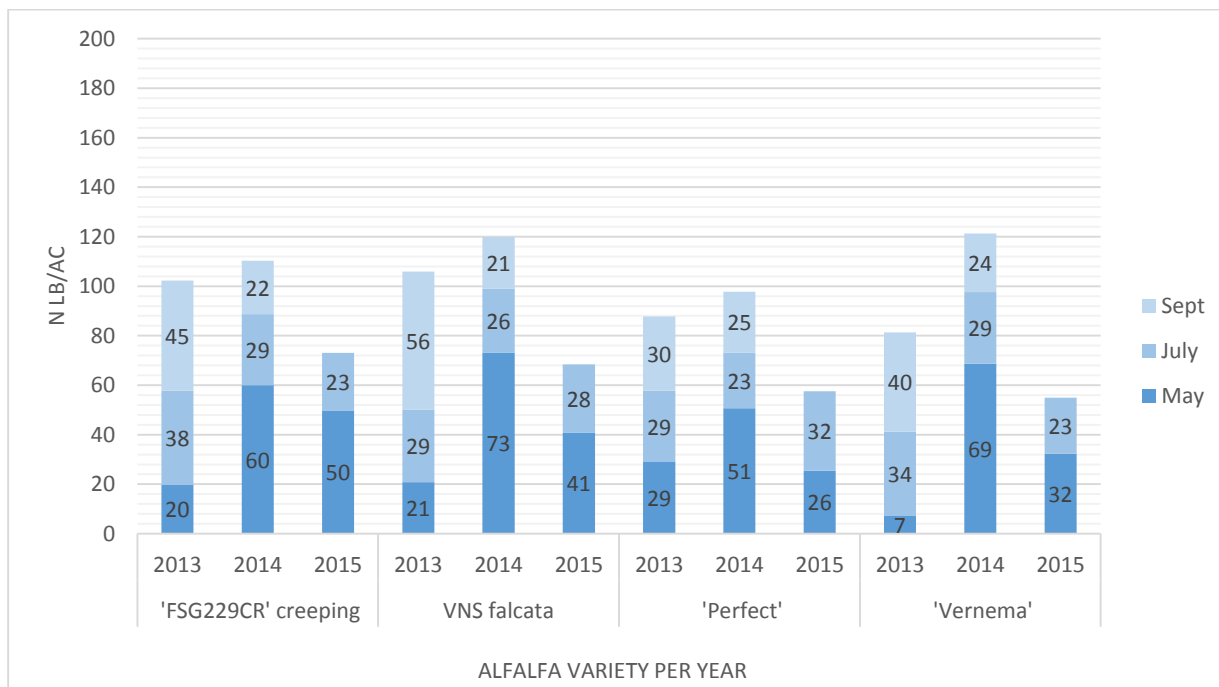


Figure A11. Biomass nitrogen production (N lb/ac) of alfalfa varieties at Orchard A near Prosser, WA. Biomass was sampled three times in 2013: 15 May, 20 July and 19 September; three times in 2014: 7 May, 15 July, and 11 September; and two times in 2015: 11 May and 15 July.

