



## Compost Application Effects on Rangeland Species Composition and Forage Production

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### ABSTRACT

Compost application on degraded rangelands in California is postulated as a method to improve forage and soil health. The objective of this replicated field study was to track changes in species composition and forage production, as well as, note any physical or chemical changes in soil properties after the addition of supplementary organic matter and nutrients. The trial was conducted over three years (2016-2019) at the Plant Materials Center in Lockeford, California. The site was divided into 3 blocks, each with a different type of rangeland vegetation including: annual weedy grasses planted to annual 'Cucamonga' California brome (*Bromus carinatus* Hook.& Arn) planted in 2015, 'Berber' orchardgrass (*Dactylis glomerata* L.) planted in 2012, and purple needlegrass (*Nasella pulchra* A.S. Hitch.) planted in 2012. Baseline evaluations were collected in 2016, and line-point intercept transects, and forage production were collected annually over the course of the trial. The plots were not grazed. In both annual and perennial species blocks, legume cover was lower in the compost treatment for the first two years but lost this effect by the third year after application. Results from the perennial species blocks indicate that an application of compost can increase the estimated dry matter yield significantly, compared to untreated plots, however, there were no significant differences in dry matter yield between treatments in the annual species block. By the third year, the compost application had little to no effect on forage quality and California brome and purple needlegrass blocks had shifted toward less desirable annual grass populations. This study indicated that a single application of compost to an introduced perennial grass species like orchardgrass may show some benefits but those benefits may not be as apparent in a native perennial grass stand, and a single compost application to an annual grass stand may not show desired long-term improvements.

### INTRODUCTION

Rangelands are the most abundant grassland use in California. Valley and coastal annual grasslands comprise over 22 million acres in the state (Ryals and Silver, 2013). The original vegetation of California valley grasslands included native perennial bunch grasses such as purple needlegrass, which were displaced as early as the 1850s in part by grazing of cattle and sheep (Burcham, 1981). The grasslands now are composed largely of non-native annual grasses and forb species including wild oats (*Avena barbata*), soft chess (*Bromus hordeaceus*), ripgut brome (*Bromus diandrus*), annual ryegrass (*Lolium multiflorum*), filaree (*Erodium* spp.), and clovers, (*Trifolium* spp). Large areas in the Central Valley in California were farmed to small grain crops from about 1910 until the end of World War II and during this time, with associated tillage and soil disturbance. (Burcham, 1957; Olmstead and Rhode, 1988) As the market decreased these areas were left fallow to return to rangelands dominated by annual weedy species. Today many

of those areas exhibit poor resource conditions with low soil aggregate stability, low organic matter and soil surface loss. In addition, even less productive noxious annual weeds including cheat grass (*Bromus tectorum*), medusahead (*Taeniatherum caput-medusae*) barbed goatgrass (*Aegilops triuncialis*), and yellow star thistle (*Centaurea solstitialis*) are increasing problems in rangeland areas.

Native California bunchgrasses, such as purple needlegrass are adapted for growth in the Mediterranean climate of California, with strong deep root systems to store carbon and promote survival in times of drought. Conversely, annual grass species have shallow root systems and utilize nitrogen during fall and early spring. When moisture levels are high enough for growth, copious seed is produced early and the plants senesce as an adaptation to drought (Jackson et al., 1988). Perennial grasses continue growth for a longer duration than annual grasses during a wet season translocating more carbon to deeper rooting zones. This shift to annual grassland leads to a reduction in carbon holding capacity of soils of an estimated 17.8 tons/acre (Koteen et al., 2011).

Grasslands have the potential to sequester carbon caused by increasing atmospheric concentrations of greenhouse gases such as carbon dioxide, methane and nitrous oxide (Chambers et al., 2016; DeLonge et al., 2013; Lal, 2004). Ryals and Silver (2013) evaluated the potential for application of compost amendments to increase net primary productivity to annual grasslands. A single compost amendment applied at two locations in California, on coastal grasslands in Nicasio and valley grasslands at the UC Sierra Foothill Research and Extension Center in Browns Valley, significantly increased carbon storage in these rangeland systems. A lifecycle model showed that using composted manure and plant wastes resulted in significant offsets to greenhouse gas emissions: improved manure and landfill management were most important by reducing emissions, followed by increased plant productivity, soil carbon sequestration and reduced need for secondary feed (DeLonge et al., 2013; Ryals et al., 2015). Compost has also been shown to increase nutrient cycling, improve soil fertility and increase soil microbes, thus increasing soil carbon sequestration (Hartz et al, 2000).

This study was coordinated with a large network of demonstration plantings established across California targeting degraded rangelands for compost application with hopes that added organic matter and nutrients would improve soil and rangeland health. The objective of the replicated study at the Plant Materials Center in Lockeford, California (CAPMC) was to track changes in plant species composition and biomass production after compost application to areas containing common weedy species on California rangelands and planted to annual 'Cucamonga' California brome (planted in 2015), 'Berber' orchardgrass (planted in 2012), and purple needlegrass (planted in 2012). Physical or chemical changes in soil properties and soil infiltration rates were tracked over the three-year trial period.

## **MATERIALS AND METHODS**

The compost application trial was conducted over three years (2016-2019) at the CAPMC, located on the eastern side of the San Joaquin Valley in central California on a historical flood plain on the east bank of the Mokelumne River. The soil series are Columbia and Vina fine sandy loams on 0-2 percent slopes. They are both very deep, well-drained soils with pH ranging from moderately acid to slightly alkaline. The mean annual maximum temperature in this area is

73.6°F and minimum temperature is 46°F (WRCC, 2018). The mean annual precipitation is 17.24 inches, mainly occurring between the months of December and March (WRCC, 2018). Precipitation totals were record breaking throughout California during the 2016-2017 growing season. Total precipitation between September 1, 2016 and August 1, 2017 at the Lockeford PMC was 32 inches, while precipitation was just under 17 inches between September 1, 2017 and August 1, 2018 and was 24 inches between September 1, 2018 and August 1, 2019 shown in Figure 1 (WWG, 2019).

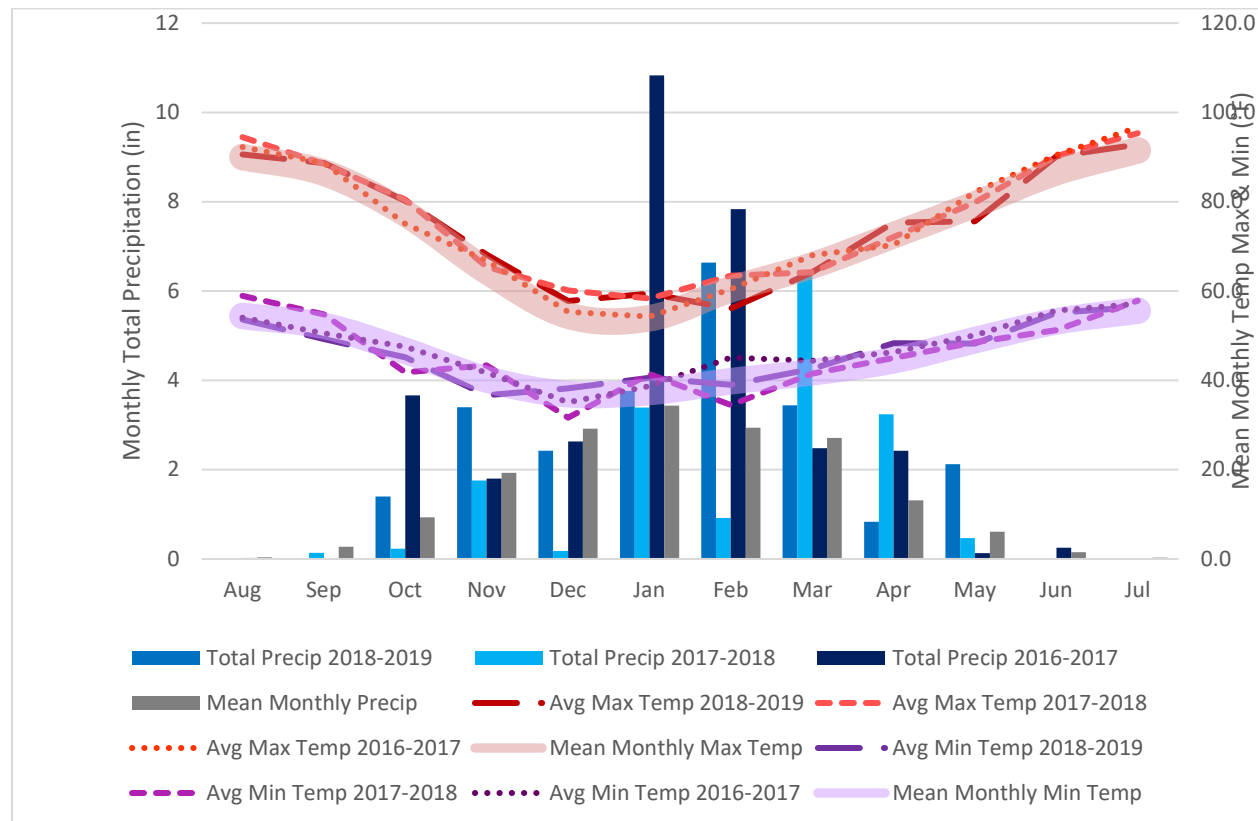


**Figure 1.** Mean minimum and maximum temperatures in the 2016/2017, 2017/2018, and 2018/2019 growing seasons generally followed annual averages. Total precipitation was nearly double the annual average in 2016/2017. Monthly weather data from September through August was provided from Western Weather Group Lockeford Weather Station located directly across the river from the CAPMC. Average weather summaries from 1893-2015 for the Lodi area were provided from Western Regional Climate Center.

The trial site in Field 4 at the CAPMC included three established areas of rangeland vegetation. In November 2012, a native perennial grass, purple needlegrass, and a non-native perennial, orchardgrass were planted using a Truax range drill at ¼ inch depth. Seeding rates were 8 lb/acre for orchardgrass and 10 lb/ac for purple needlegrass plots. A third area was dominated by invasive annual grasses and was planted in November 2015 to the annual native 'Cucamonga' California brome using a Truax range drill at 10 lb/ac at ¼ inch depth. These perennial and annual grass plots were not irrigated during establishment. After planting and establishment in 2012 and 2015, the plots were managed by an annual mowing after seed set. No herbicides were applied to the plots. The blocks were designated as follows Block 1 (B1), 'Cucamonga' California brome, Block 2 (B2), 'Berber' orchardgrass and Block 3 (B3), purple needlegrass. Each block is surrounded by an 8 ft. border and is subdivided into 4 replications (randomized compost application or no compost). Each compost treated plot was approximately 95 ft. long by 37 ft.

wide and each untreated plot was approximately 95 ft. long by 58 ft. wide (Figure 2). The difference in size between treated and untreated plots was due to a limited compost supply.

Baseline evaluations were collected within each plot before compost was applied. Baseline species composition data was collected late-April 2016 using 50 ft. line-point intercept transects within each plot. Data points were characterized by plant species or noted as organic matter or bare ground. Baseline data for forage production was collected in early May 2016. Within each plot, one sq. ft. area of vegetation was clipped to the ground during peak forage production (3 replications per plot) and then dried and weighed to determine gross productivity and dry matter yield (lb/ac).

