

Crop-Specific Multi-Year Acceptable Ranges of Applied Nitrogen Relative to Nitrogen Removed

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LIST OF ABBREVIATIONS

A	Applied nitrogen
A/R	The ratio of applied nitrogen relative to nitrogen removed
A-R	The mass balance of applied nitrogen less nitrogen removed
CDFA	California Department of Food and Agriculture
CVRWQCB	Central Valley Regional Water Quality Control Board
FREP	Fertilizer Research and Education Program
GWP	Groundwater Protection
INMP	Irrigation and Nitrogen Management Plan
LTILRP	Long-term Irrigated Lands Regulatory Program
MPEP	Management Practices Evaluation Program
N	Nitrogen
NMP	Nitrogen Management Plan
NUE	Nitrogen-use efficiency
R	Nitrogen removed with crop harvest and sequestered in perennial tissue
UC	University of California
WDR	Waste Discharge Requirement

EXECUTIVE SUMMARY

Waste Discharge Requirement (WDR) General Orders that apply to members of third-party groups (often referred to as the Long-term Irrigated Lands Regulatory Program or LTILRP) require third parties to develop and implement a Management Practices Evaluation Program (MPEP). A requirement of the MPEP is to determine acceptable ranges for the multi-year ratio target values of nitrogen (N) applied (A) relative to N removed (R), by crop, hereafter referred to as A/R Acceptable Ranges. The A/R Acceptable Ranges are to be submitted to the Central Valley Regional Water Quality Control Board (CVRWQCB). The Central Valley Water Quality Coalitions, third parties to the WDR General Orders, have come together to develop one methodology to develop A/R Acceptable Ranges.¹ The Central Valley Water Quality Coalitions that have developed this methodology include the following:

- Buena Vista Coalition
- Cawelo Water District Coalition
- East San Joaquin Water Quality Coalition
- Grassland Drainage Area Coalition
- Kaweah Basin Water Quality Association
- Kern River Watershed Coalition Authority
- Kings River Watershed Coalition Authority
- Sacramento Valley Water Quality Coalition
- San Joaquin County and Delta Water Quality Coalition
- Tule Basin Water Quality Coalition
- Westlands Water Quality Coalition
- Westside San Joaquin River Watershed Coalition
- Westside Water Quality Coalition

The thirteen Coalitions prepared a Workplan (submitted on January 26, 2024) that describes a proposed methodology to generate agronomically appropriate A/R Acceptable Ranges that should be reasonably achievable for specific cropping systems, on average and over time, across a broad set of crop production conditions. The Central Valley supports a diverse agricultural landscape comprised of more than 250 different crop types grown on a wide range of soils in various climates. Crop-specific ranges are necessary because many factors affect the amount of applied N that may be 1) taken up by the plant, and 2) removed at harvest or stored in perennial tissues. These factors reflect crop-specific growth patterns, the crop components harvested and removed from the field, general environmental conditions such as soil type and local climate, and other factors such as intense weather events, pest and disease infestations, and market forces. As such, A/R ratios achieved by growers are expected to vary not only among differing crop types, but also across different growing conditions in the Central Valley, and even within the same field under relatively consistent management. This inherent crop and environmental variation necessitate the use of multi-year A/R ratio ranges rather than single values.

According to State Water Board Order WQ 2018-0002, the purpose of the A/R Acceptable Ranges is to provide Coalitions and their members with a reliable metric to identify field-level-N over-application so that they can effectively prioritize members for follow-up of potential nitrate impacts. It is also intended to provide growers with an efficiency metric that can be used to support cost savings in N applications. State Water Board Order WQ 2018-0002 also directed the CVRWQCB, in consultation with the Central

¹ Reference to Coalitions for this submittal does not include the California Rice Commission on behalf of rice growers in the Sacramento Valley. The Acceptable Ranges provisions are not in the California Rice Commission's Third-Party Order and thus are not applicable to rice growers in the Sacramento Valley.

Valley Water Quality Coalitions, CDFA, and others, to evaluate the A and R data submitted for the purposes of developing acceptable ranges for the multi-year A/R ratio target values for crops grown in the Central Valley. However, State Water Board Order WQ 2018-0002 did not provide guidance on how to determine or define the lower and upper ratio values of the A/R Acceptable Ranges. For the purposes of this program, we define these parameters as follows:

- **The lower end of the range** represents the lowest A/R ratio values that are expected to be routinely achievable under optimal growing and market conditions. While it is possible that a given field in a given year may have a lower A/R ratio than the lower end of the Acceptable Range, it would be agronomically impractical to expect that such efficiencies could be consistently maintained across the diverse growing environments within the Central Valley. The low end of the range will be based largely on scientific literature and outreach materials from University of California (UC) agricultural advisors and reflect a theoretical efficiency at which growers can aim. This end of the range may shift over time as new data and information are generated by new scientific research.
- **The upper end of the range** represents the A/R ratio values that should be achievable in most cases, on average over multiple years, under a variety of real-world conditions (e.g., pest pressures, weather events like frost or hail, poor soil conditions, market forces, etc.) that prevent the realization of lower A/R ratios. The upper end of the range is based on the current state of the agricultural landscape and management in the Central Valley. Further, the upper end of the range is informed by data submitted to the Coalitions as directed by State Water Board Order WQ 2018-0002. This distribution of A/R is expected to shift over time as the landscape evolves through the use of new varieties, technologies, and management practices. As such, this end of the range is not related to a theoretically achievable efficiency, but rather depends on a statistical assessment of the agricultural landscape and the best professional judgment of trained, experienced agronomists.

A/R Acceptable Ranges were determined by implementing the following three steps:

- **Step 1 – Compile available data and prioritize crops.** Three key sources of data and information were compiled and reviewed, including 1) scientific literature and outreach materials from the University of California and commodity groups, 2) crop N removal (N content in the harvest or sequestered in perennial tissues) coefficients, and 3) three years of N application rates, crop yields, and achieved A/R ratios reported by Central Valley growers in their Irrigation and Nitrogen Management Plan (INMP) Summary Reports.
- **Step 2 – Determine the lower end of the A/R Acceptable Ranges.** Information from the scientific literature and outreach materials were used in conjunction with the three-year INMP Summary Report dataset (as needed) to determine routinely achievable A/R ratios for specific crops. Different approaches were used for annual and perennial crops based on key differences in the life cycle of these two groups of crops, maintenance or senescence of living biomass after a growing season, and the nature of plant tissues that are harvested and removed from the field.

- **Step 3 – Determine the upper end of the A/R Acceptable Ranges.** The three-year INMP Summary Report dataset was assessed on a crop-by-crop basis to examine the distribution of A/R ratios across the Central Valley and over time. These distributions were compared to the lower end of the A/R Acceptable Ranges and a threshold of the 75th percentile (by area) was selected as a reasonable basis that consistently identifies A/R ratios that should be routinely achievable on average over time across the Central Valley. This methodology was applied to annual and perennial crops.

A/R Acceptable Ranges were determined for Central Valley crops representing over 99% of the irrigated acreage enrolled in the LTILRP (excluding alfalfa and pasture, which represent systems for which A/R ratios are neither meaningful nor appropriate²). The resulting A/R Acceptable Ranges provide an agronomically appropriate means for Coalitions to identify inefficient cropping systems and prioritize follow-up actions for N management planning. They can also serve as a useful guideline for growers and advisors to reference during N management planning. It is anticipated that A/R Acceptable Ranges may evolve over time as new data and information become available (e.g., refined N-removal coefficients) and as advances in technologies and crop varieties enable improved capture of applied N and thus lower A/R ratios. As such, A/R Acceptable Ranges will be reviewed and updated as appropriate to reflect changes in achievable N use efficiencies.

² Alfalfa is a perennial leguminous crop that fixes N from the atmosphere and typically receives low rates of N application for stand establishment and less after establishment (often no applied N), while N removal rates are substantially higher. Only 1.5% of INMP Report acres under alfalfa from 2020-2022 have an A/R ratio greater than one. Other legumes such as dry beans are prioritized because approximately 50% of the 2020-2022 INMP Summary Report acres have an A/R ratio greater than one (meaning more N was applied than removed). Pasture is excluded due to several factors that confound the ability to compute and interpret A/R for this system. Specifically, cutting and harvesting of pasture is not practiced in all cases (65% of INMP reports report zero yield) and N removed by grazing is not known. In addition, it is common for legumes to be present at varying densities within pasture vegetation mixes making it challenging to develop an appropriate N removal coefficient (which does not currently exist). Lastly, N application is typically relatively low in these systems (acre-weighted average of 40 lb/ac) meaning nitrate leaching risk is generally low.

