Fallowed Area Mapping for Drought Impact Reporting:

2015 Assessment of Conditions in the California Central Valley

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INTRODUCTION

Working in collaboration with the California Department of Water Resources, scientists at NASA Ames Research Center (ARC), the U.S. Geological Survey (USGS), the U.S. Department of Agriculture (USDA), and California State University, Monterey Bay (CSUMB) have demonstrated the feasibility of using satellite imagery to track the extent of fallowed land in the Central Valley of California on a monthly basis.

Project partners are currently working to establish an operational fallowed land monitoring service as part of a California drought early warning information system, a pilot of the National Integrated Drought Information System (NIDIS) led by NOAA. Supported by the NASA Applied Sciences Program and the NOAA NIDIS Program Office, the primary goal of the pilot project is to provide objective, accurate, and timely assessments of fallowed acreage to decision makers in California to support drought impact assessment and mitigation planning.

Shortage of water due to drought leads to an increase in the extent of agricultural land in the Central Valley that remains unplanted, or "fallow", for one or more seasons because farmers are unable to fully irrigate crops, and will often prioritize use of the limited available agricultural water supplies to attempt to sustain perennial crops on their farms and ranches. When drought causes land to be taken out of production, farm income and agricultural input sales decrease, while unemployment increases among workers employed by farms and related businesses. Timely and accurate knowledge of the extent of fallowing can provide insights into the severity of drought impacts, and provide the basis for sound decisions for drought response. Such decisions can ensure efficient allocation of scarce available water for on-farm use, and authorize provision of emergency assistance. Drought disaster designations and emergency proclamations trigger loan and tax credit programs to help agricultural producers and businesses mitigate impacts on their operations, as well as social programs to aid farm worker households whose livelihoods are disrupted.

Despite the importance of this measure of drought impact, prior to this project there was no source of timely, comprehensive information on the extent of fallowed acreage during the growing season to support decision-making. The complete Cropland Data Layer (CDL) data products from USDA are considered market sensitive, and cannot be made available until January of the following year.

The project partners have shown that the methods for producing the annual Cropland Data Layer (CDL) of the USDA National Agricultural Statistics Service (NASS), which includes an "idle" land class, can be modified and applied to support within-season mapping of fallowed agricultural lands. Furthermore, the project team has demonstrated how new methods using time-series of data on crop canopy development from NASA and USGS satellites (Landsat, Terra, Aqua) can provide information on land fallowing and reductions in planted acreage early in the year. These imagery classifications provide the basis for monthly county tabulations, maps, and GIS files for fallowed land extent. This capability can provide early identification of changes in fallowed acreage due to water shortage during drought, filling an important information gap and reducing ambiguity surrounding drought impact assessment and decision making for drought mitigation.

ASSESSMENT OF LAND FALLOWING IN 2015

The climate across much of California supports almost year-round agricultural production, and many farms that produce annual crops are able to support two or more production cycles per year. In general, production in the California Central Valley can be divided into a winter season and a summer season. While the division between these two seasons can vary from year to year, an analysis of five years of satellite data indicated that there are consistent minimums in overall crop canopy extent in the Central Valley during the last week of May and the last week of September in each year. As such, for the purposes of this analysis, we have defined the winter season as extending from January 1st to May 31st, and the summer season from June 1st through September 30th. Crops planted in the fall are counted as winter crops the following year. Perennial crops are usually detected in both seasons.

Agricultural land is considered "fallow" if it has been idled, uncultivated, or unable to sustain a crop beyond planting and emergence for one or more production seasons. During 2014 and 2015 the project team has tracked land fallowing in the winter and summer seasons, as well as land that was fallow during both seasons. The project team provided monthly updates to DWR from March to September of each year, and also conducted retrospective analyses for 2011-2013. This report summarizes these results, with an emphasis on impacts on agricultural production observed during 2015.