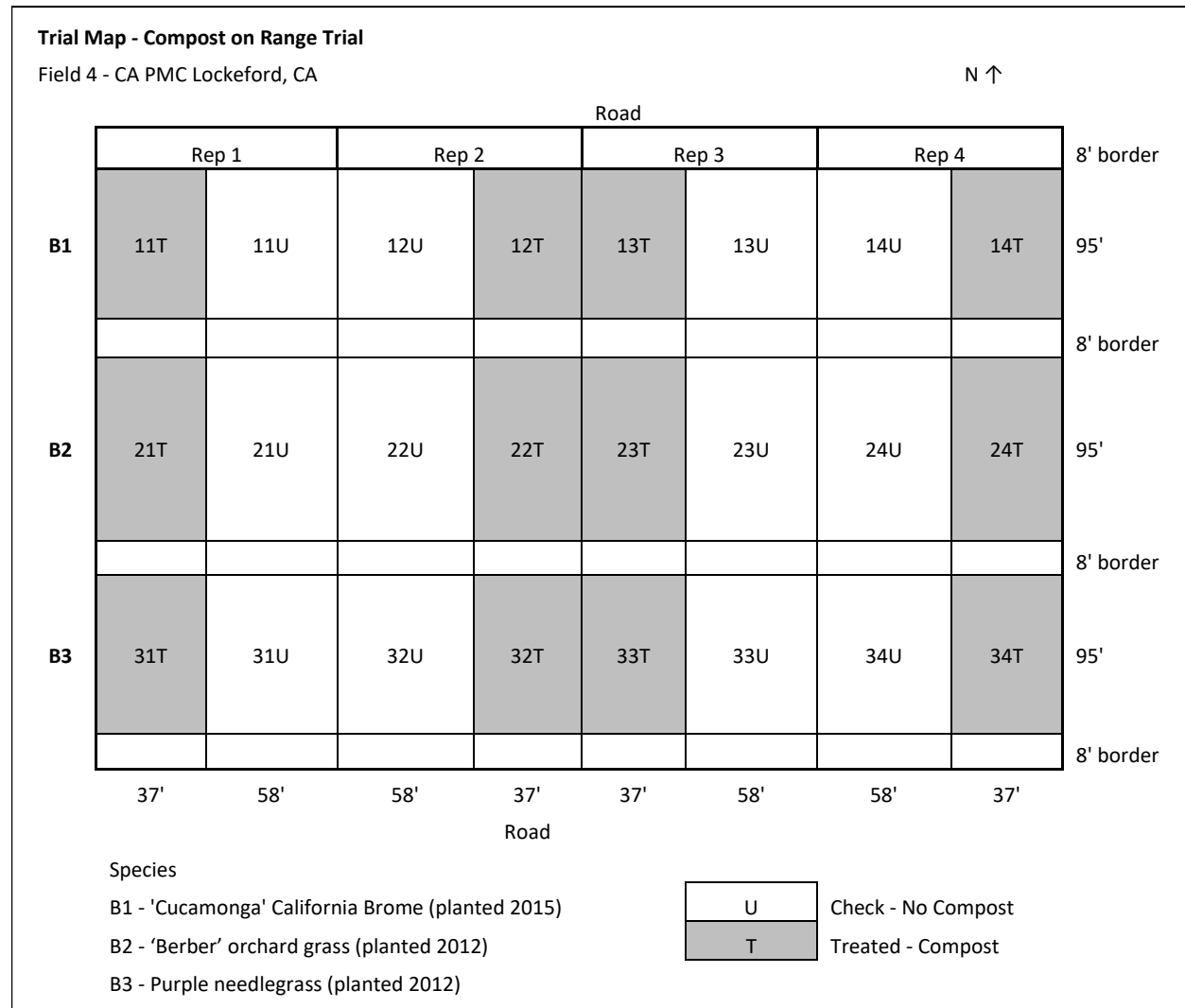


**Figure 2.** Plot map of the range compost application trial at the Lockeford CAPMC.

The application of compost took place on Nov. 28<sup>th</sup>, 2016. One acre, or thirty-four yards of compost was spread across four treated plots within each block at approximately 0.25 inches thick. Compost was spread using a wide mouthed hose connected to a semi-trailer (the same system typically used for spreading wood chips). Compost was provided from West Marin Compost. Compost was managed in accordance with USDA National Organic Program

guidelines. The compost was composed of dairy manure separator solids, green waste and equestrian materials.

Line-point intercept transects were collected every year (2017 to 2019) at a random location within each plot (late April/early May) to evaluate species composition and percent bare ground. The 50 ft. transect points were grouped into six categories: seeded plants/species, forbs, legumes, other grasses (not seeded species), bare ground, or organic matter. Forage production data was collected annually at the end of growing season (late April/early May). One sq. ft. area was clipped at peak production, with 3 replications per plot. The sample was then dried and weighed to determine gross productivity and dry matter yield (lb/ac). Infiltration rates were also collected annually within each plot at the time of peak forage production using a single ring infiltrometer in the California brome and orchardgrass blocks (by NRCS PMC staff) and a double ring infiltrometer in the purple needlegrass block (by East Stanislaus RCD staff). During the final year of the trial (2019), forage production samples were submitted to a lab for forage quality analysis. Finally, composite soil samples were collected in mid-November 2019 from all three blocks, treated and untreated plots at 0-10 cm (0-4 in), 10-30 cm (4-12 in), and 30-50 cm (12-20 in) depths. Soil samples were sent to the A&L Western Agricultural Laboratory for analysis. This trial was not grazed during the course of the study.

Statistical analysis was completed on the baseline data and across all three years of trial evaluations using Statistix 10 (Analytical Software, Tallahassee, FL). Analysis was done using the analysis of variance (AOV) procedure for a randomized complete block design (RCBD) along with Tukey's 1 Degree of Freedom test for non-additivity. Significant means were separated with Tukey's Honestly Significant Difference (HSD) All-Pairwise Comparisons Test at the 5% level.

## RESULTS AND DISCUSSION

### ***Baseline evaluations***

The baseline data in the three blocks show the population of seeded species versus forbs, legumes and other grasses, and percentage of bare ground or organic matter (above 1%) before the compost was applied. The 'Cucamonga' California brome was planted in 2015. It is a native annual cool season grass that is drought tolerant, can grow up to 3 ft tall, and reaches maturity in the early spring (USDA-NRCS, 2012). 'Berber' orchardgrass was planted in Block 2 in 2012. Orchardgrass is an introduced cool season, perennial bunchgrass that is drought tolerant and grows from 15 to 40 inches in height (USDA-NRCS, 2013). Purple needlegrass was planted in Block 3 in 2012. Purple needlegrass is a native cool season, perennial bunchgrass that grows up to 3 ft tall and is also the state grass of California (Tilley, 2009). The category of other grasses includes 'Blando' brome (*Bromus hordeaceus*), ripgut brome (*Bromus diandrus*), red brome (*Bromus rubens*), foxtail barley (*Hordeum* spp.), 'Zorro' fescue (*Vulpia myuros*), annual ryegrass (*Lolium* spp.), wild oats (*Avena* spp.), and volunteer orchardgrass (in blocks where it was not seeded). Forb species include fiddleneck (*Amsinckia* spp.), erodium (*Erodium* spp.), mustard (*Brassica* spp.), and radish (*Raphanus* spp.), while legume species include 'Lana' wollypod vetch (*Vicia villosa*) and rose clover (*Trifolium hirtum*). These species are typically common in the degraded rangelands of California.

The baseline data indicates that 41% of the ground cover in Block 1 was seeded California brome, 8% forbs, 15% legumes, and 34% other grasses (Table 1; Figure 3). In Block 2, 47% of

the ground cover was seeded orchardgrass, 2% forbs, 7% legumes, and 38% other grasses (Table 1; Figure 4). In Block 3, 26% of the ground cover was seeded purple needlegrass, 2% forbs, 13% legumes, and 58% other grasses (Table 1; Figure 5). The purple needlegrass block had a significantly higher percentage ground cover of other grasses compared to the California brome block (Table 1), indicating that there were more annual and introduced grasses in this block before the compost was applied.

**Table 1.** Baseline species composition, canopy cover and forage production as dry matter yield collected across all three species blocks in spring of 2016 at the Lockeford Plant Materials Center, CA

| Spring 2016 Canopy Cover Evaluation (pretreatment) |              |                            |                    |                      |                            |                          |                             |                            |
|----------------------------------------------------|--------------|----------------------------|--------------------|----------------------|----------------------------|--------------------------|-----------------------------|----------------------------|
| Species                                            | Year Planted | Seeded Plants <sup>§</sup> | Forbs <sup>§</sup> | Legumes <sup>§</sup> | Other Grasses <sup>§</sup> | Bare Ground <sup>§</sup> | Organic Matter <sup>§</sup> | Estimated DM Yield (lb/ac) |
|                                                    |              | ——%——                      | ——%——              | ——%——                | ——%——                      | ——%——                    | ——%——                       | ——lb/ac——                  |
| 'Cucamonga' California Brome                       | 2015         | 41.0                       | 8.5                | 14.8                 | 34.5 b*                    | 0.5                      | 0.8                         | 6313                       |
| 'Berber' orchard grass                             | 2012         | 47.3                       | 1.8                | 7.0                  | 37.8 ab                    | 3.3                      | 3.0                         | 6910                       |
| Purple needlegrass                                 | 2012         | 25.8                       | 2.3                | 12.8                 | 58.5 a                     | 0.3                      | 0.5                         | 5162                       |
| Mean                                               |              | 38.0                       | 4.2                | 11.5                 | 43.6                       | 1.3                      | 1.4                         | 6128                       |
| Std. dev <sup>#</sup>                              |              | 17.3                       | 8.0                | 17.2                 | 21.2                       | 2.7                      | 2.2                         | 1702                       |

<sup>#</sup>Standard deviation

<sup>§</sup>Canopy Cover rated as a visual estimate of the percentage of ground covered by the species or group.

\*Means in columns followed by the same letters are not significantly different at P<0.05.

DM yield samples were collected at peak production.

Est. DM Calculation: Fresh Weight Aboveground Biomass x (DM/100)

DM = dry matter, lb/ac = pounds/acre.