1 INTRODUCTION

This document describes the third-party Coalitions’³ determination of crop-specific, multi-year, acceptable ranges of the ratio target values of nitrogen (N) applied (A) relative to N removed (R), hereafter referred to as A/R Acceptable Ranges. This document includes the following sections:

- Section 1, Introduction, describes the General Order requirements for the A/R Acceptable Ranges, the third parties, (i.e., LTILRP Coalitions) participating in this approach, background on the A/R ratio, and a proposed definition of A/R Acceptable Ranges.
- Section 2, Methodology for the Determination of Crop-Specific A/R Acceptable Ranges describing the approach used including, 1) an overview of applicable datasets, 2) crop prioritization, 3) determination of the lower end of the crop-specific A/R Acceptable Ranges and, 4) determination of the upper end of the crop-specific A/R Acceptable Ranges.
- Section 3, Crop-specific Multi-year Acceptable Ranges of A/R, provides the A/R Acceptable Ranges for prioritized Central Valley crops.
- Section 4, Future Updates to A/R Acceptable Ranges, outlines the timeline for incorporation of future updates to the A/R Acceptable Ranges as advances in technologies and crop varieties enable changes in N use efficiencies and A/R ratios.

1.1 GENERAL ORDER REQUIREMENTS

The General Orders require that Third-Party Coalitions develop a Management Practices Evaluation Program (MPEP). The overall goal of the MPEP is to evaluate the effectiveness of management practices in limiting the discharge of waste from irrigated lands to groundwater under different conditions (e.g., soil type, depth to groundwater, irrigation practice, crop type, and nutrient management practices). To achieve this goal, objectives include 1) determining the crop-specific coefficients for conversion of a measured crop yield to N removed, and 2) determining acceptable ranges for the multi-year A/R ratio target values by crop. The former objective is prioritized because a) its completion is necessary for the latter objective to be fulfilled because N-removal coefficients are necessary for computing A/R ratios, and b) crop N removal rates inform growers’ N management planning.

As a part of the LTILRP General Order requirements, members must complete and submit to their Coalitions annually an Irrigation and Nitrogen Management Plan (INMP) Summary Report that includes the amount of N applied (A) and yield harvested from each of their enrolled fields for the previous year. The Coalitions calculate R and A/R from reported information and summarize and evaluate the INMP Summary Report data as a part of the Monitoring Reports submitted to the CVRWQCB. This report component includes an evaluation of both single-year and 3-year running total A/R ratios (where possible)

³ Reference to Coalitions for this submittal does not include the California Rice Commission on behalf of rice growers in the Sacramento Valley. The determination of A/R Acceptable Ranges is not in the California Rice Commission’s Third Party Order and thus are not applicable to rice growers in the Sacramento Valley.

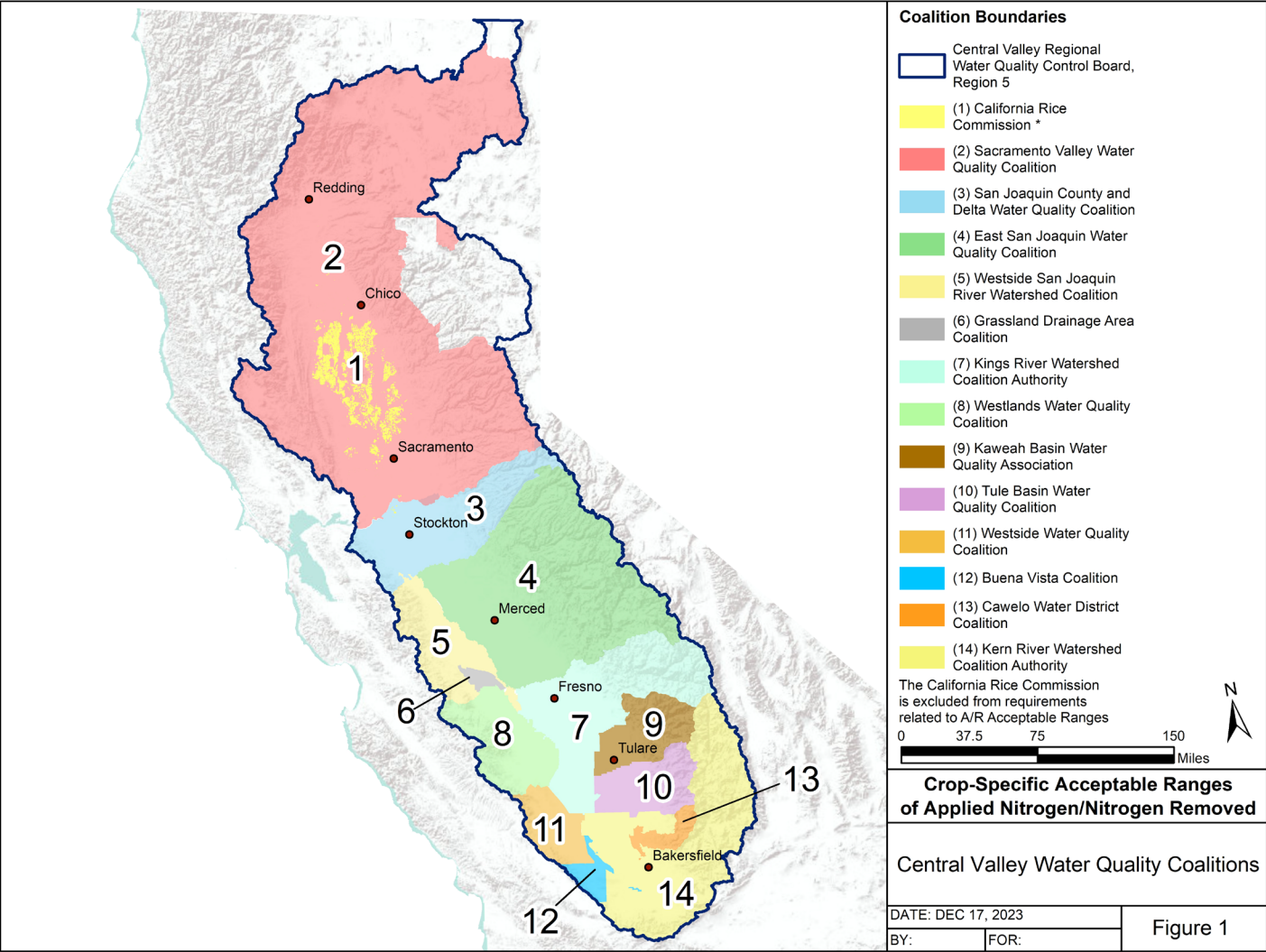
by crop type. Along with these reports the Coalitions also provide aggregated township-level and anonymized field-level INMP data records and the calculated A/R ratios.

1.2 COALITIONS

Thirteen water quality Coalitions (all the Central Valley Coalitions except the California Rice Commission) are participating in this effort to develop A/R Acceptable Ranges. As noted above, the California Rice Commission is not subject to this requirement. Figure 1 shows the locations of these participating Coalitions.

1. Buena Vista Coalition
2. Cawelo Water District Coalition
3. East San Joaquin Water Quality Coalition
4. Grassland Drainage Area Coalition
5. Kaweah Basin Water Quality Association
6. Kern River Watershed Coalition Authority
7. Kings River Watershed Coalition Authority
8. Sacramento Valley Water Quality Coalition
9. San Joaquin County and Delta Water Quality Coalition
10. Tule Basin Water Quality Coalition
11. Westlands Water Quality Coalition
12. Westside San Joaquin River Watershed Coalition
13. Westside Water Quality Coalition

FIGURE 1. MAP OF THE COALITIONS



1.3 BACKGROUND

The following subsections provide background on the A/R ratio in the LTILRP along with proposed definitions for A/R Acceptable Ranges.