Table 1 summarizes the land fallowing in the California Central Valley through September 30, 2015, and includes winter fallowed acreage (fallow from January 1st to May 31st), summer fallowed acreage (fallow from June 1st to September 30th), and year-to-date annual fallowed acreage (fallow during both seasons, from January 1st to September 30th). We used data from 2011 as the reference year to calculate the change in fallowed acreage, since 2011 was the last calendar year that followed a winter with average or above-average rainfall across most of California. The spatial patterns in land fallowing across California are shown in Figures 1A-1C, and Figure 2 provides a comparison between the USDA and NASA estimates for year-to-date fallowed acreage for 2015 showing good overall agreement. Data on land fallowing from USDA NASS is based on analysis of satellite data from April to September of each year, and is only available for year-to-date annual fallowed acreage.

Winter fallowed acreage: During the 2015 winter season, the project documented more than 1.77 million acres in the California Central Valley that remained fallow throughout the winter, an increase of 1.038 million acres relative to the 2011 winter season.

Summer fallowed acreage: During the 2015 summer season, the project documented more than 1.91 million acres in the California Central Valley that remained fallow throughout the summer, an increase of 522,000 acres relative to summer 2011.

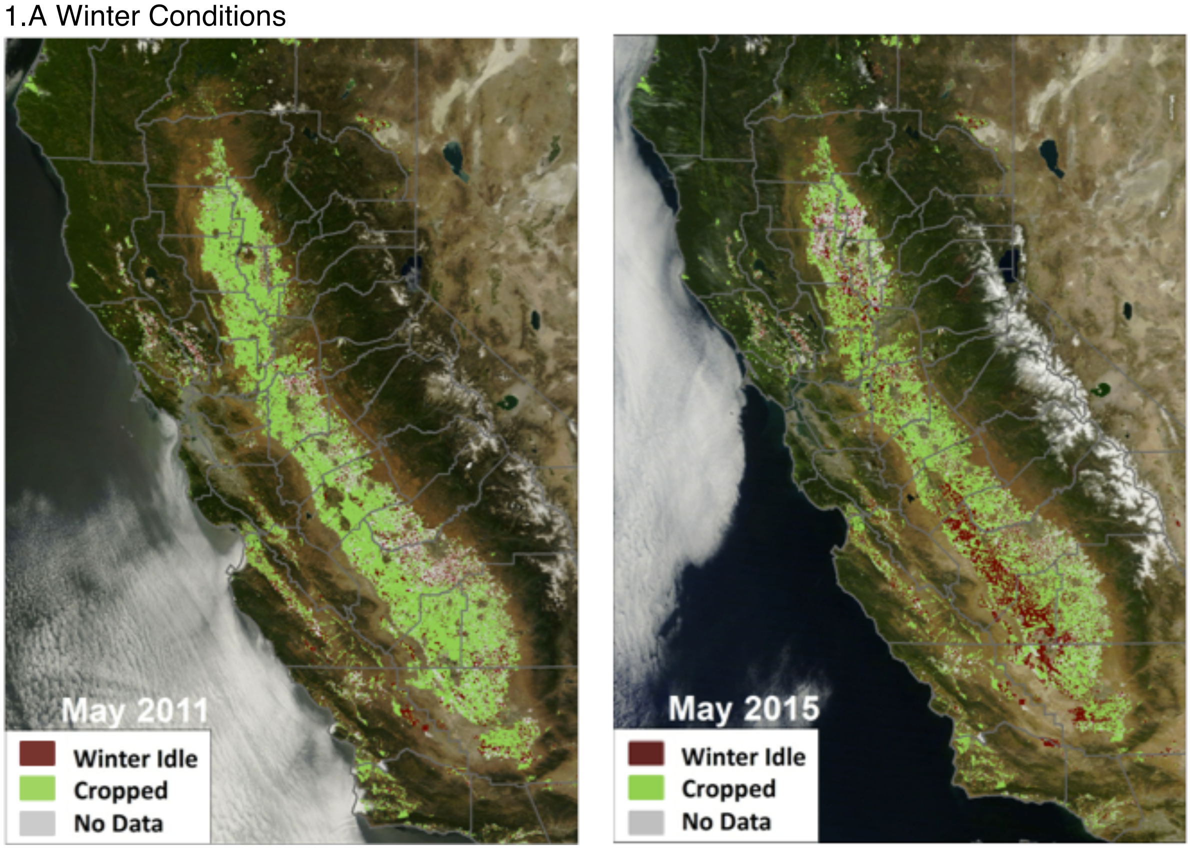
Annual fallowed acreage: In 2015, the project documented more than 1.03 million acres in the California Central Valley that remained fallow throughout the year, an increase of 626,000 acres relative to 2011. The estimates for 2015 based on the USDA NASS algorithm were 1.034 million acres (as of September 30th), while the estimates based on the NASA algorithm were 1.033 million acres (as of September 30th), a difference of less than 1%. The close agreement of the two estimates further increases confidence in the overall accuracy of the estimates for annual fallowed acreage.