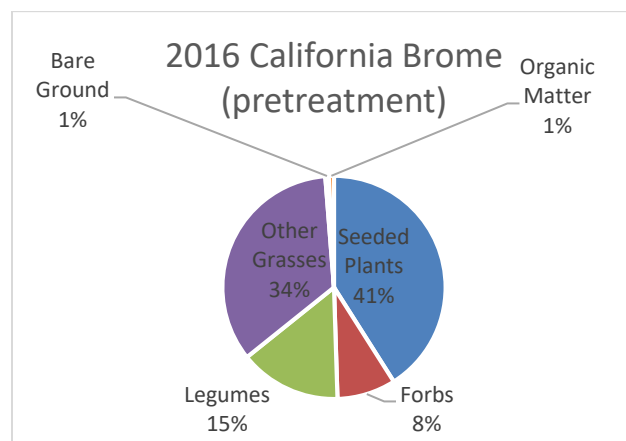


**Figure 3.** Baseline percent canopy cover in California brome (block 1) collected in spring of 2016.

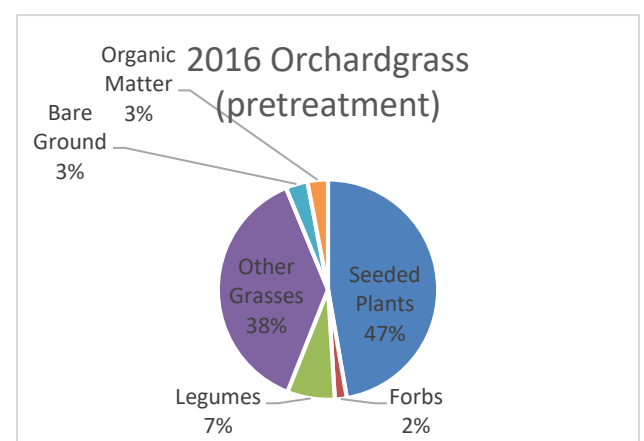


**Figure 4.** Baseline percent canopy cover in orchardgrass (block 2) collected in spring of 2016.

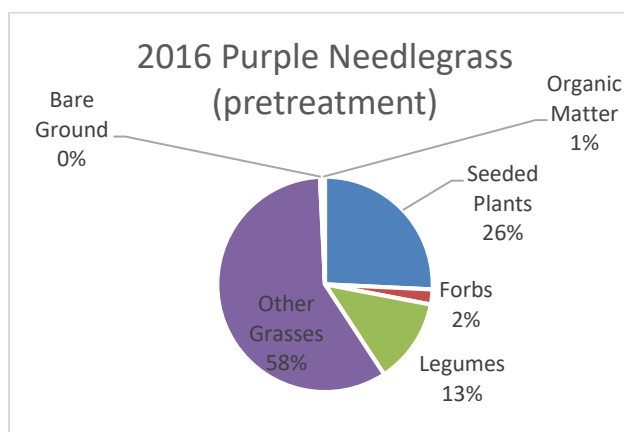


**Figure 5.** Baseline percent canopy cover in purple needlegrass (block 3) collected in spring of 2016

### ***California Brome (Block 1)***

#### ***Species Composition***

In the California brome block, the first year after compost application (2017) resulted in a significantly higher percentage of legume ground cover in the untreated plots (34%), compared to the compost treated plots (8%) using Tukey's HSD at the 5% level (Figures 6 and 7; Table 2). However, the compost treated plots had double the percent of seeded species (49%), compared to the untreated plots (25%). Other grasses, forbs, organic matter and bare ground were similar across treated and untreated plots. In the second year, 2018, again the legume ground cover was significantly higher in the untreated plot (10%) than in the compost treated plots (1%) (Figures 8 and 9; Table 3). The second year also showed a slightly higher percentage of seeded species, forbs, and other grasses in the control plots, while the compost treated plots had a higher percentage of organic matter ground cover. By the third and final year in 2019, no significant differences were seen between treated and untreated plots (Table 4). Little to no seeded California brome species were found (0% untreated; 0.5% treated). Forb and organic matter canopy cover were also very low. The majority of the plots were composed of legumes and other grass species, with the control plots still having a higher legume canopy cover (54% legumes; 39% other grasses) than the compost treated plots (38% legumes; 55% other grasses) (Figures 10 and 11). No bare ground was recorded in any of the plot treatments.

#### ***Dry Matter Yield***

The highest estimated dry matter yield was during the first year, prior to compost application (2016) in the California brome plots (Figure 12), with all subsequent years (2017, 2018, and 2019) having lower dry matter yield estimates. There were no significant differences in dry matter yield between treatments, and numerical trends show that the pounds per acre were very similar in both treated and untreated plots. Variability between years is more likely due to differences in weather and precipitation than due to treatment effects.

#### ***Forage Quality***

Forage quality was only collected during the last year of the trial (2019). There were no differences in Crude Protein (CP), Total Digestible Nutrients (TDN), Acid Detergent Fiber (ADF), or Neutral Detergent Fiber (NDF) in treated versus untreated plots during the third year of evaluations (Table 5). The CP fell in the range of average or good legume/grass hay values

(11-14%), while the TDN fell in the range of high or excellent legume/grass hay value (57-62%), according to NC and MSU cooperative extension (Duckett 2003; Lemus 2020).

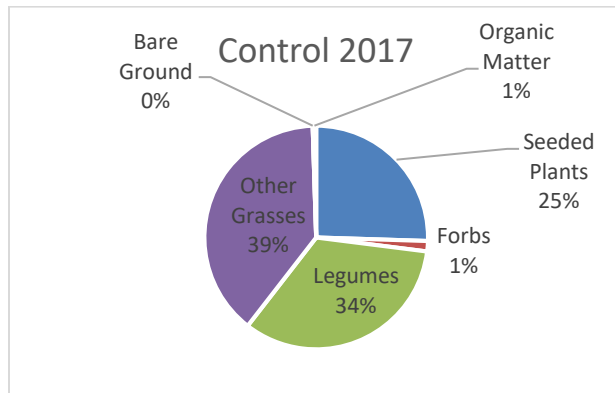


**Figure 6.** Percent canopy cover in untreated plots of California brome (block 1) collected in spring of 2017.

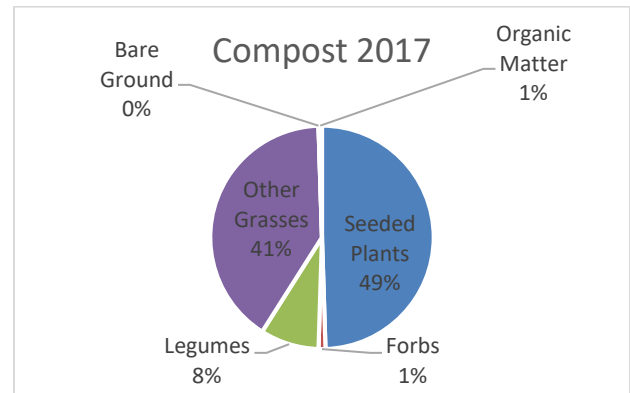


**Figure 7.** Percent canopy cover in compost treated plots of California brome (block 1) collected in spring of 2017.

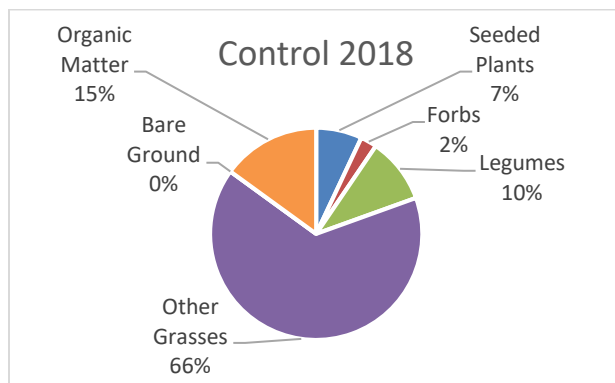


**Figure 8.** Percent canopy cover in untreated plots of California brome (block 1) collected in spring of 2018.

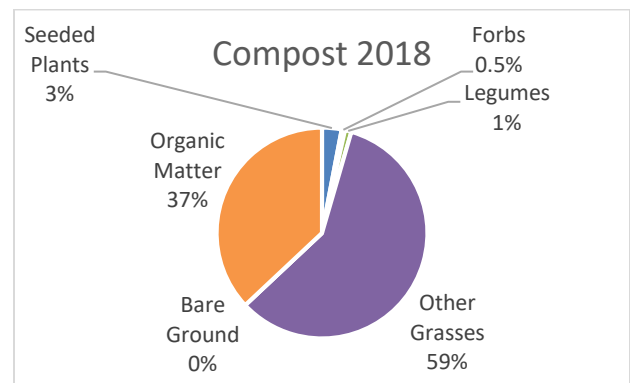


**Figure 9.** Percent canopy cover in compost treated plots of California brome (block 1) collected in spring of 2018.

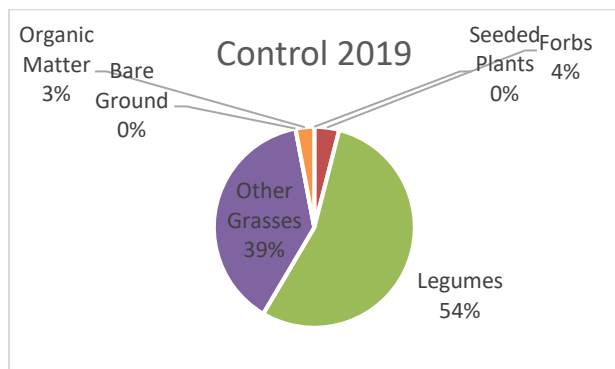


**Figure 10.** Percent canopy cover in untreated plots of California brome (block 1) collected in spring of 2019.

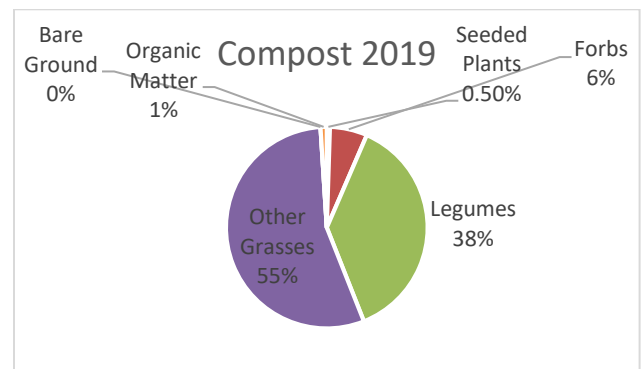


**Figure 11.** Percent canopy cover in compost treated plots of California brome (block 1) collected in spring of 2019.

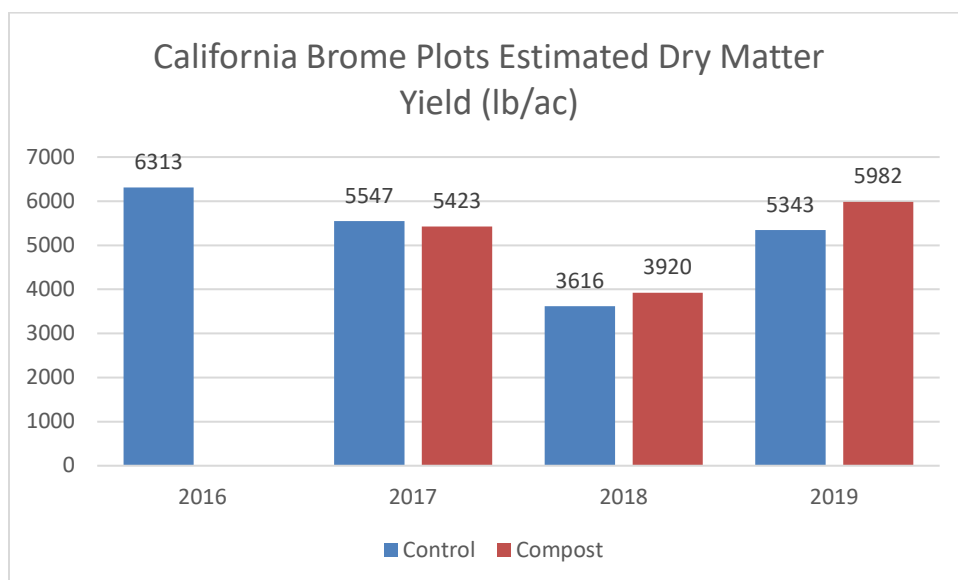


**Figure 12.** Forage production as dry matter yield of California brome across four years collected in block 1 at the Lockeford Plant Materials Center, CA.