1.3.1 RATIO OF APPLIED N OVER N REMOVED

The CVRWQCB has adopted, per direction provided by the State Water Board in Order WQ 2018-0002, two metrics that focus on components that are readily quantified, namely applied N, or “A”, and the amount of N removed in yield, or “R”. The R term is calculated through multiplication of the mass of harvested yield by a representative crop-specific N removal coefficient and consideration of the mass of N sequestered in perennial tissues⁴. The first metric is the ratio of A/R, which illustrates the relationship between the mass of N applied (in fertilizers, amendments, and irrigation water) and N mass removed from the field during harvest. The second metric is the difference between A and R (A-R), also referred to as the partial N mass balance (or “N balance”, for short), which reflects the mass of applied N that was not removed at harvest or sequestered in perennial tissue and is potentially available for loss to the environment. These two metrics have distinct purposes.

The A/R ratio, which is the focus of this document and the metric to which A/R Acceptable Ranges apply, was recommended by the expert panel (Burt et al., 2014) as a primary metric to evaluate grower performance and to track progress in the efficient use of N and improvements in nitrate source control over time. The panel highlighted the need to assess multi-year A/R values as opposed to single-year ratios due to inherent variability in crop yields, precipitation, N transformations in the soil, etc. In addition, they articulated the difference between *total* crop N uptake as compared to N removal as well as known inefficiencies of N applications intrinsic to California cropping systems. Lastly, the panel made it clear that because of these agricultural realities, an A/R ratio of 1 or less cannot be expected for non-leguminous crops. Moving forward, members’ multi-year average A/R ratios for fields will be compared to A/R Acceptable Ranges to track progress in the efficient use of N and to help prioritize outreach and education activities.

⁴ As of December 2023, consideration of N sequestered in perennial tissues has yet to be expressly considered by the Coalitions in their annual reporting of Irrigation and Nitrogen Summary Report information. Section 1.3.4. provides more information on future plans to address this data gap.

1.3.2 PROPOSED DEFINITION OF A/R ACCEPTABLE RANGES

The State Water Board Order WQ 2018-0002 did not provide guidance on how to determine or define the lower and upper ratio values of the A/R Acceptable Ranges. For the purposes of this program, we define these parameters as follows:

- **Lower end of the range.** This represents the lowest A/R ratios that are expected to be routinely achievable under optimal growing and market conditions. While it is possible that a given field in a given year may have a lower A/R ratio than the lower end of the Acceptable Range, it would be agronomically impractical to expect that such efficiencies could be consistently maintained across the diverse growing environments in the Central Valley and across multiple growing seasons. The low end of the range is based largely upon scientific literature and outreach materials from UC agricultural advisors and reflects an ideal efficiency for growers to aim for. This end of the range may shift over time as new data and information are generated by new scientific research.
- **Upper end of the range.** This represents the A/R ratios that should be achievable in most cases, on average over multiple years, under a variety of real-world conditions (e.g., pest pressures, weather events like frost or hail, poor soil conditions, market forces, etc.). that prevent the realization of lower A/R ratios. The upper end of the range is based on the current state of the agricultural landscape in the Central Valley, reflecting the distribution of currently achieved A/R ratios. It is based on data submitted to the Coalitions as directed by State Water Board Order WQ 2018-0002. The distribution of A/R is expected to shift over time as the landscape evolves through the use of new varieties, technologies, and management practices. As such, this end of the range is not related to an ideal achievable efficiency, but rather based on statistical assessment of the actual agricultural landscape as well as the best professional judgment of trained, experienced agronomists, informed by INMP Summary Report A and R data submitted to the Coalitions by their members.

2 METHODOLOGY FOR DETERMINING CROP-SPECIFIC A/R ACCEPTABLE RANGES

This section describes data and methods utilized to determine crop-specific A/R Acceptable Ranges.

2.1 OVERVIEW OF APPLICABLE DATASETS

Key datasets for determining A/R Acceptable Ranges include scientific literature and UC Extension materials, crop N-removal coefficients, and INMP Summary Report data. The rigor and relevance of these datasets affect the means and accuracy of calculating appropriate A/R Acceptable Ranges. Major-acreage crops tend to be better studied and intrinsically have larger INMP Summary Report datasets. Conversely, minor-acreage crops may be less studied, and/or have uncertain N-removal coefficients and fewer INMP Summary Report records. As such, methods for determining A/R Acceptable Ranges are adapted to available information. Specifically, A/R Acceptable Ranges for major-acreage crops are based directly on available data and information specific to them, whereas some minor-acreage crops have been assigned appropriate generic A/R Acceptable Ranges (Section 2.5). Relevant references are presented for perennial and annual crops in Table 1 and Table 3, respectively, while Table 5 includes the data source for N-removal coefficients and the approach used to determine A/R Acceptable Ranges for each crop. Key datasets used for determining A/R Acceptable Ranges are as follows:

- **Scientific literature and University of California Extension materials.** This source of information reflects the current state of scientific knowledge and recommendations regarding routinely achievable N-use efficiencies (NUEs) and A/R ratios for numerous commodities grown in the Central Valley. While useful and informative, this information is typically derived from controlled plot-scale experiments designed to understand optimal NUEs as opposed to appropriate efficiency *ranges* across the landscape and varying growing conditions. As such, this information was used to determine the lower end of the A/R Acceptable Ranges (i.e., the lowest A/R ratios that are expected to be routinely achievable under optimal growing and market conditions).
- **Crop N-removal coefficients.** Crop N-removal coefficients (Geisseler 2016, 2021, 2024) are available for approximately 97% of total INMP acres reported in crop years 2020-2022 with updates pending for roughly 25 crops that reflect 5% of acres upon the completion of an ongoing study by the Coalitions with UC Davis (Geisseler, in progress), funded by the California Department of Food and Agriculture (CDFA) Fertilizer Research and Education Program (FREP). As described in the General Orders, N removal includes N sequestered in the standing biomass of perennial crops (i.e., trunk, branches, roots). While not yet expressly included in N removal calculations for INMP Summary Reports, literature-based estimates are included in the computation of N removed and A/R ratios for the determination of the upper end of the A/R Ranges and are presented in Table 1. While it is likely that N sequestration rates vary depending on stand age, sufficient data to accurately quantify these differences are lacking. As such, the approach taken involves using average values for specific crops regardless of stand age that in some cases may under- or overestimate N sequestration, but should nevertheless be reasonable estimates of the average over time. To determine these average N sequestration rates, total plant N estimates (in pounds

per acre) reported in scientific literature were divided by the stand ages to calculate clear and defensible estimates of annual sequestration rates. In addition, for perennials that are routinely pruned to support production, an estimate of N removed during pruning is included. These crop types are identified in Table 1.

Expansion and refinement of crop-specific N-removal coefficients will affect A/R ratios, improving their accuracy. The completion of Phase 2 of the Coalition/UC Davis N-removed project will result in improved N-removal coefficients for key crop types that currently have uncertain estimates. It is also expected that improved N-removal coefficients will have a relatively strong effect on the calculation of A/R ratios for some crops that previously had limited or less relevant data on N removal.

- **Grower reported Irrigation and Nitrogen Management Plan Summary Reports.** The INMP dataset is robust in that it contains multiple years of information for many crops produced across millions of Central Valley acres encompassing a broad range of growing conditions. In conjunction with the N-removal coefficients, the INMP Summary Report dataset allows for the assessment of actual A/R ratios achieved across the Central Valley. In 2014, these ratios were acknowledged by the expert panel to be an uncertain and yet crucial parameter for determining A/R Acceptable Ranges (Burt et al., 2014). To address this need, the INMP dataset has been analyzed and interpreted to inform the A/R Acceptable Ranges by evaluating the distributions of applied N rates, realized yields, and A/R ratios that are achieved by Central Valley growers.

The most recent INMP Summary Reports collected by all 13 coalitions from crop years 2020-2022 (three years) inform A/R Acceptable Ranges. These data were screened to flag and remove potentially erroneous entries of applied N and/or yield. Furthermore, INMP Summary Reports with an A/R of less than 1 (more N is removed with crop harvest than was applied) have been excluded from this analysis to eliminate agronomically unsustainable systems from the determination of A/R Acceptable Ranges.