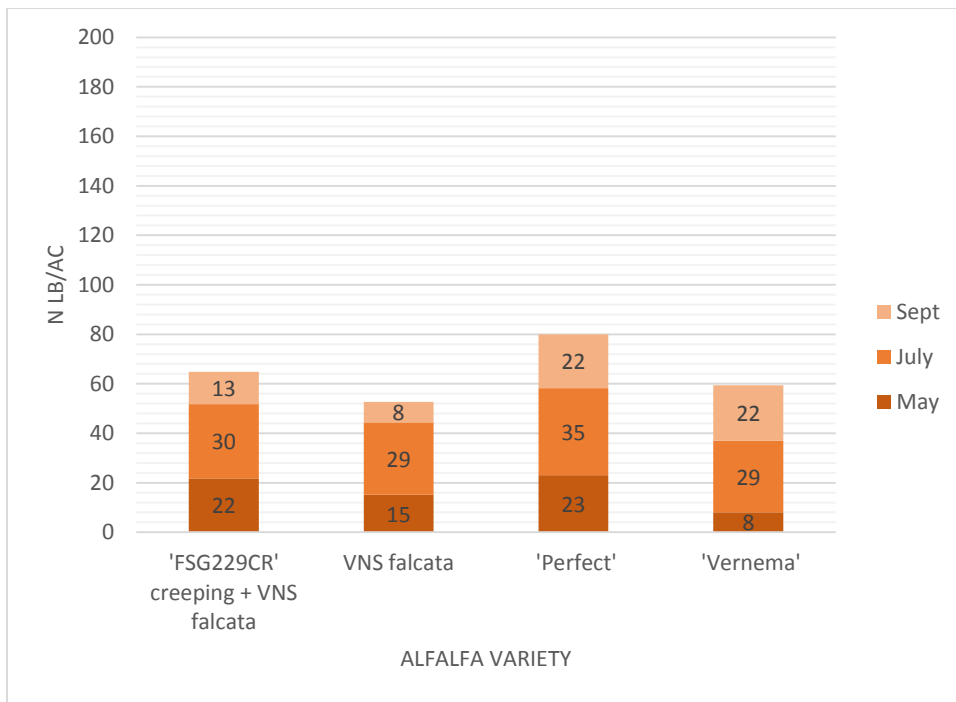


Figure A12. Biomass nitrogen production (N lb/ac) of alfalfa varieties at Orchard B near Zillah, WA. Biomass was sampled three times: 16 May, 23 July, and 18 September.