**Table 2.** Percent species composition, canopy cover and forage production as dry matter yield collected in block 1 in spring of 2017 at the Lockeford Plant Materials Center, CA.

| Cucamonga' California Brome - Spring 2017 Canopy Cover Evaluation |                            |                    |                      |                            |                          |                             |                            |
|-------------------------------------------------------------------|----------------------------|--------------------|----------------------|----------------------------|--------------------------|-----------------------------|----------------------------|
| Treatment                                                         | Seeded Plants <sup>§</sup> | Forbs <sup>§</sup> | Legumes <sup>§</sup> | Other Grasses <sup>§</sup> | Bare Ground <sup>§</sup> | Organic Matter <sup>§</sup> | Estimated DM Yield (lb/ac) |
|                                                                   | ---%---                    | ---%---            | ---%---              | ---%---                    | ---%---                  | ---%---                     | ---lb/ac---                |
| Control                                                           | 25.5                       | 1.5                | 33.5 a               | 39.0                       | 0.0                      | 0.5                         | 5547                       |
| Compost <sup>¥</sup>                                              | 49.5                       | 1.0                | 8.5 b                | 40.5                       | 0.0                      | 0.5                         | 5423                       |
| Mean                                                              | 37.5                       | 1.3                | 21.0                 | 39.8                       | 0.0                      | 0.5                         | 5485                       |
| Std. dev <sup>#</sup>                                             | 16.7                       | 1.5                | 16.8                 | 12.1                       | 0.0                      | 0.9                         | 1369                       |

<sup>#</sup>Standard deviation

<sup>§</sup>Canopy Cover rated as a visual estimate of the percentage of ground covered by the species or group.

\*Means in columns followed by the same letters are not significantly different at  $P < 0.05$ .

<sup>¥</sup>Compost applied on 11/28/16.

DM yield samples were collected at peak production.

Est. DM Calculation: Fresh Weight Aboveground Biomass x (DM/100)

DM = dry matter, lb/ac = pounds/acre.

**Table 3.** Percent species composition, canopy cover and forage production as dry matter yield collected in block 1 in spring of 2018 at the Lockeford Plant Materials Center, CA.

| Cucamonga' California Brome - Spring 2018 Canopy Cover Evaluation |                               |                    |                      |                               |                             |                                |                                  |
|-------------------------------------------------------------------|-------------------------------|--------------------|----------------------|-------------------------------|-----------------------------|--------------------------------|----------------------------------|
| Treatment                                                         | Seeded<br>Plants <sup>§</sup> | Forbs <sup>§</sup> | Legumes <sup>§</sup> | Other<br>Grasses <sup>§</sup> | Bare<br>Ground <sup>§</sup> | Organic<br>Matter <sup>§</sup> | Estimated<br>DM Yield<br>(lb/ac) |
|                                                                   | ——%——                         | ——%——              | ——%——                | ——%——                         | ——%——                       | ——%——                          | ——lb/ac——                        |
| Control                                                           | 7.0                           | 2.5                | 10.0 a               | 65.5                          | 0.0                         | 15.0                           | 3616                             |
| Compost <sup>‡</sup>                                              | 3.0                           | 0.5                | 1.0 b                | 58.5                          | 0.0                         | 37.0                           | 3920                             |
| Mean                                                              | 5.0                           | 1.5                | 5.5                  | 62.0                          | 0.0                         | 26.0                           | 3398                             |
| Std. dev <sup>#</sup>                                             | 4.5                           | 1.8                | 5.8                  | 13.4                          | 0.0                         | 17.8                           | 568                              |

<sup>#</sup>Standard deviation

<sup>§</sup>Canopy Cover rated as a visual estimate of the percentage of ground covered by the species or group.

\*Means in columns followed by the same letters are not significantly different at  $P < 0.05$ .

<sup>‡</sup>Compost applied on 11/28/16.

DM yield samples were collected at peak production.

Est. DM Calculation: Fresh Weight Aboveground Biomass x (DM/100)

DM = dry matter, lb/ac = pounds/acre.

**Table 4.** Percent species composition, canopy cover and forage production as dry matter yield collected in block 1 in spring of 2019 at the Lockeford Plant Materials Center, CA.

| Cucamonga' California Brome - Spring 2019 Canopy Cover Evaluation |                               |                    |                      |                               |                             |                                |                                  |
|-------------------------------------------------------------------|-------------------------------|--------------------|----------------------|-------------------------------|-----------------------------|--------------------------------|----------------------------------|
| Treatment                                                         | Seeded<br>Plants <sup>§</sup> | Forbs <sup>§</sup> | Legumes <sup>§</sup> | Other<br>Grasses <sup>§</sup> | Bare<br>Ground <sup>§</sup> | Organic<br>Matter <sup>§</sup> | Estimated<br>DM Yield<br>(lb/ac) |
|                                                                   | ——%——                         | ——%——              | ——%——                | ——%——                         | ——%——                       | ——%——                          | ——lb/ac——                        |
| Control                                                           | 0.0                           | 4.0                | 54.5 a               | 38.5                          | 0.0                         | 3.0                            | 5343                             |
| Compost <sup>‡</sup>                                              | 0.5                           | 6.0                | 37.5 a               | 55.0                          | 0.0                         | 1.0                            | 5982                             |
| Mean                                                              | 0.3                           | 5.0                | 46.0                 | 46.8                          | 0.0                         | 2.0                            | 5663                             |
| Std. dev <sup>#</sup>                                             | 0.7                           | 3.9                | 20.8                 | 17.9                          | 0.0                         | 2.8                            | 1212                             |

<sup>#</sup>Standard deviation

<sup>§</sup>Canopy Cover rated as a visual estimate of the percentage of ground covered by the species or group.

\*Means in columns followed by the same letters are not significantly different at  $P < 0.05$ .

<sup>‡</sup>Compost applied on 11/28/16.

DM yield samples were collected at peak production.

Est. DM Calculation: Fresh Weight Aboveground Biomass x (DM/100)

DM = dry matter, lb/ac = pounds/acre.

**Table 5.** Forage quality analysis results collected in block 1 in spring of 2019 at the Lockeford Plant Materials Center, CA.

| Cucamonga' California Brome - Forage Quality (2019) |               |                            |                      |                         |
|-----------------------------------------------------|---------------|----------------------------|----------------------|-------------------------|
| Treatment                                           | Crude Protein | Total Digestible Nutrients | Acid Detergent Fiber | Neutral Detergent Fiber |
|                                                     | %             | %                          | %                    | %                       |
| Control                                             | 10.5          | 62.0                       | 36.2                 | 59.5                    |
| Compost <sup>‡</sup>                                | 11.1          | 59.6                       | 38.4                 | 59.1                    |
| Mean                                                | 10.8          | 60.8                       | 37.3                 | 59.3                    |
| Std. dev. <sup>#</sup>                              | 0.4           | 1.7                        | 1.6                  | 0.3                     |

<sup>#</sup>Standard deviation

All values listed are on a dry matter basis.

California Brome 2019 mean sample content (23% legumes, 23% grasses).

<sup>‡</sup>Compost applied on 11/28/16.

### ***'Berber' Orchardgrass (Block 2)***

#### *Species Composition*

During the first year after compost application (2017), there were no significant differences between the treated and untreated plots in the orchardgrass block (Table 6). Numerically, the percentage of orchardgrass species was slightly higher in the compost treated plots (59%) versus the control plots (45%), while the percentage of legumes was higher in the control plots (16%) versus the treated plots (7%) (Figures 13 and 14). Results from the second year of the trial (2018) show very similar trends to the previous year, with no significant difference in species composition (Table 7). Again, the compost treated plot had slightly higher seeded species (59%) than the untreated plots (46%), but lower percent canopy cover of legumes (5% treated; 17% untreated) (Figures 15 and 16). In the third year of the trial (2019), both treated and untreated plots had lower percentage of seeded species (38% control; 44% treated) than the previous two years (Figures 17 and 18; Table 8). The third year also showed an increase in the percentage canopy cover of legumes in both treated and untreated plots (39% control; 42% treated).

#### *Dry Matter Yield*

Estimated dry matter yields were significantly higher in the compost treated plots than in the untreated plots in both 2018 and 2019 (Figure 13; Tables 7 and 8). In 2017, the compost treated plots numerically had a higher dry matter yield than the untreated orchardgrass plots, but it was not significant using Tukey's HSD at the 5% level (Table 6). The third and final year of the trial also had the highest peak forage production across all three years of the trial.

#### *Forage Quality*

The forage quality of the orchardgrass plots was tested during the final year of the trial (2019). No differences were shown between CP, TDN, ADF, or NDF in treated versus untreated plots (Table 9). Both CP forage samples results fell in the range of average or good legume/grass hay values (11-14%), and high or excellent range for TDN legume/grass hay value (57-62%) (Duckett 2003; Lemus 2020).