Mature perennial crop stands are distinguished from young for the purposes of defining A/R Acceptable Ranges given the differences in root system development, rate of N sequestration in perennial tissues, and the amount of crop generated and harvested and removed from the field. Table 1 displays the stand-age thresholds used to distinguish young from mature perennial crops.

Analysis of this dataset revealed very weak (or no) correlation between applied N and yield for individual crops in most cases (e.g., the maximum crop-specific coefficient of determination (R^2) is 0.28, with many cases being considerably lower), highlighting the significance of other covariates such as climate, soil type, and nutrient management practices in explaining crop yield. The lack of a strong relationship between applied N and yield means that these data cannot be assessed (in the way that highly controlled field trials are) to determine optimum N application rates for a given yield level, or to deduce optimal A/R ratios since evaluating the relationship of only applied N and yield does not take into account these other variables. However, based on the proposed definition of the upper end of the A/R Acceptable Ranges, the INMP Summary Report

data from 2020 – 2022 can be used to define agronomically and environmentally reasonable A/R ratios to support the identification of growers for outreach and education.

TABLE 1. NITROGEN SEQUESTRATION RATES AND STAND AGE THRESHOLDS FOR PERENNIAL CROPS.

Crop	Annual of Perennial	Years to Maturity	N Stored in Perennial Tissue (lb N/acre-year)	References
Almonds	Perennial	4	26	Muhammad et al. (2020)
Pistachios	Perennial	8	11	Rosecrance et al. (1995)
Walnuts	Perennial	5	16	Weinbaum and Van Kessel (1998)
Grapes (Wine, Table, Raisin)	Perennial	3	10 ^a	
Orange	Perennial	7	18	Brown et al. (2023)
Mandarin	Perennial	6	18	Brown et al. (2023)
Cherries ^b	Perennial	5	14	Brown et al. (2023)
Peaches/Nectarines ^b	Perennial	4	12	Niederholzer et al. (2001), Rufat and DeJong (2001)
Prunes/Plums ^b	Perennial	4	13	Weinbaum et al. (1994)

^a. Generic estimate is used. Field-based research data are forthcoming.

^b. N stored in perennial tissue estimate assumes an additional 2 lb/ac-yr for routine pruning.

2.2 CROP PRIORITIZATION

Crops are prioritized based on reported acreage associated with the 2020-2022 INMP Summary Reports to ensure that the vast majority of the recently cropped acreage enrolled in the LTILRP (i.e., greater than 99% of acres for which A/R ratios are meaningful and appropriate [Table 2]) have a crop-specific A/R Acceptable Range. Table 2 provides a summary of prioritized crops and associated acreage while Table 5 displays crop-specific information regarding prioritization. There are several specific conditions for which crops are excluded from the determination of A/R Acceptable Ranges. The following identifies these conditions and supporting justification for not developing A/R Acceptable Ranges:

- Alfalfa, a perennial leguminous crop that fixes atmospheric N, is not prioritized because N application outside of dairy operations is typically limited to low rates for stand establishment and even less post-establishment (often no applied N), while N removal rates are substantially higher. In fact, only 1.5% of INMP Report acres under alfalfa from 2020-2022 have an A/R ratio greater than one. Other legumes such as dry beans are prioritized because approximately 50% of the 2020-2022 INMP Summary Report acres have an A/R ratio greater than one (meaning more N was applied than removed).
- Pasture is excluded due to several factors that confound the ability to compute and interpret A/R for this system. Specifically, cutting and harvesting of pasture is not practiced in all cases (65% of INMP Summary Reports report zero yield) and N removed by grazing is not known. In addition, it is common for legumes to be present at varying densities within pasture vegetation mixes, making it challenging to develop an appropriate N-removal coefficient. Perhaps due to these and

other factors, no research-based N-removal coefficient currently exists for pasture. Lastly, N application is typically relatively low (an acre-weighted average of 40 lb/ac) in these systems, so that nitrate leaching risk is also generally low.

- Rice grown outside of the California Rice Commission geographic extent⁵ is not prioritized due to predominant growing conditions that pose very limited risk of nitrate leaching to groundwater, as has been documented⁶. Specifically, rice grown outside of the Sacramento Valley is typically grown in flooded paddy systems on soils similar to those that predominate in the Sacramento Valley). These soils tend to have low rates of percolation (LaHue and Linquist, 2021). In addition, mineral N in rice systems tends to exist as ammonium, not nitrate. Ammonium is positively charged and adsorbs to negatively charged sites on soil minerals and organic matter. Furthermore, flooding induces anaerobic conditions that lead to denitrification (conversion of nitrate-N to gaseous forms) of any nitrate that develops during periods when rice fields are drained. These facts illustrate that the determination and application of A/R Acceptable Ranges as a tool for prioritizing follow-up actions to mitigate nitrate leaching risk to groundwater are not relevant for rice cropping systems in the Central Valley.
- Minor-acreage crops with no N-removal coefficient nor a reasonable surrogate are not prioritized because A/R ratios cannot be calculated, and the crop cannot be assessed against A/R Acceptable Ranges. Moreover, there are limited data and information to inform credible A/R Ranges for these crops. Lastly, minor-acreage crops intrinsically have a small impact on the broader landscape (due to their limited area); those with no N-removal coefficient constitute less than 0.5% of the total acreage reported in 2020-2022 INMP Summary Reports. As illustrated in Table 2, 99% of INMP Summary Report acres (excluding alfalfa and pasture) have an A/R Acceptable Range, meaning the exclusion of specific minor-acreage crops has a de minimis effect on the acreage captured by this approach.

⁵ The Acceptable Ranges provisions are not in the California Rice Commission's Third-Party Order and thus are not applicable to rice growers in the Sacramento Valley.

⁶ Attachment A to Order R5-2014-0032-03 Information Sheet. Sacramento Valley Rice Growers.

https://www.waterboards.ca.gov/centralvalley/board_decisions/adopted_orders/general_orders/r5-2014-0032-03.pdf

TABLE 2. SUMMARY OF PRIORITIZED CROPS FOR THE DETERMINATION OF A/R ACCEPTABLE RANGES BASED UP INMP SUMMARY REPORTS FROM 2020-2022.

Parameter	Value
Total Crop Count	193
Total INMP Summary Reports	253,466
Total INMP Acreage across 2020-2022 ^a	11,653,154
Average Annual INMP Acreage across 2020-2022	3,884,385
Prioritized Crops with A/R Acceptable Ranges	102
Average Annual Acreage with A/R Acceptable Ranges	3,625,182 (93% of total)
Average Annual INMP Acreage for Alfalfa and Pasture	212,242
Percent Average Annual Acreage with A/R Acceptable Ranges, excluding Alfalfa and Pasture	99%

^a. With the INMP dataset spanning three years, many physical acres within the Central Valley furnish at least two or three reported acres to the total; therefore, the summed acreage was divided by three to produce the “Average Annual INMP Acreage across 2020-2022”).

2.3 DETERMINATION OF THE LOWER END OF THE A/R ACCEPTABLE RANGES

The lower end of the A/R Acceptable Ranges is informed by scientific literature and recommendations from the University of California Extension specialists and researchers, as well as INMP data in the case of some annual crops (see Section 2.3.1). Different approaches are taken for annual crops versus perennial crops due to intrinsic differences in plant physiology and N removal rates in harvested materials associated with these differing cropping systems. Sections below describe the methods for determining the lower end of the A/R Acceptable Ranges for annual and perennial crops.

2.3.1 ANNUAL CROPS

The approach for annual crops integrates several key pieces of information from scientific literature and grower-reported INMP data in conjunction with N-removal coefficients. For crops where substantial data exist in scientific literature from California or comparable environments on crop response to N fertilization, crop N uptake and removal in harvest, such literature weighs heavily in the development of the lower A/R Acceptable Range. For crops where such data are not robust, an empirical approach was used to develop the lower end of the A/R Acceptable Ranges. The factors considered in addition to scientific literature are: 1) the fraction of total crop N uptake removed at common levels of yield, 2) comparative rooting depth (shallow rooted crops tend to be less efficient at N recovery), and 3) the distribution of A/R ratios reported in the three-year INMP Summary Report dataset as a guide to what N use efficiency appears achievable given current technology. Table 3 summarizes this information and displays the lower end of the A/R Acceptable Ranges for select annual crops.