Clovers

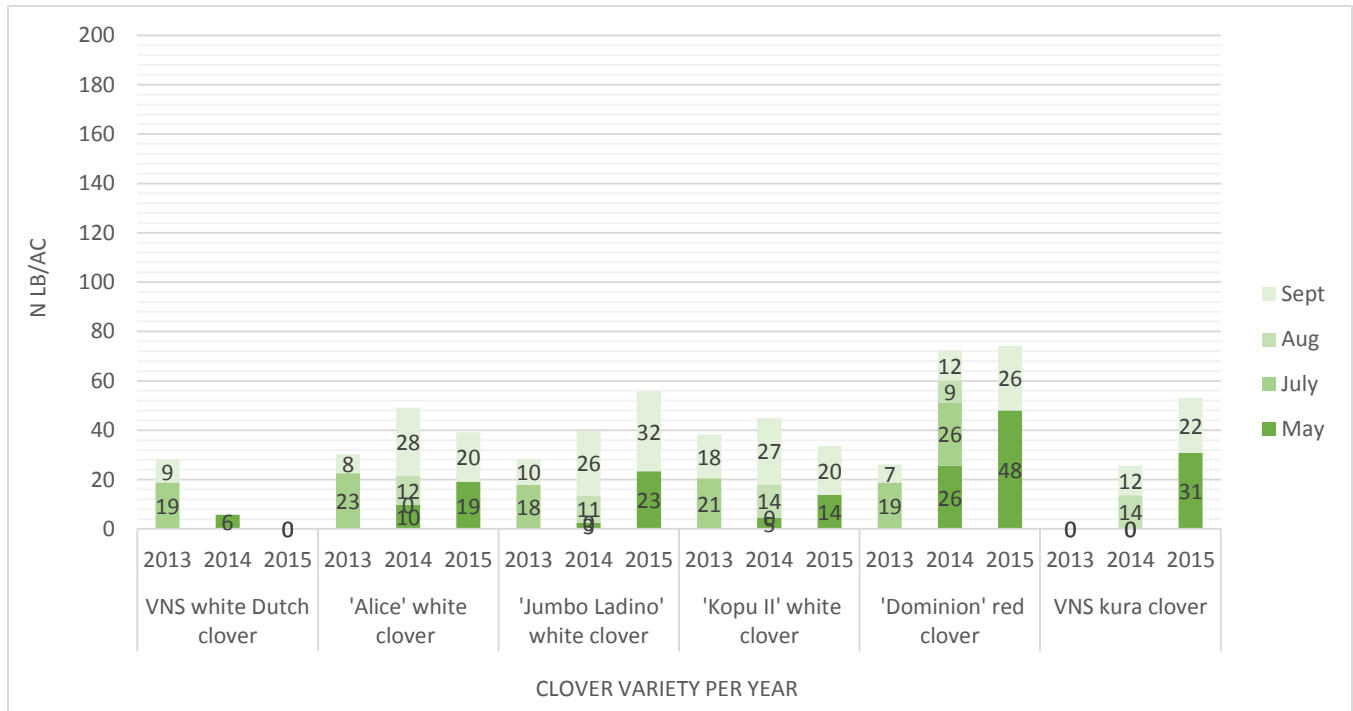


Figure A13. Biomass nitrogen production (N lb/ac) of clover varieties at Orchard T near Grandview, WA. Biomass was sampled two times in 2013: 22 July and 19 September; four times in 2014: 7 May, 14 July, 15 August, and 11 September; and two times in 2015: 11 May and 14 September.

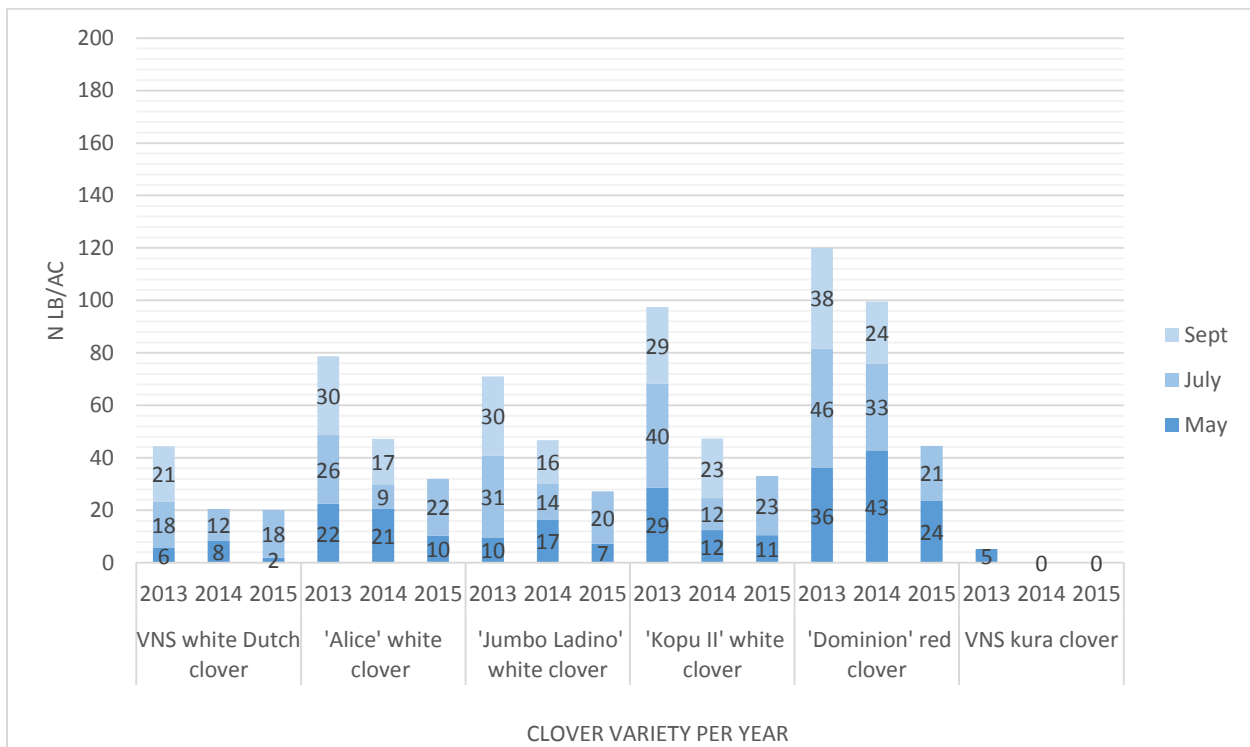


Figure A14. Biomass nitrogen production (N lb/ac) of clover varieties at Orchard A near Prosser, WA. Biomass was sampled three times in 2013: 15 May, 20 July and 19 September; three times in 2014: 7 May, 15 July, and 11 September; and two times in 2015: 11 May and 15 July.