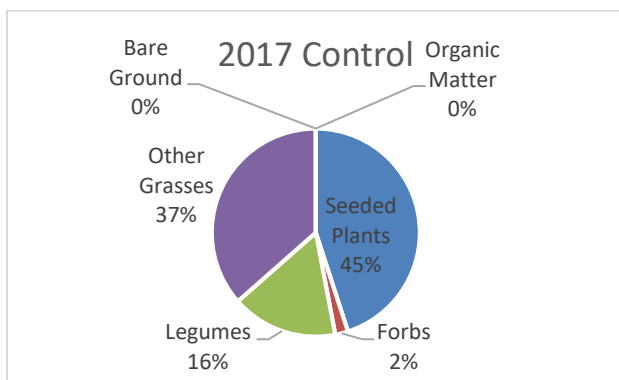


**Figure 13.** Percent canopy cover in untreated plots of orchardgrass (block 2) collected in spring of 2017.

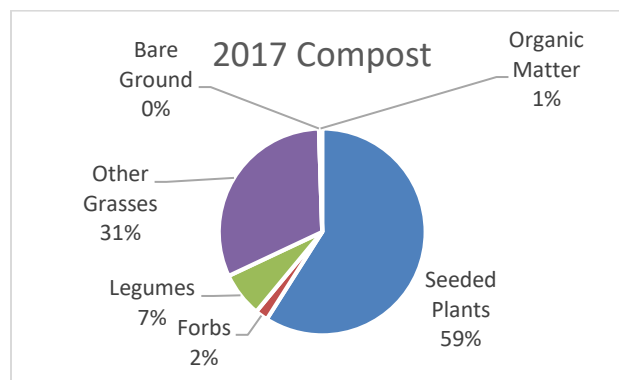


**Figure 14.** Percent canopy cover in compost treated plots of orchardgrass (block 2) collected in spring of 2017.

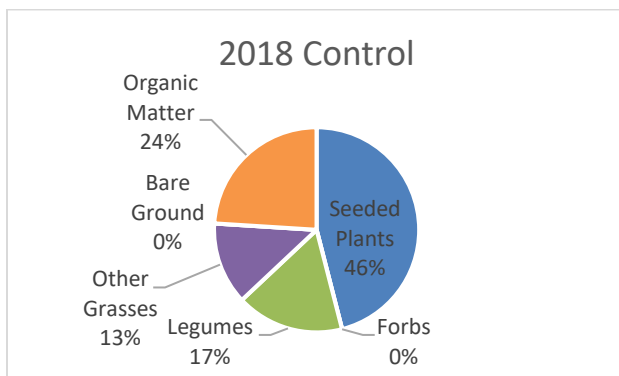


**Figure 15.** Percent canopy cover in untreated plots of orchardgrass (block 2) collected in spring of 2018.

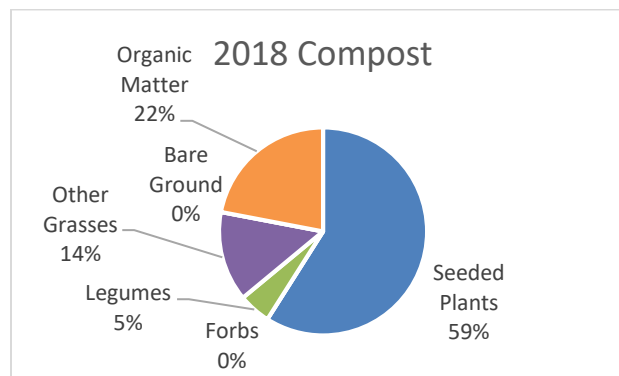


**Figure 16.** Percent canopy cover in compost treated plots of orchardgrass (block 2) collected in spring of 2018.

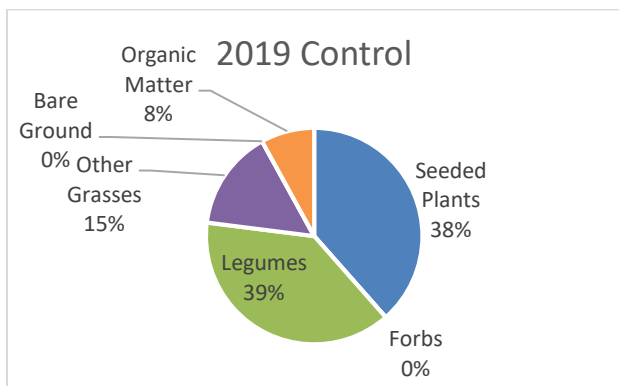


**Figure 17.** Percent canopy cover in untreated plots of orchardgrass (block 2) collected in spring of 2019.

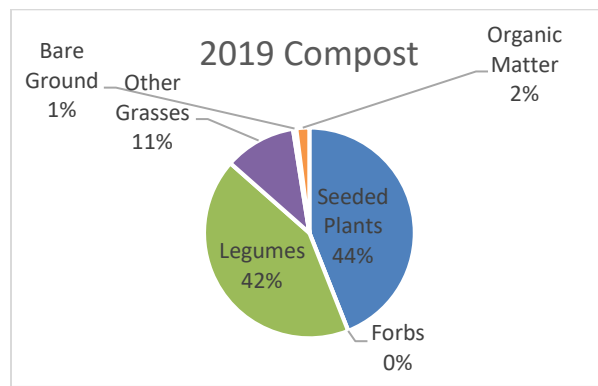


**Figure 18.** Percent canopy cover in compost treated plots of orchardgrass (block 2) collected in spring of 2019.

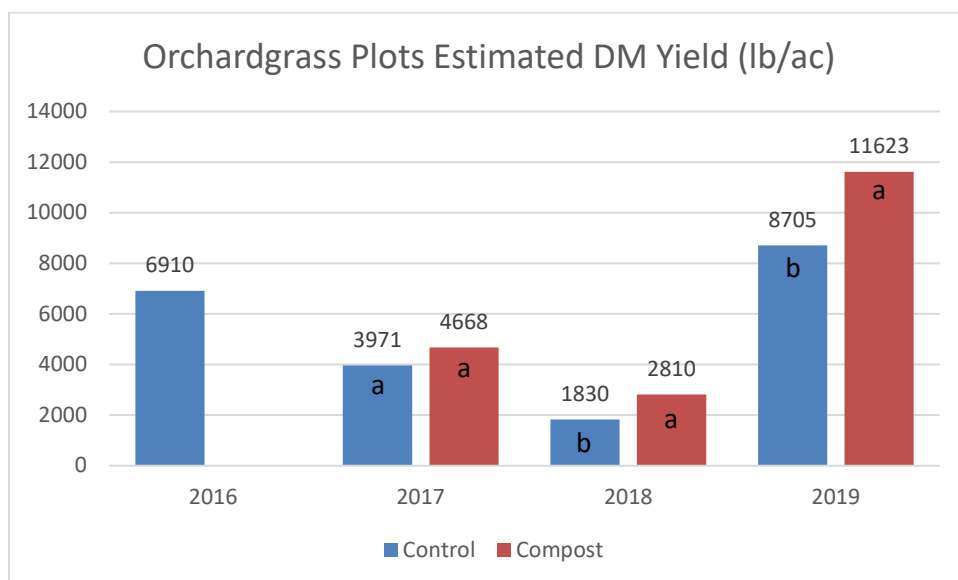


**Figure 19.** Forage production as dry matter yield of orchardgrass across four years collected in block 2 at the Lockeford Plant Materials Center, CA.

**Table 6.** Percent species composition, canopy cover and forage production as dry matter yield collected in block 2 in spring of 2017 at the Lockeford Plant Materials Center, CA.

| 'Berber' orchard grass - Spring 2017 Canopy Cover Evaluation |                            |                    |                      |                            |                          |                             |                            |
|--------------------------------------------------------------|----------------------------|--------------------|----------------------|----------------------------|--------------------------|-----------------------------|----------------------------|
| Treatment                                                    | Seeded Plants <sup>§</sup> | Forbs <sup>§</sup> | Legumes <sup>§</sup> | Other Grasses <sup>§</sup> | Bare Ground <sup>§</sup> | Organic Matter <sup>§</sup> | Estimated DM Yield (lb/ac) |
|                                                              | —%—                        | —%—                | —%—                  | —%—                        | —%—                      | —%—                         | —lb/ac—                    |
| Control                                                      | 45.0                       | 2.0                | 16.5                 | 36.5                       | 0.0                      | 0.0                         | 3971 a                     |
| Compost <sup>¥</sup>                                         | 59.0                       | 2.0                | 7.0                  | 31.5                       | 0.0                      | 0.5                         | 4668 a                     |
| Mean                                                         | 52.0                       | 2.0                | 11.8                 | 34.0                       | 0.0                      | 0.3                         | 4320                       |
| Std. dev <sup>#</sup>                                        | 23.2                       | 3.0                | 12.1                 | 20.2                       | 0.0                      | 0.7                         | 1251                       |

<sup>#</sup>Standard deviation

<sup>§</sup>Canopy Cover rated as a visual estimate of the percentage of ground covered by the species or group.

\*Means in columns followed by the same letters are not significantly different at  $P < 0.05$ .

<sup>¥</sup>Compost applied on 11/28/16.

DM yield samples were collected at peak production.

Est. DM Calculation: Fresh Weight Aboveground Biomass x (DM/100)

DM = dry matter, lb/ac = pounds/acre.

**Table 7.** Percent species composition, canopy cover and forage production as dry matter yield collected in block 2 in spring of 2018 at the Lockeford Plant Materials Center, CA.

| 'Berber' orchard grass - Spring 2018 Canopy Cover Evaluation |                            |                    |                      |                            |                          |                             |                            |
|--------------------------------------------------------------|----------------------------|--------------------|----------------------|----------------------------|--------------------------|-----------------------------|----------------------------|
| Treatment                                                    | Seeded Plants <sup>§</sup> | Forbs <sup>§</sup> | Legumes <sup>§</sup> | Other Grasses <sup>§</sup> | Bare Ground <sup>§</sup> | Organic Matter <sup>§</sup> | Estimated DM Yield (lb/ac) |
|                                                              | ----%----                  | ---%---            | ---%---              | ---%---                    | ----%----                | ----%----                   | ---lb/ac---                |
| Control                                                      | 46.0                       | 0.0                | 17.0                 | 13.0                       | 0.0                      | 24.0                        | 1830 b                     |
| Compost <sup>‡</sup>                                         | 59.0                       | 0.0                | 5.0                  | 14.0                       | 0.0                      | 22.0                        | 2810 a                     |
| Mean                                                         | 52.5                       | 0.0                | 11.0                 | 13.5                       | 0.0                      | 23.0                        | 2320                       |
| Std. dev <sup>#</sup>                                        | 16.2                       | 0.0                | 9.2                  | 8.4                        | 0.0                      | 7.6                         | 786                        |

<sup>#</sup>Standard deviation

<sup>§</sup>Canopy Cover rated as a visual estimate of the percentage of ground covered by the species or group.

\*Means in columns followed by the same letters are not significantly different at  $P < 0.05$ .

<sup>‡</sup>Compost applied on 11/28/16.

DM yield samples were collected at peak production.

Est. DM Calculation: Fresh Weight Aboveground Biomass x (DM/100)

DM = dry matter, lb/ac = pounds/acre.

**Table 8.** Percent species composition, canopy cover and forage production as dry matter yield collected in block 2 in spring of 2019 at the Lockeford Plant Materials Center, CA.

| 'Berber' orchard grass - Spring 2019 Canopy Cover Evaluation |                            |                    |                      |                            |                          |                             |                            |
|--------------------------------------------------------------|----------------------------|--------------------|----------------------|----------------------------|--------------------------|-----------------------------|----------------------------|
| Treatment                                                    | Seeded Plants <sup>§</sup> | Forbs <sup>§</sup> | Legumes <sup>§</sup> | Other Grasses <sup>§</sup> | Bare Ground <sup>§</sup> | Organic Matter <sup>§</sup> | Estimated DM Yield (lb/ac) |
|                                                              | ----%----                  | ---%---            | ---%---              | ---%---                    | ----%----                | ----%----                   | ---lb/ac---                |
| Control                                                      | 38.5                       | 0.0                | 38.5                 | 15.0                       | 0.0                      | 8.0                         | 8705 b                     |
| Compost <sup>‡</sup>                                         | 44.0                       | 0.0                | 42.5                 | 11.0                       | 0.5                      | 2.0                         | 11623 a                    |
| Mean                                                         | 41.3                       | 0.0                | 40.5                 | 13.0                       | 0.3                      | 5.0                         | 10164                      |
| Std. dev <sup>#</sup>                                        | 11.3                       | 0.0                | 10.3                 | 9.3                        | 0.7                      | 6.5                         | 2566                       |

<sup>#</sup>Standard deviation

<sup>§</sup>Canopy Cover rated as a visual estimate of the percentage of ground covered by the species or group.

\*Means in columns followed by the same letters are not significantly different at  $P < 0.05$ .

<sup>‡</sup>Compost applied on 11/28/16.

DM yield samples were collected at peak production.

Est. DM Calculation: Fresh Weight Aboveground Biomass x (DM/100)

DM = dry matter, lb/ac = pounds/acre.

**Table 9.** Forage quality analysis results collected in block 2 in spring of 2019 at the Lockeford Plant Materials Center, CA.

| ‘Berber’ orchard grass - Forage Quality (2019) |               |                            |                      |                          |
|------------------------------------------------|---------------|----------------------------|----------------------|--------------------------|
| Treatment                                      | Crude Protein | Total Digestible Nutrients | Acid Detergent Fiber | Neautral Detergent Fiber |
|                                                | %             | %                          | %                    | %                        |
| Control                                        | 12.7          | 59.8                       | 38.2                 | 55.7                     |
| Compost <sup>‡</sup>                           | 12.1          | 59.4                       | 38.5                 | 60.3                     |
| Mean                                           | 1.4           | 59.6                       | 38.4                 | 58.0                     |
| Std. dev <sup>#</sup>                          | 0.4           | 0.3                        | 0.2                  | 3.3                      |

<sup>#</sup>Standard deviation

All values listed are on a dry matter basis.

Orchard grass 2019 mean sample content (20% legumes, 27% grasses).

<sup>‡</sup>Compost applied on 11/28/16.

### ***Purple Needlegrass (Block 3)***

#### *Species Composition*

In the purple needlegrass plots, the first spring evaluations in 2017 showed no significant differences in species composition after compost application (Table 10). Numerical trends did show an increase in legumes in the untreated plots, but a lower percentage of other grasses (28% legumes; 49% other grasses) compared to the compost treated plots (13% legumes; 65% other grasses) (Figures 20 and 21). During the second year (2018), the control plots again had a higher percentage of legumes than treated plots (22% untreated; 9% treated), however seeded species were slightly higher in the compost treats plots (19% untreated; 28% treated) (Figures 22 and 23). Results of the final year evaluations (2019) show that both treated and untreated plots had a low percentage of seeded species. The compost treated plots increased to 50% other grasses, while the untreated plots increased to 50% legumes (Figures 24 and 25).