TABLE 3. OVERVIEW OF PERTINENT CHARACTERISTICS ASSOCIATED WITH THE LOWER END OF THEIR A/R ACCEPTABLE RANGES, AND RELEVANT REFERENCES FOR SELECT ANNUAL CROPS.

Crop	Rooting Depth	Percent of total N Uptake Removed with Yield	Lower end of the A/R Acceptable Range	References
Tomatoes, Processing	Moderate	65	1.43	Hartz and Bottoms (2009), Lazcano et al. 2015), Geisseler et al. (2020)
Cotton	Deep	60	1.55	Fritschi et al. (2004), Bronson (2021)
Corn Silage ^a	Moderate	90	1.33	
Corn Grain	Moderate	60	1.43	Bender et al. (2013), Hernandez-Ramirez et al. (2011), Omonode and Vyn (2019)
Wheat Common Grain	Deep	75	1.43	Linguist et al. (1992), McGuire et al. (1998), Blankenau et al. (2002)
Wheat Silage ^a	Deep	90	1.33	
Carrots	Moderate	55	1.6	Hartz et al. (2005), Westerveld et al. (2006), Makries and Warncke (2013), Montazar et al. (2021)
Potatoes	Moderate	70	1.5	Sullivan et al. (1999), Marsh (2016; 2019)
Garlic	Shallow	70	1.5	Rosen and Tong (2001)
Onion	Shallow	70	1.5	Sullivan et al. (1999), Geisseler et al. (2022)
Melons, Cantaloupe	Moderate	60	1.43	Hartz (2006), Soto-Ortiz (2008)
Lettuce	Shallow	55	1.6	Hartz (2006), Soto-Ortiz (2008)
Broccoli	Moderate	30	2.4	Smith et al. (2016a)

^a. Silage crops have a smaller A/R ratio than grain crops due to a larger fraction of plant material that is harvested and removed.

2.3.2 PERENNIAL CROPS

Recommendations from the University of California tend to promote targeting an NUE of at least 70% (A/R of 1.43) for many perennial crops and as such, this value will be used for the lower end of the A/R Acceptable Ranges for all perennial crops. While achievable efficiencies may be higher or somewhat lower for certain crops/circumstances, this value serves as a useful guideline for growers and advisors to consider.

2.4 DETERMINATION OF THE UPPER END OF THE A/R ACCEPTABLE RANGES

As described in Section 2.1, the 2020-2022 INMP Summary Report dataset, in contrast to scientific literature and UC Extension materials, captures the distribution of achieved A/R ratios across crop types grown in the Central Valley and contains the necessary information to determine the upper bounds of appropriate crop-specific A/R ratios given the range of conditions experienced by Central Valley growers. Given the differences in applicable datasets and how they may be applied (as described in Section 2.1), different methodologies are required to determine the lower and upper ends of the A/R Acceptable Ranges. As such, the upper end of the A/R Acceptable Ranges for annual and perennial crops is based exclusively on analysis of the 2020-2022 INMP Summary Report dataset. Specifically, the crop-specific

distributions of A/R ratios from the three-year INMP Summary Report dataset were assessed against the lower end of the A/R Acceptable Ranges to quantify the fraction of reports and acres below, at, or above these values. The objective of these comparisons was to determine an appropriate threshold (i.e., percentile) to define the upper end of the A/R Acceptable Ranges. Based on this analysis, the 75th percentile was selected as a reasonable threshold that consistently identifies A/R ratios that should be routinely achievable on average, over time, across the Central Valley. This is said with the understanding that there may be events outside the grower's control that affect their A/R ratio for multiple years and are not currently reflected in the distribution of data in this assessment (see Section 4 Future Updates to A/R Acceptable Ranges).

2.5 MINOR-ACREAGE CROPS

Minor-acreage crops tend to lack specific data and information for determining appropriate A/R Acceptable Ranges. To mitigate this issue, minor-acreage crops that have been prioritized (see Section 2.2) have been addressed in two ways. First, A/R Acceptable Ranges for physiologically similar, major-acreage crops are used where applicable (e.g., orange for grapefruit). Second, in cases where no such relationship is apparent, minor crops are grouped based on more general physiological characteristics that relate to N use dynamics. Since there is inherent uncertainty in actual N uptake and removal with these crops, and therefore uncertainty in their A/R Acceptable Ranges, each group has been assigned a representative, generic A/R Acceptable Range based on a major-acreage crop within this group with the broadest A/R Acceptable Range (Table 4). In the case of minor acreage vegetable crops such as lettuce and mixed vegetables, N removal can vary considerably by crop type and crop age. As such, a generic A/R Acceptable Range was determined based on a review of INMP Summary Reports for multiple pertinent crop types and relevant scientific research conducted in the Central Coast on these crops.

Table 5 defines whether crop-specific or generic A/R Acceptable Ranges are used for particular crops. Some minor-acreage crops do not have an explicit N-removal coefficient but have still been assigned a generic A/R Acceptable Range in the alternative based on this approach (see Table 5).

TABLE 4. SUMMARY OF GENERIC CROP CLASSES USED FOR ASSIGNING A/R ACCEPTABLE RANGES FOR MINOR ACREAGE CROPS.

Crop Class	Surrogate Crop Used to Inform A/R Acceptable Ranges	Lower end of the A/R Acceptable Range	Upper end of the A/R Acceptable Range	Number of Crops Assigned
Perennials	Pistachio	1.43	2.38	2
Vegetables	Lettuce	1.60	4.00	17
Cool-season grains	Wheat Grain	1.43	1.49	1
Cool-season hay/silage	Wheat Silage	1.33	2.09	14
Warm-season hay/silage	Corn Silage	1.33	1.40	1

3 CROP-SPECIFIC MULTI-YEAR ACCEPTABLE RANGES OF A/R

This section includes the A/R Acceptable Ranges for prioritized Central Valley crops identified in Section 2.2, which are presented in Table 5.

TABLE 5. CROP-SPECIFIC A/R ACCEPTABLE RANGES.