Table 1. NASA Estimates of Fallow Acreage in the California Central Valley (acres)

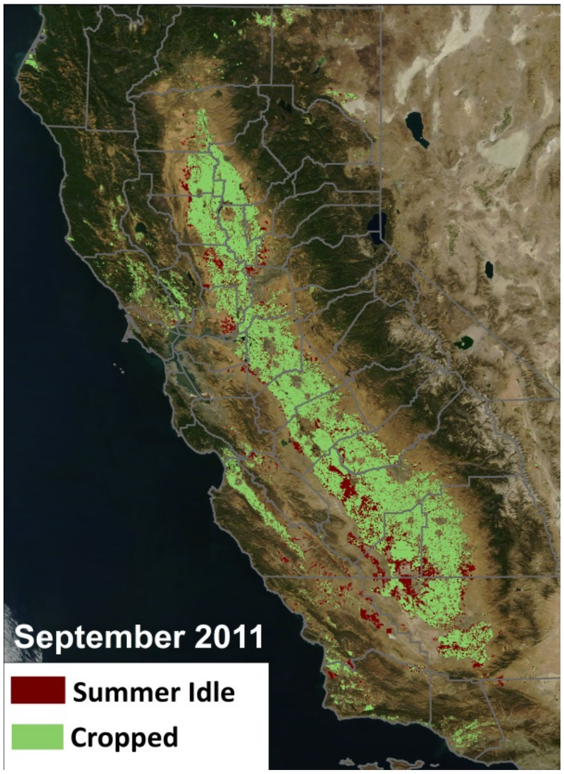
Year	Winter	Summer	Annual
2015	1,778,174	1,917,058	1,032,508
2011	740,445	1,394,906	405,996
Change from 2011 to 2015	1,037,729	522,152	626,512
Estimate range based on accuracy assessment	913,000 to 1,162,000	459,000 to 553,000	551,000 to 664,000

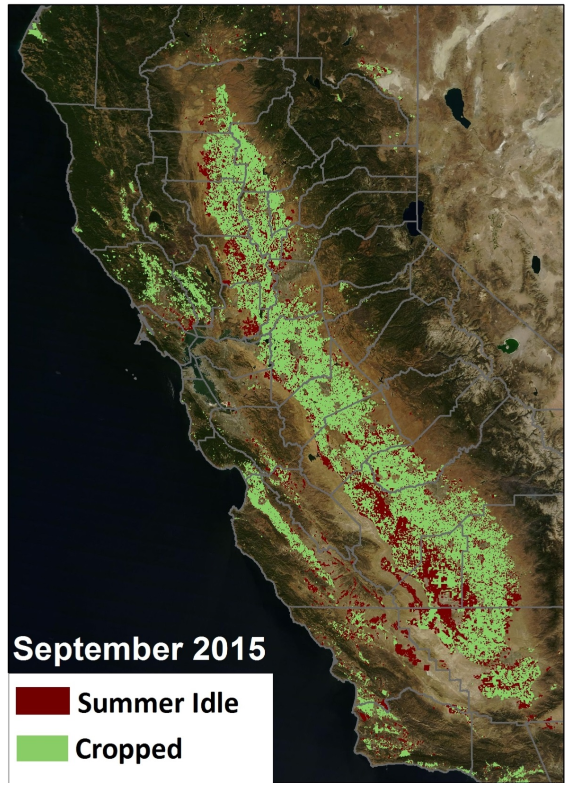
Figure 1. Maps of (A) winter, (B) summer, and (C) annual idle acreage in 2011 and 2015. Acreage that has been fallow all season is shown in brown, whereas cultivated acreage is shown in green. Areas typically associated with perennial crops or rice production are shown in gray (No Data) during the winter if no clear evidence of a crop production has been detected.