#### *Dry Matter Yield*

Estimated dry matter yields varied in high forage production between the treated and untreated plots over the three-year trial (Figure 26). The third and final year (2019) results show that the compost treated plots had significantly higher yield than the untreated plots using Tukey’s HSD at the 5% level, and a higher yield than any purple needlegrass plot in any other year (Table 8).

#### *Forage Quality*

Forage quality results from the purple needlegrass block show differences in quality between treated and untreated plots (Table 13). Control plots had higher CP and TDN, and lower ADF and NDF than compost treated plots. This resulted in a higher forage quality for the untreated plots with CP falling in the range of average or good legume/grass hay values (11-14%) and TDN falling high or excellent range values (57-62%) (Duckett 2003; Lemus 2020). Compost treated plots forage quality results fell in the low or poor range for CP (<10%) and average or good legume/grass hay values for TDN (55-57%).

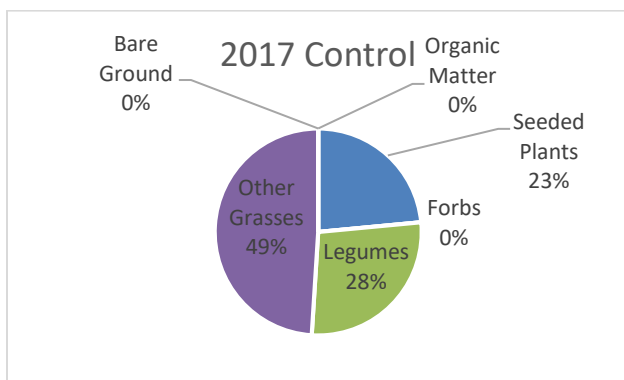


**Figure 20.** Percent canopy cover in untreated plots of purple needlegrass (block 3) collected in spring of 2017.

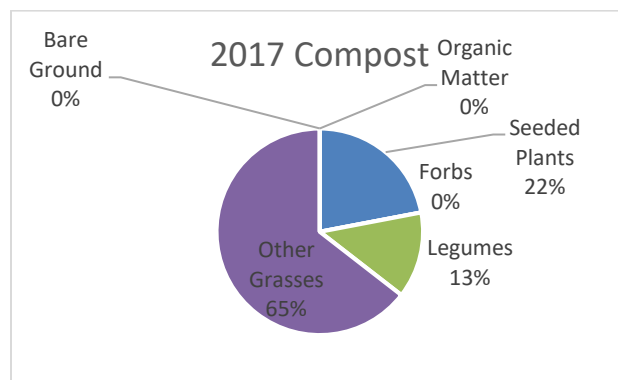


**Figure 21.** Percent canopy cover in compost treated plots of purple needlegrass (block 3) collected in spring of 2017.

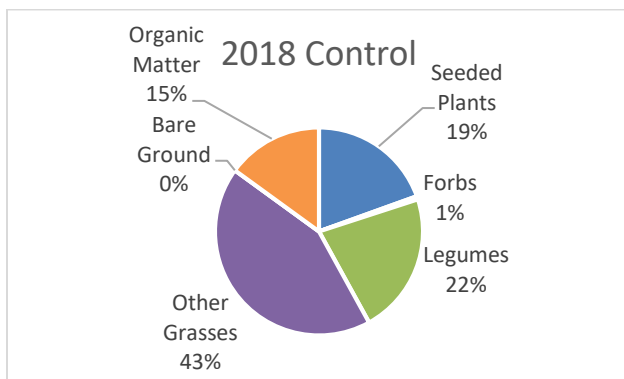


**Figure 22.** Percent canopy cover in untreated plots of purple needlegrass (block 3) collected in spring of 2018.

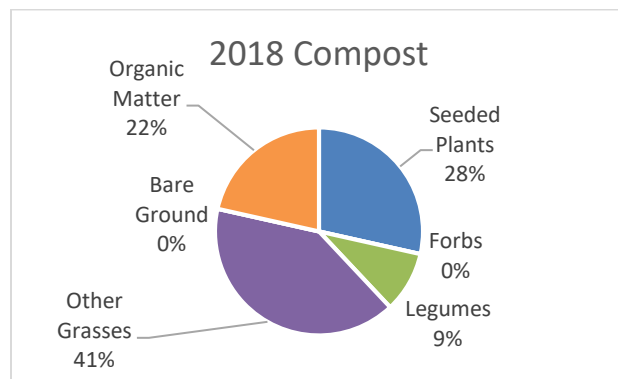


**Figure 23.** Percent canopy cover in compost treated plots of purple needlegrass (block 3) collected in spring of 2018.

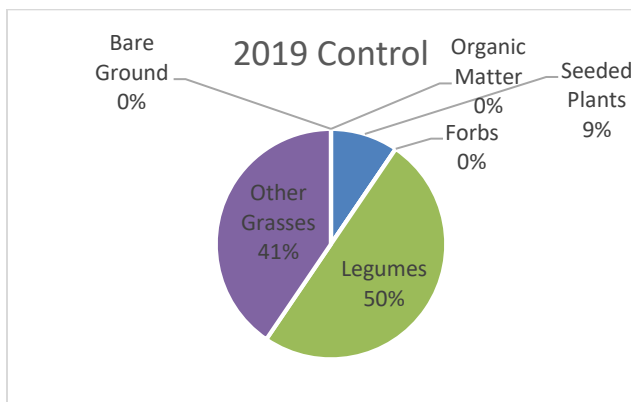


**Figure 24.** Percent canopy cover in untreated plots of purple needlegrass (block 3) collected in spring of 2019.

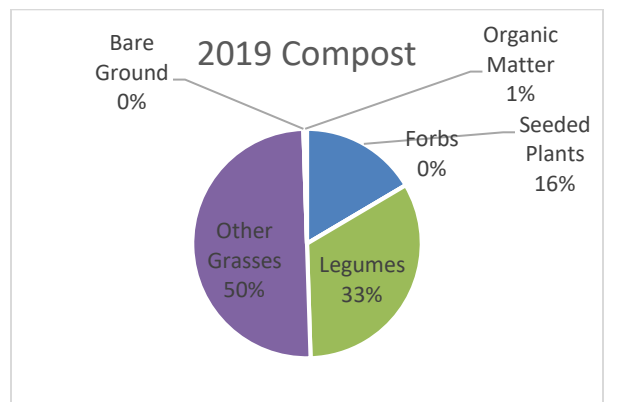


**Figure 25.** Percent canopy cover in compost treated plots of purple needlegrass (block 3) collected in spring of 2019.

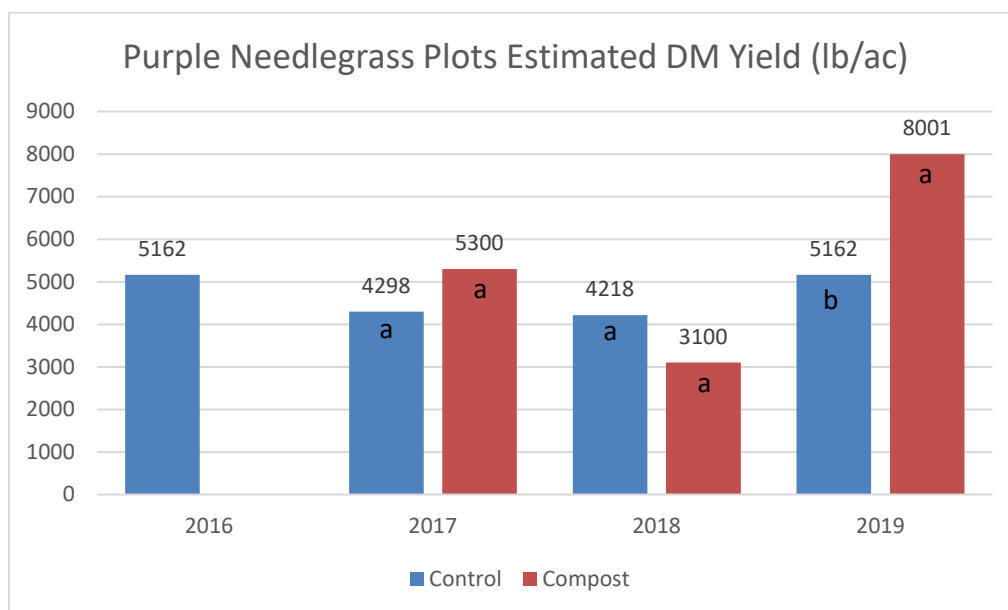


**Figure 26.** Forage production as dry matter yield of purple needlegrass across four years collected in block 3 at the Lockeford Plant Materials Center, CA.

**Table 10.** Percent species composition, canopy cover and forage production as dry matter yield collected in block 3 in spring of 2017 at the Lockeford Plant Materials Center, CA.

| Purple needlegrass - Spring 2017 Canopy Cover Evaluation |                            |                    |                      |                            |                          |                             |                            |
|----------------------------------------------------------|----------------------------|--------------------|----------------------|----------------------------|--------------------------|-----------------------------|----------------------------|
| Treatment                                                | Seeded Plants <sup>§</sup> | Forbs <sup>§</sup> | Legumes <sup>§</sup> | Other Grasses <sup>§</sup> | Bare Ground <sup>§</sup> | Organic Matter <sup>§</sup> | Estimated DM Yield (lb/ac) |
|                                                          | ----%----                  | ---%---            | ---%---              | ---%---                    | ---%---                  | ---%---                     | ---lb/ac---                |
| Control                                                  | 23.5                       | 0.0                | 27.5                 | 49.0                       | 0.0                      | 0.0                         | 4298 a                     |
| Compost <sup>¥</sup>                                     | 22.0                       | 0.0                | 13.5                 | 64.5                       | 0.0                      | 0.0                         | 5300 a                     |
| Mean                                                     | 22.8                       | 0.0                | 20.5                 | 56.8                       | 0.0                      | 0.0                         | 4799                       |
| Std. dev <sup>#</sup>                                    | 8.3                        | 0.0                | 19.1                 | 18.3                       | 0.0                      | 0.0                         | 1331                       |

<sup>#</sup>Standard deviation

<sup>§</sup>Canopy Cover rated as a visual estimate of the percentage of ground covered by the species or group.

\*Means in columns followed by the same letters are not significantly different at  $P < 0.05$ .

<sup>¥</sup>Compost applied on 11/28/16.

DM yield samples were collected at peak production.

Est. DM Calculation: Fresh Weight Aboveground Biomass x (DM/100)

DM = dry matter, lb/ac = pounds/acre.