Area Rank	Crop	Number of INMP Summary Reports	Total INMP Summary Report Acres from 2020-2022	Average Annual Acres in Reported In INMPs ^a	Percent of Total Acres	Cumulative Percent of Total Acres	N Removal Coefficient Source	Prioritized For Determination of A/R Acceptable Range	Crop-specific or Generic A/R Acceptable Range	Estimate of N sequestered in wood (lb/ac-yr)	Lower end of the A/R Acceptable Range	Upper end of the A/R Acceptable Range
1	Almonds	71,731	3,688,732	1,229,577	31.7%	31.7%	Geisseler (2016)	Y	Crop-specific	26	1.43	Mature = 1.44 Young = 2.79
2	Pistachios	18,173	1,376,851	458,950	11.8%	43.5%	Geisseler (2021)	Y	Crop-specific	11	1.43	Mature = 2.38 Young = 5.68
3	Walnuts	21,905	739,761	246,587	6.3%	49.8%	Geisseler (2021)	Y	Crop-specific	16	1.43	Mature = 2.14 Young = 3.44
4	Grapes, Wine	14,613	685,937	228,646	5.9%	55.7%	Geisseler (2016); update pending	Y	Crop-specific	10	1.43	Mature = 1.83 Young = 3.00
5	Tomatoes, Processing	8,599	577,952	192,651	5.0%	60.7%	Geisseler (2021)	Y	Crop-specific		1.43	1.80
6	Alfalfa Hay	10,023	523,114	174,371	4.5%	65.2%	Geisseler (2016)	N				
7	Cotton	5,557	366,327	122,109	3.1%	68.3%	Geisseler (2024)	Y	Crop-specific		1.55	2.05
8	Citrus, Oranges	16,287	360,160	120,053	3.1%	71.4%	Geisseler (2024)	Y	Crop-specific	18	1.43	Mature = 2.18 Young = 3.23
9	Corn Silage	5,476	268,840	89,613	2.3%	73.7%	Geisseler (2021)	Y	Crop-specific		1.33	1.39
10	Grapes, Table	6,332	247,630	82,543	2.1%	75.8%	Geisseler (2016); update pending	Y	Crop-specific	10	1.43	Mature = 2.52 Young = 3.30
11	Grapes, Raisin	6,990	230,261	76,754	2.0%	77.8%	Geisseler (2016); update pending	Y	Crop-specific	10	1.43	Mature = 2.31 Young = 3.75
12	Citrus, Mandarins	6,074	181,287	60,429	1.6%	79.4%	Geisseler (2024)	Y	Crop-specific	18	1.43	Mature = 2.61 Young = 4.45
13	Wheat Common Grain	2,859	167,977	55,992	1.4%	80.8%	Geisseler (2016)	Y	Crop-specific		1.43	1.49
14	Corn Grain	1,943	149,651	49,884	1.3%	82.1%	Geisseler (2016)	Y	Crop-specific		1.43	1.81
15	Pasture	2,354	113,613	37,871	1.0%	83.1%		N				
16	Safflower	988	105,128	35,043	0.9%	84.0%	Geisseler (2021)	Y	Crop-specific		1.80	2.46
17	Sunflower	1,871	101,385	33,795	0.9%	84.8%	Geisseler (2021)	Y	Crop-specific		1.90	3.59
18	Cherries	4,346	92,177	30,726	0.8%	85.6%	Geisseler (2016); update pending	Y	Crop-specific	14	1.43	Mature = 3.43 Young = 3.77
19	Olives	2,039	84,158	28,053	0.7%	86.3%	Geisseler (2016); update pending	Y	Crop-specific	10	1.43	Mature = 3.31 Young = 5.00
20	Wheat Silage	1,454	79,709	26,570	0.7%	87.0%	Geisseler (2016)	Y	Crop-specific		1.33	2.09
21	Grass Hay	1,551	74,921	24,974	0.6%	87.7%	Geisseler (2016)	Y	Generic - cool-season hay/silage		1.33	2.09
22	Peaches, Fresh Market	3,800	71,169	23,723	0.6%	88.3%	Geisseler (2021)	Y	Crop-specific	12	1.43	Mature = 2.62 Young = 4.43
23	Carrots	1,433	69,999	23,333	0.6%	88.9%	Geisseler (2021)	Y	Crop-specific		1.60	2.86

Area Rank	Crop	Number of INMP Summary Reports	Total INMP Summary Report Acres from 2020-2022	Average Annual Acres in Reported In INMPs ^a	Percent of Total Acres	Cumulative Percent of Total Acres	N Removal Coefficient Source	Prioritized For Determination of A/R Acceptable Range	Crop-specific or Generic A/R Acceptable Range	Estimate of N sequestered in wood (lb/ac)	Lower end of the A/R Acceptable Range	Upper end of the A/R Acceptable Range
24	Potatoes	1,333	59,763	19,921	0.5%	89.4%	Geisseler (2016); update pending	Y	Crop-specific		1.50	2.54
25	Garlic	739	59,643	19,881	0.5%	89.9%	Geisseler (2016); update pending	Y	Crop-specific		1.50	2.22
26	Pomegranates	844	58,182	19,394	0.5%	90.4%	Geisseler (2021)	Y	Crop-specific	10	1.43	Mature = 2.32 Young = 4.00
27	Citrus, Lemons	2,614	51,241	17,080	0.4%	90.8%	Geisseler (2024)	Y	Crop-specific	18	1.43	Mature = 2.27 Young = 3.44
28	Plums	2,414	47,573	15,858	0.4%	91.2%	Geisseler (2021)	Y	Crop-specific	13	1.43	Mature = 3.07 Young = 3.85
29	Wheat Hay	933	46,055	15,352	0.4%	91.6%		Y	Generic - cool-season hay/silage		1.33	2.09
30	Nectarines	2,744	44,835	14,945	0.4%	92.0%	Geisseler (2024)	Y	Crop-specific	12	1.43	Mature = 2.50 Young = 4.04
31	Onion	549	41,438	13,813	0.4%	92.4%	Geisseler (2016); update pending	Y	Crop-specific		1.50	3.84
32	Prunes	1,185	37,623	12,541	0.3%	92.7%	Geisseler (2016)	Y	Crop-specific	13	1.43	Mature = 3.81 Young = 5.25
33	Melons, Cantaloupe	626	37,152	12,384	0.3%	93.0%	Geisseler (2016); update pending	Y	Crop-specific		1.43	2.64
34	Citrus, All Other	1,374	31,078	10,359	0.3%	93.3%	Average	Y	Generic - Orange	18	1.43	Mature = 2.18 Young = 3.23
35	Sweet Potatoes	1,022	30,100	10,033	0.3%	93.5%	Geisseler (2016); update pending	Y	Crop-specific		1.43	2.12
36	Beans, Dry	613	28,455	9,485	0.2%	93.8%	Average	Y	Crop-specific		0.00	1.93
37	Oat Silage	693	27,865	9,288	0.2%	94.0%		Y	Generic - Oat Hay		1.33	1.89
38	Oat Hay	663	27,172	9,057	0.2%	94.3%	Geisseler (2016)	Y	Crop-specific		1.33	1.89
39	Sudan Hay	323	26,303	8,768	0.2%	94.5%		Y	Generic - warm-season hay/silage		1.33	1.48
40	Corn, Sweet	565	26,140	8,713	0.2%	94.7%	Geisseler (2016); update pending	Y	Crop-specific		2.10	3.79
41	Rice	330	25,652	8,551	0.2%	94.9%		N				
42	Figs	377	23,306	7,769	0.2%	95.1%	Geisseler (2016); update pending	Y	Generic - Perennials. N removal coefficient requires update	10	1.43	Mature = 2.38 Young = 5.68
43	Tomatoes, Fresh Market	463	21,615	7,205	0.2%	95.3%	Geisseler (2016); update pending	Y	Crop-specific		2.40	3.15
44	Melons, Watermelon	404	21,522	7,174	0.2%	95.5%	Geisseler (2016); update pending	Y	Crop-specific		1.90	4.96

Area Rank	Crop	Number of INMP Summary Reports	Total INMP Summary Report Acres from 2020-2022	Average Annual Acres in Reported In INMPs ^a	Percent of Total Acres	Cumulative Percent of Total Acres	N Removal Coefficient Source	Prioritized For Determination of A/R Acceptable Range	Crop-specific or Generic A/R Acceptable Range	Estimate of N sequestered in wood (lb/ac)	Lower end of the A/R Acceptable Range	Upper end of the A/R Acceptable Range
45	Vegetables, Mixed	956	19,831	6,610	0.2%	95.7%		Y	Generic - vegetables		1.60	4.00
46	Triticale Grain	394	19,566	6,522	0.2%	95.8%	Geisseler (2016)	Y	Crop-specific		1.40	1.55
47	Vine, Seed	472	17,904	5,968	0.2%	96.0%		N				
48	Peaches, Processing	888	17,095	5,698	0.1%	96.1%	Geisseler (2021)	Y	Crop-specific	12	1.43	Mature = 1.91 Young = 3.87
49	Berries	516	14,748	4,916	0.1%	96.3%	FREP Central Coast	Y	Crop-specific	5	1.43	9.87
50	Pears	516	13,558	4,519	0.1%	96.4%	Geisseler (2016)	Y	Crop-specific	10	1.43	3.58 (insufficient acreage to determine young vs mature)
51	Peaches	541	13,543	4,514	0.1%	96.5%	Geisseler (2021)	Y	Generic - Fresh Market Peach	12	1.43	Mature = 2.62 Young = 4.43
52	Rice, Wild	177	13,048	4,349	0.1%	96.6%		N				
53	Beans, Garbanzo	147	12,680	4,227	0.1%	96.7%	Geisseler (2016)	Y	Crop-specific		0.00	1.58
54	Small Grain	149	12,556	4,185	0.1%	96.8%	Average	Y	Generic - cool-season grain		1.43	1.49
55	Apricots	606	11,821	3,940	0.1%	96.9%	Geisseler (2016); update pending	Y	Crop-specific	12	1.43	2.70 (insufficient acreage to determine young vs mature)
56	Lettuce	512	11,810	3,937	0.1%	97.0%	Average	Y	Generic - vegetables		1.60	4.00
57	Cucumber	213	11,684	3,895	0.1%	97.1%	FREP Central Coast	Y	Crop-specific		2.00	6.77
58	Small Grain Hay	226	11,397	3,799	0.1%	97.2%		Y	Generic - cool-season hay/silage		1.33	2.09
59	Melons, Honeydew	173	11,381	3,794	0.1%	97.3%	Geisseler (2016); update pending	Y	Crop-specific		1.60	2.74
60	Small Grain Silage	203	11,285	3,762	0.1%	97.4%	Average	Y	Generic - cool-season hay/silage		1.33	2.09
61	Pecans	396	10,791	3,597	0.1%	97.5%		Y	Generic - Perennials	16	1.43	Mature = 2.38 Young = 5.68
62	Lettuce, Iceberg	93	10,540	3,513	0.1%	97.6%	FREP Central Coast	Y	Generic - vegetables		1.60	4.00
63	Grass Sod	343	10,089	3,363	0.1%	97.7%		N				
64	Kiwi	497	9,658	3,219	0.1%	97.8%	Geisseler (2024)	Y	Crop-specific	10	1.43	6.30 (insufficient acreage to determine young vs mature)
65	Broccoli	264	9,522	3,174	0.1%	97.9%	FREP Central Coast	Y	Crop-specific		2.40	4.00