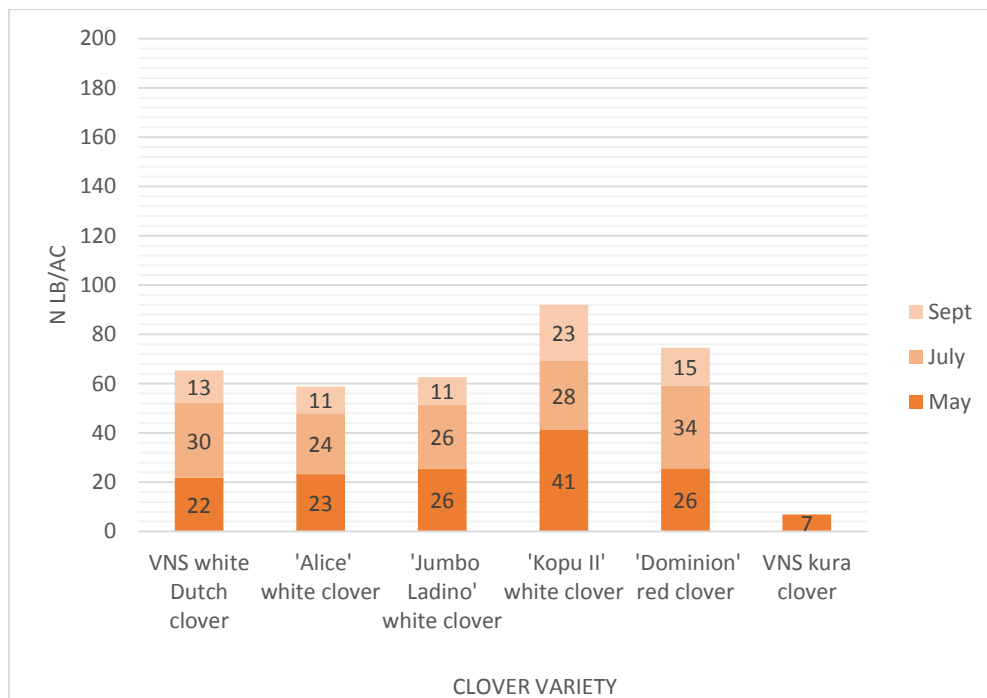


Figure A15. Biomass nitrogen production (DM lb/ac) of clover varieties at Orchard B near Zillah, WA. Biomass was sampled three times: 16 May, 23 July, and 18 September.