**Table 11.** Percent species composition, canopy cover and forage production as dry matter yield collected in block 3 in spring of 2017 at the Lockeford Plant Materials Center, CA.

| Purple needlegrass - Spring 2018 Canopy Cover Evaluation |                            |                    |                      |                            |                          |                             |                            |
|----------------------------------------------------------|----------------------------|--------------------|----------------------|----------------------------|--------------------------|-----------------------------|----------------------------|
| Treatment                                                | Seeded Plants <sup>§</sup> | Forbs <sup>§</sup> | Legumes <sup>§</sup> | Other Grasses <sup>§</sup> | Bare Ground <sup>§</sup> | Organic Matter <sup>§</sup> | Estimated DM Yield (lb/ac) |
|                                                          | ——%——                      | ——%——              | ——%——                | ——%——                      | ——%——                    | ——%——                       | ——lb/ac——                  |
| Control                                                  | 19.5                       | 0.5                | 22.0                 | 43.0                       | 0.0                      | 15.0                        | 4218 a                     |
| Compost <sup>‡</sup>                                     | 28.5                       | 0.0                | 9.5                  | 40.5                       | 0.0                      | 21.5                        | 3100 a                     |
| Mean                                                     | 24.0                       | 0.3                | 15.8                 | 41.8                       | 0.0                      | 18.3                        | 3659                       |
| Std. dev <sup>#</sup>                                    | 14.2                       | 0.7                | 11.4                 | 9.0                        | 0.0                      | 7.4                         | 1043                       |

<sup>#</sup>Standard deviation

<sup>§</sup>Canopy Cover rated as a visual estimate of the percentage of ground covered by the species or group.

\*Means in columns followed by the same letters are not significantly different at  $P < 0.05$ .

<sup>‡</sup>Compost applied on 11/28/16.

DM yield samples were collected at peak production.

Est. DM Calculation: Fresh Weight Aboveground Biomass x (DM/100)

DM = dry matter, lb/ac = pounds/acre.

**Table 12.** Percent species composition, canopy cover and forage production as dry matter yield collected in block 3 in spring of 2019 at the Lockeford Plant Materials Center, CA.

| Purple needlegrass - Spring 2019 Canopy Cover Evaluation |                            |                    |                      |                            |                          |                             |                            |
|----------------------------------------------------------|----------------------------|--------------------|----------------------|----------------------------|--------------------------|-----------------------------|----------------------------|
| Treatment                                                | Seeded Plants <sup>§</sup> | Forbs <sup>§</sup> | Legumes <sup>§</sup> | Other Grasses <sup>§</sup> | Bare Ground <sup>§</sup> | Organic Matter <sup>§</sup> | Estimated DM Yield (lb/ac) |
|                                                          | ——%——                      | ——%——              | ——%——                | ——%——                      | ——%——                    | ——%——                       | ——lb/ac——                  |
| Control                                                  | 9.5                        | 0.0                | 50.0                 | 40.5                       | 0.0                      | 0.0                         | 5162 b                     |
| Compost <sup>‡</sup>                                     | 16.5                       | 0.0                | 33.0                 | 50.0                       | 0.0                      | 0.5                         | 8001 a                     |
| Mean                                                     | 13.0                       | 0.0                | 41.5                 | 45.3                       | 0.0                      | 0.3                         | 6581                       |
| Std. dev <sup>#</sup>                                    | 8.6                        | 0.0                | 21.5                 | 14.9                       | 0.0                      | 0.7                         | 2191                       |

<sup>#</sup>Standard deviation

<sup>§</sup>Canopy Cover rated as a visual estimate of the percentage of ground covered by the species or group.

\*Means in columns followed by the same letters are not significantly different at  $P < 0.05$ .

<sup>‡</sup>Compost applied on 11/28/16.

DM yield samples were collected at peak production.

Est. DM Calculation: Fresh Weight Aboveground Biomass x (DM/100)

DM = dry matter, lb/ac = pounds/acre.

**Table 13.** Forage quality analysis results collected in block 3 in spring of 2019 at the Lockeford Plant Materials Center, CA.

| Purple needlegrass - Forage Quality (2019) |               |                            |                      |                          |
|--------------------------------------------|---------------|----------------------------|----------------------|--------------------------|
| Treatment                                  | Crude Protein | Total Digestible Nutrients | Acid Detergent Fiber | Neautral Detergent Fiber |
|                                            | %             | %                          | %                    | %                        |
| Control                                    | 11.0          | 60.0                       | 38.0                 | 61.4                     |
| Compost <sup>‡</sup>                       | 9.1           | 55.3                       | 42.2                 | 66.8                     |
| Mean                                       | 10.1          | 57.7                       | 40.1                 | 64.1                     |
| Std. dev <sup>#</sup>                      | 1.3           | 3.3                        | 3.0                  | 3.8                      |

<sup>#</sup>Standard deviation

All values listed are on a dry matter basis.

Purple needlegrass 2019 mean sample content (21% legumes, 29% grass)

<sup>‡</sup>Compost applied on 11/28/16.

## Soil Analysis

### *Soil Infiltration Rates*

Infiltration rates were collected at the time of peak forage production in treated and untreated plots every year for the duration of the trial based on the USDA Soil Quality Test Kit guidelines (Soil Quality Institute, 2001). No differences were seen in the California brome blocks between treated and untreated plots and all evaluations fell under the infiltration class of very rapid (>20 in/hr) (Table 14). In the orchardgrass block, infiltration rates for the compost treated plots fell in the very rapid range all three years, while infiltration rates in the untreated plots were moderately rapid (2-6 in/hr) during 2017, and rapid (6-20 in/hr) during 2018 and 2019 evaluations (Table 15). Infiltration rates for the purple needlegrass block showed no differences between compost treated and untreated plots and all three years of evaluations fell into the rapid infiltration class (6-20 in/hr) (Table 16). These results indicate that, in the introduced perennial species block, compost application may help to increase soil infiltration.

### *Soil Analysis Results*

Composite soil samples were collected in the fall of 2019 from treated and untreated plots in all blocks, to detect any chemical differences in the top 50 cm (20 in) of soil. Soil lab results are shown in Table 17. The soil samples from the California brome, orchardgrass and purple needlegrass blocks show very similar treated and untreated results, across all analyses. The compost treated plots show a slight increase in phosphorus and potassium values in all three sampled depths across all three species blocks compared to the untreated plots. Due to the consistency across all blocks, it is likely that this is a result from the compost application. Surprisingly, soil results did not show an increase in nitrogen content of the treated blocks, due to the higher nitrogen content of the compost (5.2 mg/kg NO<sub>3</sub>-N on dry weight basis). There may have been an initial increase in the treated plots, but this nitrogen has either been incorporated back into the system or leached after three seasons. Calcium values were also higher in the untreated orchardgrass and purple needlegrass plots, but this could be from a difference in soil properties due to landscape position and not a treatment effect.

**Table 14.** Infiltration rates in California brome (block 1) treated and untreated plots across three years at the Lockeford Plant Materials Center, CA.

| Cucamonga' California Brome - Infiltration Rates |         |                    |         |                    |         |                    |
|--------------------------------------------------|---------|--------------------|---------|--------------------|---------|--------------------|
| Treatment                                        | 2017    | Infiltration Class | 2018    | Infiltration Class | 2019    | Infiltration Class |
|                                                  | (in/hr) |                    | (in/hr) |                    | (in/hr) |                    |
| Control                                          | 50.3    | VR                 | 31.5    | VR                 | 97.7    | VR                 |
| Compost <sup>‡</sup>                             | 98.7    | VR                 | 70.8    | VR                 | 37.4    | VR                 |
| Mean                                             | 74.5    |                    | 51.1    |                    | 67.5    |                    |
| Std. dev <sup>#</sup>                            | 79.0    |                    | 55.6    |                    | 63.2    |                    |

<sup>#</sup>Standard deviation

Infiltration rates were measured in inches per hour (in/hr).

Infiltration classes: Very Rapid (VR)=>20 in/hr; Rapid (R)=6-20 in/hr; Moderately Rapid (MR)=2-6 in/hr; Moderate (M)=0.6-2 in/hr; Moderately Slow (MS)=0.2-0.6 in/hr; Slow (S)=0.06-0.2 in/hr; Very Slow (VS)=0.0015-0.06 in/hr; Impermeable (I)=<0.0015.

<sup>‡</sup>Compost applied on 11/28/16.

**Table 15.** Infiltration rates in orchardgrass (block 2) treated and untreated plots across three years at the Lockeford Plant Materials Center, CA.

| 'Berber' orchard grass - Infiltration Rates |         |                    |         |                    |         |                    |
|---------------------------------------------|---------|--------------------|---------|--------------------|---------|--------------------|
| Treatment                                   | 2017    | Infiltration Class | 2018    | Infiltration Class | 2019    | Infiltration Class |
|                                             | (in/hr) |                    | (in/hr) |                    | (in/hr) |                    |
| Control                                     | 4.3     | MR                 | 10.9    | R                  | 18.3    | R                  |
| Compost <sup>‡</sup>                        | 30.0    | VR                 | 29.9    | VR                 | 23.9    | VR                 |
| Mean                                        | 17.2    |                    | 20.4    |                    | 21.1    |                    |
| Std. dev <sup>#</sup>                       | 26.8    |                    | 14.1    |                    | 16.7    |                    |

<sup>#</sup>Standard deviation

Infiltration rates were measured in inches per hour (in/hr).

Infiltration classes: Very Rapid (VR)=>20 in/hr; Rapid (R)=6-20 in/hr; Moderately Rapid (MR)=2-6 in/hr; Moderate (M)=0.6-2 in/hr; Moderately Slow (MS)=0.2-0.6 in/hr; Slow (S)=0.06-0.2 in/hr; Very Slow (VS)=0.0015-0.06 in/hr; Impermeable (I)=<0.0015.

<sup>‡</sup>Compost applied on 11/28/16.

**Table 16.** Infiltration rates in purple needlegrass (block 3) treated and untreated plots across three years at the Lockeford Plant Materials Center, CA.

| Purple needlegrass - Infiltration Rates |         |                    |         |                    |         |                    |
|-----------------------------------------|---------|--------------------|---------|--------------------|---------|--------------------|
| Treatment                               | 2017    | Infiltration Class | 2018    | Infiltration Class | 2019    | Infiltration Class |
|                                         | (in/hr) |                    | (in/hr) |                    | (in/hr) |                    |
| Control                                 | 11.0    | R                  | 6.4     | R                  | 6.2     | R                  |
| Compost <sup>‡</sup>                    | 11.3    | R                  | 12.7    | R                  | 10.9    | R                  |
| Mean                                    | 11.2    |                    | 9.5     |                    | 8.5     |                    |
| Std. dev <sup>#</sup>                   | 10.3    |                    | 6.3     |                    | 3.6     |                    |

<sup>#</sup>Standard deviation

Infiltration rates were measured in inches per hour (in/hr).

Infiltration classes: Very Rapid (VR)=>20 in/hr; Rapid (R)=6-20 in/hr; Moderately Rapid (MR)=2-6 in/hr; Moderate (M)=0.6-2 in/hr; Moderately Slow (MS)=0.2-0.6 in/hr; Slow (S)=0.06-0.2 in/hr; Very Slow (VS)=0.0015-0.06 in/hr; Impermeable (I)=<0.0015.

<sup>‡</sup>Compost applied on 11/28/16.