Area Rank	Crop	Number of INMP Summary Reports	Total INMP Summary Report Acres from 2020-2022	Average Annual Acres in Reported In INMPs ^a	Percent of Total Acres	Cumulative Percent of Total Acres	N Removal Coefficient Source	Prioritized For Determination of A/R Acceptable Range	Crop-specific or Generic A/R Acceptable Range	Estimate of N sequestered in wood (lb/ac)	Lower end of the A/R Acceptable Range	Upper end of the A/R Acceptable Range
66	Sorghum Silage	247	9,141	3,047	0.1%	97.9%	Geisseler (2016)	Y	Crop-specific		1.33	2.00
67	Wheat Durum Grain	93	8,513	2,838	0.1%	98.0%	Geisseler (2016)	Y	Crop-specific		1.43	1.57
68	Sorghum Hay	188	8,231	2,744	0.1%	98.1%		Y	Generic – Sorghum silage		1.33	2.00
69	Citrus, Grapefruit	534	7,844	2,615	0.1%	98.2%	Geisseler (2016)	Y	Generic - Orange	18	1.43	Mature = 2.18 Young = 3.23
70	Peppers, Bell	163	7,833	2,611	0.1%	98.2%	Geisseler (2016); update pending	Y	Crop-specific		1.60	4.21
71	Alfalfa Greenchop	142	7,540	2,513	0.1%	98.3%	Geisseler (2016)	N				
72	Ryegrass Hay	176	7,526	2,509	0.1%	98.3%		Y	Generic - cool-season hay/silage		1.33	2.09
73	Barley Grain	129	7,272	2,424	0.1%	98.4%	Geisseler (2016)	Y	Crop-specific		1.43	1.94
74	Pumpkins	203	6,992	2,331	0.1%	98.5%	Geisseler (2016); update pending	Y	Generic - Vegetables. N removal coefficient requires update		1.60	4.00
75	Seed Crops	224	6,639	2,213	0.1%	98.5%		N				
76	Oat Grain	127	6,580	2,193	0.1%	98.6%	Geisseler (2016)	Y	Crop-specific		1.43	1.82
77	Sorghum Grain	139	6,368	2,123	0.1%	98.6%	Geisseler (2024)	Y	Crop-specific		1.43	1.66
78	Cabbage	198	5,744	1,915	0.05%	98.69%	FREP Central Coast	Y	Crop-specific		1.60	4.10
79	Beans, Lima	91	5,679	1,893	0.05%	98.74%	Geisseler (2016)	Y	Crop-specific		0.00	1.18
80	Alfalfa Seed	72	5,425	1,808	0.05%	98.78%		N				
81	Alfalfa Haylage	115	5,274	1,758	0.05%	98.83%	Geisseler (2016)	N				
82	Triticale Silage	107	5,251	1,750	0.05%	98.87%	Geisseler (2016)	Y	Generic - cool-season hay/silage		1.33	2.09
83	Grapes	155	5,203	1,734	0.04%	98.92%	Average; update pending	Y	Generic - Table Grapes	10	1.43	Mature = 2.52 Young = 3.30
84	Persimmons	546	5,096	1,699	0.04%	98.96%		Y	Generic – Fresh Market Peaches	12	1.43	Mature = 2.62 Young = 4.43
85	Cauliflower	149	5,072	1,691	0.04%	99.00%	FREP Central Coast	Y	Generic - vegetables		1.60	4.00
86	Apples	303	5,003	1,668	0.04%	99.05%	Geisseler (2016)	Y	Generic - Pears	10	1.43	3.58 (insufficient acreage to determine young vs mature)
87	Onion, Dehydrator	94	4,768	1,589	0.04%	99.09%	Geisseler (2016); update pending	Y	Generic - Onion		1.50	3.84

Area Rank	Crop	Number of INMP Summary Reports	Total INMP Summary Report Acres from 2020-2022	Average Annual Acres in Reported in INMPs ^a	Percent of Total Acres	Cumulative Percent of Total Acres	N Removal Coefficient Source	Prioritized For Determination of A/R Acceptable Range	Crop-specific or Generic A/R Acceptable Range	Estimate of N sequestered in wood (lb/ac)	Lower end of the A/R Acceptable Range	Upper end of the A/R Acceptable Range
88	Beans, Blackeye	131	4,587	1,529	0.04%	99.13%	Geisseler (2016)	Y	Crop-specific		0.00	1.78
89	Squash	196	4,174	1,391	0.04%	99.16%	Geisseler (2016); update pending	Y	Generic - Vegetables		1.60	4.00
90	Peppers	114	3,861	1,287	0.03%	99.20%	Geisseler (2016)	Y	Generic - Peppers, Bell		1.60	4.21
91	Parsley	142	3,645	1,215	0.03%	99.23%	FREP Central Coast	Y	Generic - Vegetables		1.60	4.00
92	Grass Silage	45	3,637	1,212	0.03%	99.26%		Y	Generic - cool-season hay/silage		1.33	2.09
93	Flowers	108	3,488	1,163	0.03%	99.29%		N				
94	Safflower Seed	24	3,326	1,109	0.03%	99.32%		N				
95	Tomatoes	72	3,234	1,078	0.03%	99.35%	Average	Y	Generic - Processing Tomato		1.43	1.80
96	Beans, Green	86	3,172	1,057	0.03%	99.37%	Geisseler (2016)	Y	Crop-specific		0	5.54
97	Kale	244	3,134	1,045	0.03%	99.40%	FREP Central Coast	Y	Generic - Vegetables		1.60	4.00
98	Herbs	147	3,079	1,026	0.03%	99.43%		N				
99	Lettuce, Romaine	61	3,026	1,009	0.03%	99.45%	FREP Central Coast	Y	Generic - Vegetables		1.60	4.00
100	Asparagus	75	2,926	975	0.03%	99.48%	Geisseler (2016)	Y	Crop-specific		2.00	16.00
101	Wheat Straw	29	2,829	943	0.02%	99.50%	Geisseler (2016)	Y	Generic - cool-season hay/silage		1.33	2.09
102	Melons	55	2,816	939	0.02%	99.53%	Average	Y	Generic - Watermelon		1.60	4.96
103	Spinach	104	2,639	880	0.02%	99.55%	FREP Central Coast	Y	Generic - Vegetables		1.60	4.00
104	Triticale Hay	64	2,572	857	0.02%	99.57%		Y	Generic - cool-season hay/silage		1.33	2.09
105	Hemp	48	2,459	820	0.02%	99.59%		N				
106	Chard	67	2,281	760	0.02%	99.61%		N				
107	Radish	88	2,251	750	0.02%	99.63%	FREP Central Coast	Y	Generic - Vegetables		1.60	4.00
108	Clover	38	2,243	748	0.02%	99.65%		N				
109	Citrus, Tangelos	111	2,203	734	0.02%	99.67%	Average	Y	Generic - Orange	18	1.43	Mature = 2.18 Young = 3.23
110	Greens, Collard	59	2,157	719	0.02%	99.69%		N				
111	Vetch	52	2,150	717	0.02%	99.71%		N				
112	Melons, Watermelon Seed	55	1,928	643	0.02%	99.72%		N				
113	Turf	25	1,843	614	0.02%	99.74%		N				