Other Legumes and Mixes

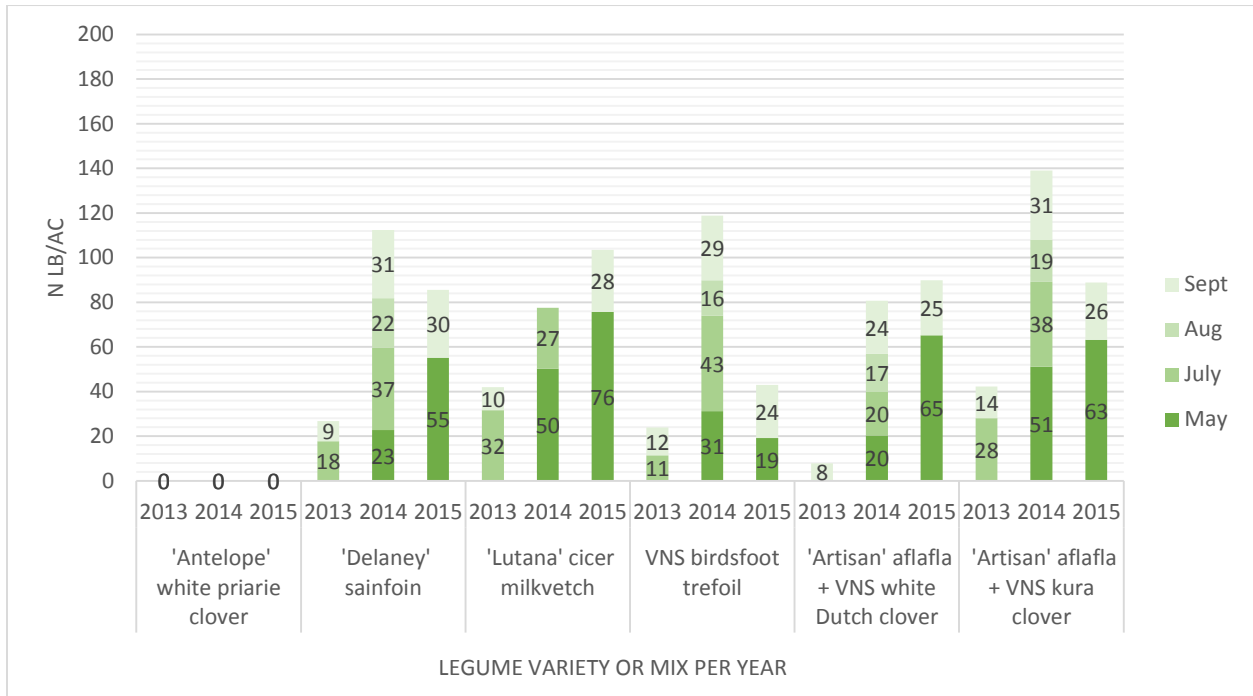


Figure A16. Biomass nitrogen production (N lb/ac) of other legume varieties and mixes at Orchard T near Grandview, WA. Biomass was sampled two times in 2013: 22 July and 19 September; four times in 2014: 7 May, 14 July, 15 August, and 11 September; and two times in 2015: 11 May and 14 September.