**Table 17.** Chemical analysis of composite soil samples at three depths from treated and untreated plots in three species blocks (California brome, orchardgrass, and purple needlegrass) at the Lockeford Plant Materials Center, CA.

| SAMPLE ID | Depth (cm) | Organic Matter % Rating | Phosphorus (ppm) | Potassium (ppm) | Magnesium (ppm) | Calcium (ppm) | Sodium (ppm) | pH  | CEC (meq/100g) | Nitrogen NO <sub>3</sub> -N (ppm) | Sulfur (ppm) | Soluble Salts (mmhos/cm) |
|-----------|------------|-------------------------|------------------|-----------------|-----------------|---------------|--------------|-----|----------------|-----------------------------------|--------------|--------------------------|
| CBT1      | 0-10       | 2.3                     | 50               | 353             | 162             | 1187          | 13           | 6.7 | 8.6            | 20                                | 6            | 0.7                      |
| CBT2      | 10-30      | 1.7                     | 30               | 151             | 161             | 1540          | 20           | 7.2 | 9.5            | 5                                 | 4            | 0.4                      |
| CBT3      | 30-50      | 1.7                     | 22               | 65              | 149             | 1663          | 26           | 7.5 | 9.8            | 3                                 | 4            | 0.3                      |
| CBU1      | 0-10       | 2.3                     | 42               | 294             | 150             | 1160          | 12           | 6.4 | 8.6            | 27                                | 4            | 0.8                      |
| CBU2      | 10-30      | 1.4                     | 28               | 129             | 166             | 1288          | 13           | 6.8 | 8.4            | 4                                 | 2            | 0.2                      |
| CBU3      | 30-50      | 1.3                     | 20               | 68              | 167             | 1553          | 20           | 7.4 | 9.4            | 2                                 | 2            | 0.2                      |
| OGT1      | 0-10       | 2.3                     | 44               | 290             | 154             | 1195          | 9            | 6.6 | 8.5            | 1                                 | 4            | 1                        |
| OGT2      | 10-30      | 1.2                     | 41               | 166             | 151             | 1070          | 13           | 6.3 | 7.9            | 1                                 | 2            | 0.2                      |
| OGT3      | 30-50      | 0.8                     | 22               | 81              | 135             | 1012          | 19           | 6.5 | 7              | 2                                 | 2            | 0.1                      |
| OGU1      | 0-10       | 1.9                     | 38               | 253             | 139             | 1221          | 9            | 6.8 | 8.2            | 1                                 | 3            | 0.2                      |
| OGU2      | 10-30      | 1.3                     | 26               | 140             | 178             | 1210          | 12           | 6.3 | 8.8            | 1                                 | 2            | 0.1                      |
| OGU3      | 30-50      | 1.3                     | 21               | 67              | 169             | 1456          | 19           | 7.1 | 8.9            | 1                                 | 2            | 0.1                      |
| PNT1      | 0-10       | 2.4                     | 47               | 376             | 165             | 1101          | 12           | 6.3 | 8.8            | 8                                 | 4            | 0.4                      |
| PNT2      | 10-30      | 1.8                     | 31               | 156             | 163             | 1123          | 15           | 6.1 | 8.6            | 3                                 | 3            | 0.2                      |
| PNT3      | 30-50      | 1.7                     | 18               | 65              | 166             | 1284          | 25           | 6.3 | 9              | 2                                 | 2            | 0.1                      |
| PNU1      | 0-10       | 2.4                     | 40               | 320             | 148             | 1296          | 14           | 6.6 | 9.1            | 8                                 | 3            | 0.4                      |
| PNU2      | 10-30      | 1.3                     | 28               | 131             | 174             | 1249          | 15           | 6.2 | 9.2            | 5                                 | 3            | 0.1                      |
| PNU3      | 30-50      | 1.3                     | 18               | 60              | 161             | 1269          | 23           | 6.6 | 8.4            | 1                                 | 2            | 0.1                      |

CBT = California brome compost treated; CBU = California brome untreated

OGT = Orchardgrass compost treated; OGU = Orchardgrass untreated

PNT = Purple needlegrass compost treated; PNU = Purple needlegrass untreated

### Discussion

The results from the California brome block indicate that after a single application of compost to areas primarily composed of annual grasses (California brome in this case), in the absence of grazing, species composition will shift toward less desirable annual grass populations. The compost application also appeared to suppress legume growth for the first two years but lost this effect by the third year after application. Even though there was a shift in species composition, the forage quality in this block was average to excellent.

Results from the perennial species blocks indicate that an application of compost can increase the estimated dry matter yield significantly, compared to untreated plots. In the orchardgrass blocks, the compost treatment slightly increased the percentage of seeded species. However, this was not the case in the purple needlegrass plots, as they gradually decreased in seeded species in both treated and untreated plots over time. In both perennial species blocks, the compost application also appeared to suppress legume growth for the first two years but lost this effect by the third year after application. The compost application appeared to have no effect on the orchardgrass forage quality, which was average to excellent. In the purple needlegrass block, forage quality was lower in the compost treatment, possibly due to the higher percentage of other grasses that were lower in forage quality.

The legume species that were most abundant were woolly pod vetch, and rose clover (*Trifolium hirtum*), both are non-native species naturalized in degraded California rangelands. Their relative abundance in the non-compost plots would serve to add nitrogen and improve forage and biomass quality in these plots. The absence of grazing in this trial, indicates that results in rangeland may vary. Cattle reportedly graze preferentially in areas treated with compost (J. Borum, personal communication, June 12, 2020). Grazing compost treated areas would lead to further inputs of manure and urine with the possibility of a “virtuous cycle” of increased nutrient inputs and growth. During the three years of the trial, the compost application did not cause significant differences to soil infiltration and soil chemical properties with the exception of a slight increase in phosphorous and potassium in the surface horizons.

## CONCLUSION

Results from the perennial species blocks indicate that an application of compost can increase the estimated dry matter yield significantly, compared to untreated plots. However, this does not necessarily equate with improved forage quality. For example, the compost treatment in the purple needlegrass block reduced forage quality in the third year of the trial compared to the untreated plots. Additionally, in the annual species block, there were no significant differences in dry matter yield between treatments.

By the third year, compost application had little to no effect in the blocks and California brome and purple needlegrass blocks shifted toward less desirable annual grass species populations. Legume growth was reduced with the compost application compared to the control for the first two years in all three species blocks but lost this effect by the third year after application. This study indicates that the benefits of a single application of compost depends on the desired grass species. A single application of compost to an introduced perennial grass species, like orchardgrass, may show some improvements but those benefits may not be as apparent in a native perennial grass stand. A single compost application to an annual grass stand may not show desirable long-term enhancement. Grazing effects on species composition in compost treatments should be evaluated in the future.

## ACKNOWLEDGEMENTS

The Lockeford Plant Materials Center staff would like to thank everyone who contributed to this project: Jeff Borum, Soil Health Conservationist at the East Stanislaus Resource Conservation District, John Wick, co-founder of the Marin Carbon Project, and Dr. Whendee Silver, Professor of Ecosystem Ecology at UC Berkeley.

## LITERATURE CITED

- Booker, K., L. Huntsinger, J.W. Bartolome, N.F. Sayre and W. Stewart. 2013. What Can Ecological Science tell us About Opportunities for Carbon Sequestration on Arid Rangelands in the United States? *Global Environmental Change*, 23: 240-251.
- Burcham, L.T. 1957. California Range Land: An Historic-Ecological Study of the Range Resource of California. Division of Forestry, Dept. of Natural Resources, State of California, Sacramento. Pp 261.
- Burcham, L.T. 1981. California Rangelands in Historical Perspective. *Rangelands*. 3:95-104.

- Chambers, A., R. Lal, and K. Paustian. 2016. Soil carbon sequestration potential of US croplands and grasslands: Implementing the 4 per Thousand Initiative. *J. Soil and Water Conservation*. 71:68-74.
- DeLonge, M.S., R. Ryals, and W.L. Silver. 2013. A lifecycle model to evaluate carbon sequestration potential and greenhouse gas dynamics of managed grasslands. *Ecosystems* 16: 962-979.
- Duckett, S., and T. McGaha. 2003. How to Read a Forage Analysis Report. North Carolina Cooperative Extension Service.
- Hartz, T.K., J.P. Mitchell and C. Giannini. 2000. Nitrogen and carbon mineralization dynamics of manures and composts. *HortScience* 35: 209-212.
- Hicks Pries, C.E., B.N. Sulman, C. West. C. O'Neill, E. Poppleton, R.C. Porras, C. Castanha, B. Zhu, D.B. Wiedemeier and M.S. Torn. 2018. Root litter decomposition slows with soil depth. *Soil Biology and Biochemistry* 125: 103-114.
- Jackson, L.E., R.B. Strauss, M.K. Firestone and J.W. Bartolome. 1988. Plant and soil nitrogen dynamics in California annual grassland. *Plant and Soil* 110, 9-17
- Koteen, L.E., Baldocchi, D.D. and J. Harte. 2011. Invasion of non-native grasses causes a drop in soil carbon storage in California grasslands. *Environ. Res. Lett.* 6: 1-10.
- Lemus, R. 2020. Hay Testing and Understanding Forage Quality. Mississippi State University Extension. Publication 2539 (POD-02-20).
- Olmstead, A.L., and P. Rhode. 1988. An Overview of California Agricultural Mechanization, 1870-1930. *Agricultural History*, 62: 86–112. *JSTOR*, [www.jstor.org/stable/3743209](http://www.jstor.org/stable/3743209). Accessed 21 Sept. 2020
- Ryals, R., M.D. Hartman, W.J. Parton, M.S. DeLonge and W.L. Silver. 2015. Long-term climate change mitigation potential with organic matter management on grasslands. *Ecological Applications*. 2015: 531-545.
- Ryals, R. and W. L Silver. 2013. Effects of Organic Matter Amendments on Net Primary Productivity and Greenhouse Gas Emissions in Annual Grasslands. *Ecological Applications*, 23: 46-59.
- Soil Quality Institute. 2001. Soil Quality Test Kit Guide. USDA-Agricultural Research Service and USDA-Natural Resources Conservation Service,
- Stromberg, Mark R., Corbin, J.D., D'Antonio, C.M., 2007. *California Grasslands: Ecology and Management*, University of California Press.
- Statistix 10. 2013 Analytical software, Tallahassee, FL.
- Tautges, N.E., J.L. Chiartas, A.C.M. Gaudin, A.T. O'Gean, I. Herrera and K.M. Scow. 2019. Deep soil inventories reveal that impacts of cover crops and compost on soil carbon sequestration differ in surface and subsurface soils. *Glob. Change Biol.* 2019;00:1-14.
- Tilley, Derek, D. Dyer, and J. Anderson. 2009. Plant Guide for Purple Needlegrass. USDA-Natural Resources Conservation Service, California Plant Materials Center, Lockeford, CA 95237.
- USDA-Natural Resources Conservation Service, Lockeford Plant Materials Center. Lockeford, CA. 'Cucamonga' California Brome. Published [June 2012], revised [December 2017].
- USDA-Natural Resources Conservation Service, California Plant Materials Center. Lockeford, CA 95237. Release Brochure for 'Berber' orchardgrass (*Dactylis glomerata* L.). Published [August, 2013]. Revised [December, 2017];
- Wang, Yugang, et al., 2010. Profile Storage of Organic/Inorganic Carbon in Soil: From Forest to Desert. *Science of the Total Environment*, Vol 408 (2010): 1325-1931.
- Western Regional Climate Center. Period of Record Monthly Climate Summary for Lodi, California (Accessed: 01/02/18): <https://wrcc.dri.edu/cgi-bin/cliMAIN.pl?ca5032>.

Western Weather Group. Historical Weather Database Monthly Summaries for Lockeford  
(Accessed: 01/02/18):  
<https://westernwx.com/weatherdb/index.php?q=wwg/reports/wwgmonthly>



**Figure 27.** 'Cucamonga' California brome untreated plot, May 2018.



**Figure 28.** 'Berber' orchardgrass untreated plot, May 2018.



**Figure 29.** Purple needlegrass untreated plot with volunteer 'Berber' orchardgrass, May 2018.



**Figure 30.** ‘Berber’ orchardgrass plot with rose clover, hairy vetch and Painted Lady butterflies.

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