Area Rank	Crop	Number of INMP Summary Reports	Total INMP Summary Report Acres from 2020-2022	Average Annual Acres in Reported In INMPs ^a	Percent of Total Acres	Cumulative Percent of Total Acres	N Removal Coefficient Source	Prioritized For Determination of A/R Acceptable Range	Crop-specific or Generic A/R Acceptable Range	Estimate of N sequestered in wood (lb/ac)	Lower end of the A/R Acceptable Range	Upper end of the A/R Acceptable Range
114	Onion, Green	56	1,815	605	0.02%	99.75%		N				
115	Fruit Tree	145	1,734	578	0.01%	99.77%		Y	Generic – Fresh Market Peaches	12	1.43	Mature = 2.62 Young = 4.43
116	Strawberries	117	1,667	556	0.01%	99.78%	FREP Central Coast	Y	Generic - vegetables		1.60	4.00
117	Barley Straw	24	1,652	551	0.01%	99.80%	Geisseler (2016)	Y	Generic - cool-season hay/silage		1.33	2.09
118	Small Grain Straw	14	1,201	400	0.01%	99.81%		Y	Generic - cool-season hay/silage		1.33	2.09
119	Peppers, Chile	21	1,190	397	0.01%	99.82%		N				
120	Cilantro	26	1,127	376	0.01%	99.83%	FREP Central Coast	Y	Generic - vegetables		1.60	4.00
121	Pluots	105	1,124	375	0.01%	99.84%		N				
122	Ryegrass	29	1,078	359	0.01%	99.85%	Geisseler (2016)	Y	Generic - cool-season hay/silage		1.33	2.09
123	Radicchio	29	1,067	356	0.01%	99.86%	FREP Central Coast	Y	Generic - vegetables		1.60	4.00
124	Sudan Seed	17	1,058	353	0.01%	99.86%		N				
125	Dichondria	23	1,017	339	0.01%	99.87%		N				
126	Sudan Silage	33	1,011	337	0.01%	99.88%		N				
127	Eggplant	56	961	320	0.01%	99.89%		N				
128	Barley Hay	17	881	294	0.01%	99.90%		N				
129	Broccolini	30	831	277	0.01%	99.90%	FREP Central Coast	Y	Generic - vegetables		1.60	4.00
130	Millet	12	588	196	0.01%	99.91%		N				
131	Barley Silage	3	570	190	0.005%	99.91%	Average	Y	Generic - cool-season hay/silage		1.33	2.09
132	Onion, Seed	31	566	189	0.005%	99.92%		N				
133	Basil	23	554	185	0.005%	99.92%		N				
134	Mustard	82	529	176	0.005%	99.93%		N				
135	Teff Hay	21	489	163	0.004%	99.93%		N				
136	Jujube	32	488	163	0.004%	99.94%		N				
137	Bok Choy	24	465	155	0.004%	99.94%	FREP Central Coast	Y	Generic - vegetables		1.60	4.00
138	Vegetables, Asian	10	440	147	0.004%	99.94%		N				
139	Arugula	22	432	144	0.004%	99.95%	FREP Central Coast	Y	Generic - vegetables		1.60	4.00
140	Lettuce Seed	11	417	139	0.004%	99.95%		N				
141	Cucumber, Seed	20	386	129	0.003%	99.96%		N				
142	Oat Straw	4	386	129	0.003%	99.96%	Geisseler (2016)	Y	Generic - cool-season hay/silage		1.33	2.09
143	Squash, Seed	22	379	126	0.003%	99.96%		N				

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144	Avocados	44	365	122	0.003%	99.97%		N				
145	Mint	4	317	106	0.003%	99.97%		N				
146	Turnip, Greens	57	290	97	0.002%	99.97%		N				
147	Beets	13	208	69	0.002%	99.97%	FREP Central Coast	N				
148	Ryegrass Silage	8	187	62	0.002%	99.97%		N				
149	Okra	11	184	61	0.002%	99.98%		N				
150	Wheatgrass Silage	4	184	61	0.002%	99.98%		N				
151	Leeks	60	174	58	0.001%	99.98%	FREP Central Coast	N				
152	Sweet Potatoes Seed	4	170	57	0.001%	99.98%		N				
153	Melons, Seed	8	163	54	0.001%	99.98%		N				
154	Peas	4	158	53	0.001%	99.98%	FREP Central Coast	N				
155	Dill	3	144	48	0.001%	99.98%		N				
156	Chestnuts	36	140	47	0.001%	99.98%		N				
157	Broccoli, Seed	8	138	46	0.001%	99.99%		N				
158	Potatoes Seed	7	133	44	0.001%	99.99%		N				
159	Hops	28	123	41	0.001%	99.99%		N				
160	Brussels Sprouts	2	116	39	0.001%	99.99%	FREP Central Coast	N				
161	Wheatgrass	2	103	34	0.001%	99.99%		N				
162	Kohlrabi	58	97	32	0.001%	99.99%		N				
163	Citrus, Limes	18	94	31	0.001%	99.99%		N				
164	Daikon	11	94	31	0.001%	99.99%		N				
165	Sorghum Straw	3	86	29	0.001%	99.99%		N				
166	Celery	4	82	27	0.001%	99.99%	FREP Central Coast	N				
167	Beans	3	80	27	0.001%	99.99%		N				
168	Lettuce, Iceberg Seed	1	78	26	0.001%	100.00%		N				
169	Quince	16	76	25	0.001%	100.00%		N				
170	Lettuce, Romaine Seed	1	75	25	0.001%	100.00%		N				
171	Dates	3	60	20	0.001%	100.00%		N				
172	Celery, Root	3	43	14	<.001%	100.00%		N				
173	Pumpkins, Seed	4	43	14	<.001%	100.00%		N				
174	Jojoba	6	39	13	<.001%	100.00%		N				
175	Dandelion	2	36	12	<.001%	100.00%		N				

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176	Radish Seed	2	28	9	<.001%	100.00%		N				
177	Cabbage, Seed	2	27	9	<.001%	100.00%		N				
178	Artichoke	3	22	7	<.001%	100.00%	FREP Central Coast	N				
179	Teff Grain	1	17	6	<.001%	100.00%		N				
180	Beets, Sugar	2	10	3	<.001%	100.00%		N				
181	Fennel	21	8	3	<.001%	100.00%	FREP Central Coast	N				
182	Turnips	1	8	3	<.001%	100.00%		N				
183	Canola	2	6	2	<.001%	100.00%		N				
184	Turnips Seed	1	6	2	<.001%	100.00%		N				
185	Zucchini	1	5	2	<.001%	100.00%	FREP Central Coast	N				
186	Kale Seed	1	4	1	<.001%	100.00%		N				
187	Tomatillos	1	4	1	<.001%	100.00%		N				
188	Escarole	1	3	1	<.001%	100.00%	FREP Central Coast	N				
189	Melons, Cantaloupe Seed	1	3	1	<.001%	100.00%		N				
190	Mulberries	3	3	1	<.001%	100.00%		N				
191	Endive	1	2	1	<.001%	100.00%	FREP Central Coast	N				
192	Hazelnut	3	2	1	<.001%	100.00%		N				
193	Dragonfruit	1	0	0	<.001%	100.00%		N				

^a Average of INMP reporting acreage for crop during the 2020-22 period.

4 FUTURE UPDATES TO A/R ACCEPTABLE RANGES

It may be necessary in some cases to refine A/R Acceptable Ranges as new data and information become available (e.g., refined N-removal coefficients) and as advances in technologies and crop varieties further enable improved NUEs and A/R ratios. In addition, the methodology used to compute the upper end of the A/R Acceptable Ranges is based upon the current state of the agriculture, which is anticipated to evolve in response to outreach, education, and technological advances, meaning the A/R distributions should gradually diminish. A/R Acceptable Ranges will be evaluated at regular intervals (e.g., every five years) to assess whether distributions have shifted, and then updated in accordance with the results of these evaluations.

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