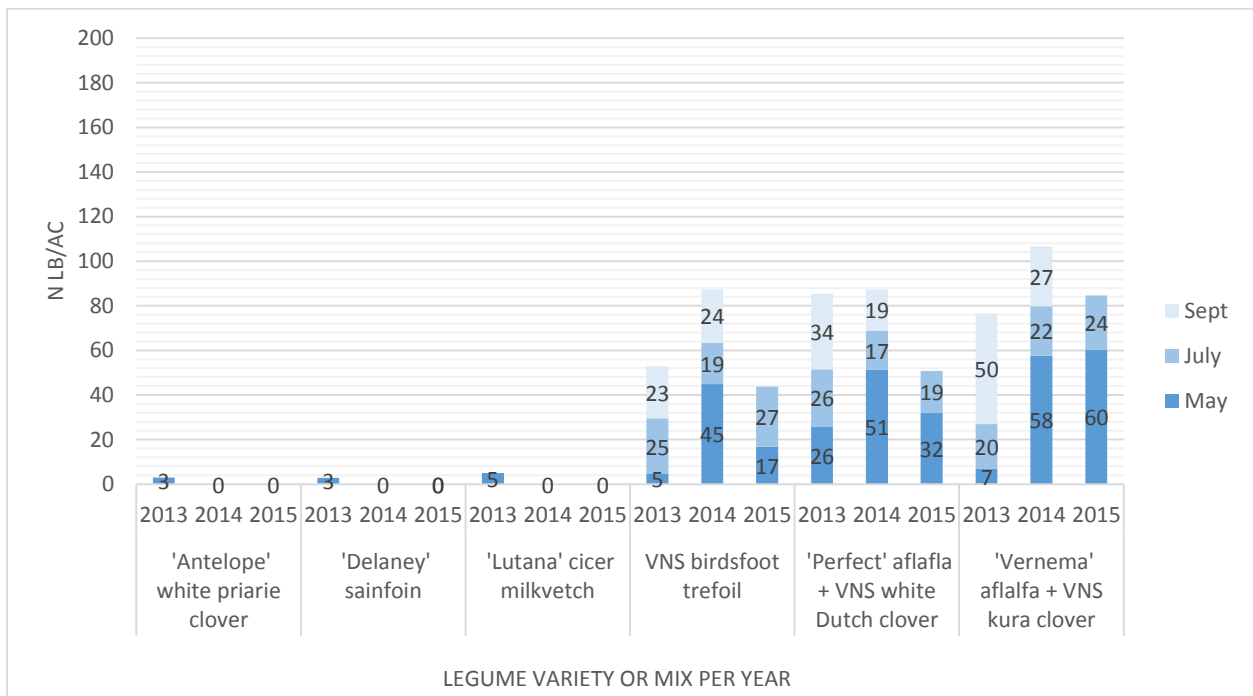


Figure A17. Biomass nitrogen production (N lb/ac) of other legume varieties and mixes at Orchard A near Prosser, WA. Biomass was sampled three times in 2013: 15 May, 20 July and 19 September; three times in 2014: 7 May, 15 July, and 11 September; and two times in 2015: 11 May and 15 July.

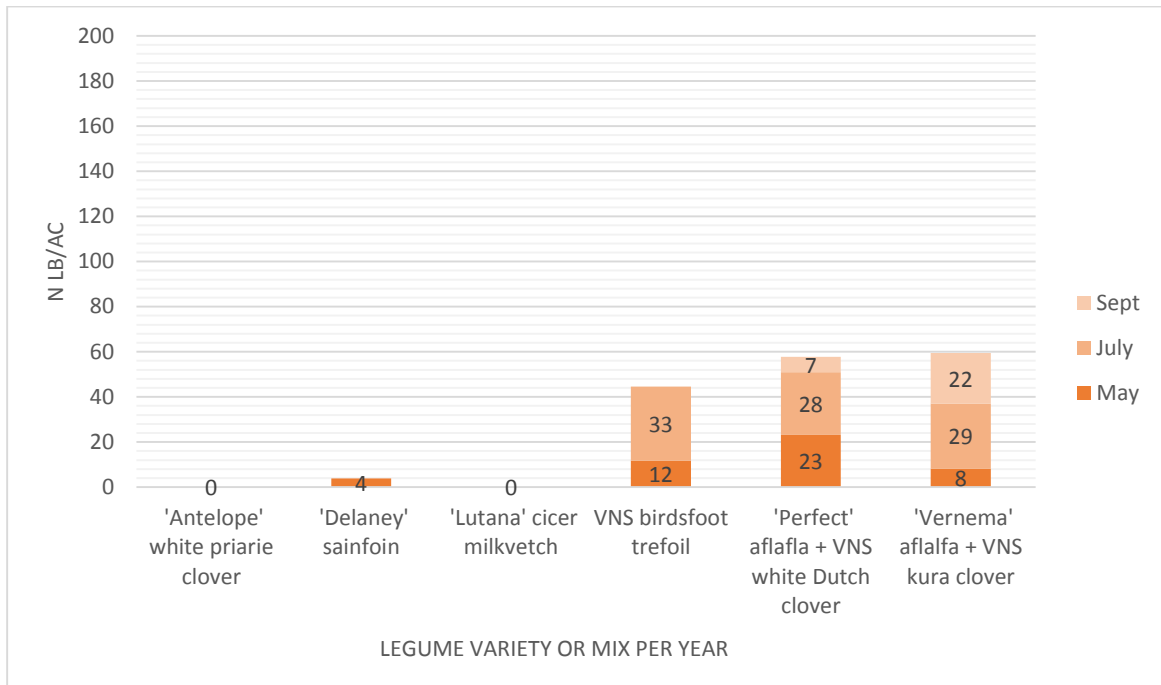


Figure A18. Biomass nitrogen production (DM lb/ac) of other legume varieties and mixes at Orchard B near Zillah, WA. Biomass was sampled three times: 16 May, 23 July, and 18 September.

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