Yield Gap Dynamics of Rainfed Alfalfa in the United States

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The United States (U.S.) is the largest alfalfa (*Medicago sativa* L.) producer in the world; however, there have only been limited attempts to understand the alfalfa forage yield gap. Considering that yield and production of rainfed alfalfa have been relatively stagnant in the country for decades, there is a need to better understand the magnitude of the yield gap in this region. Thus, the main objective of this study was to estimate the current yield gap in respect to water availability in major U.S. rainfed alfalfa producing states. We collected 10-yr (2009-2018) county-level government-reported yield and weather data from 393 counties within 12 major U.S. rainfed alfalfa producing states and delineated alfalfa growing season using probabilistic approaches based on temperature thresholds for crop development. We then calculated county-level growing season rainfall (GSR), which was plotted against county-level yield to determine attainable yield (Ya) using frontier function analysis, and water-limited potential yield (Yw) using boundary function analysis. Average and potential water use efficiencies (WUE) were estimated, and associated yield gap referring to attainable (YGa) or water-limited yields (YGw) were calculated. Finally, we used conditional inference trees (CIT) to identify major weather-related yield-limiting factors to alfalfa forage yield. The frontier model predicted a mean Ya of 9.6±1.5 Mg ha^{-1} and an associated optimum GSR of 670 mm, resulting in a mean YGa of 34%. The boundary function suggested a mean Yw of 15.3±3 Mg ha^{-1} at the mean GSR of 672±153 mm, resulting in a mean yield gap of 58%. The potential alfalfa WUE was 30 kg ha^{-1} mm^{-1} with associated minimum water losses of 163 mm (or 24% of mean GSR), which was three times greater than the mean WUE of 10 kg ha^{-1} mm^{-1}. The CIT suggested that GSR and minimum temperature in the season were the weather variables most associated with alfalfa in rainfed alfalfa production in the U.S. The findings of this study could be useful to alfalfa producers, farm managers, researchers, and policymakers to minimize the current yield gap.