1.A Winter Conditions

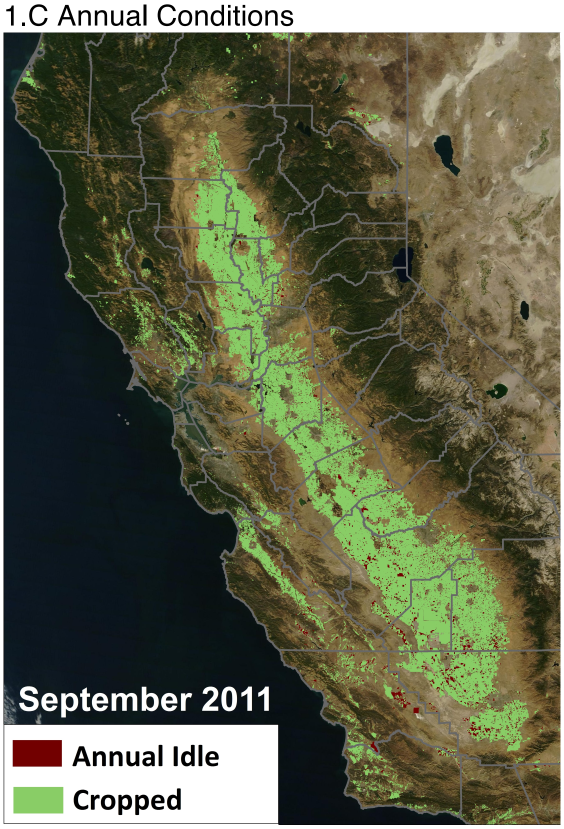


1.B Summer Conditions





1.C Annual Conditions



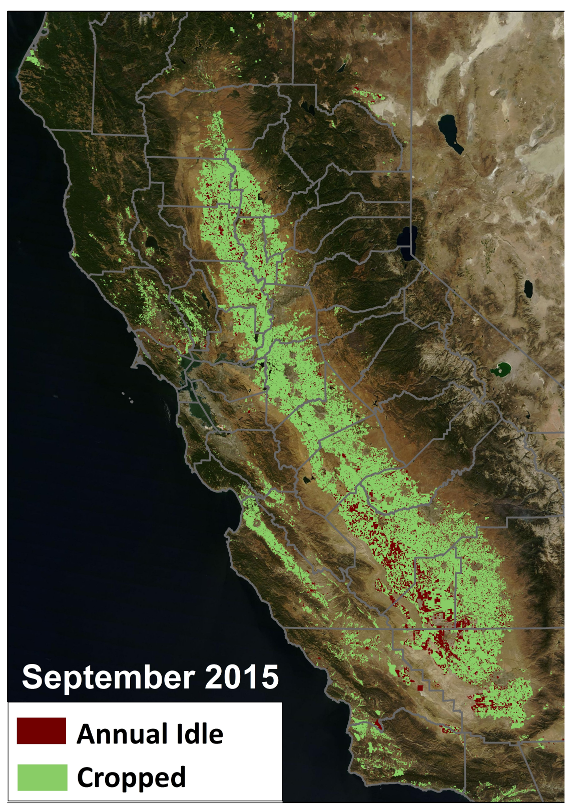
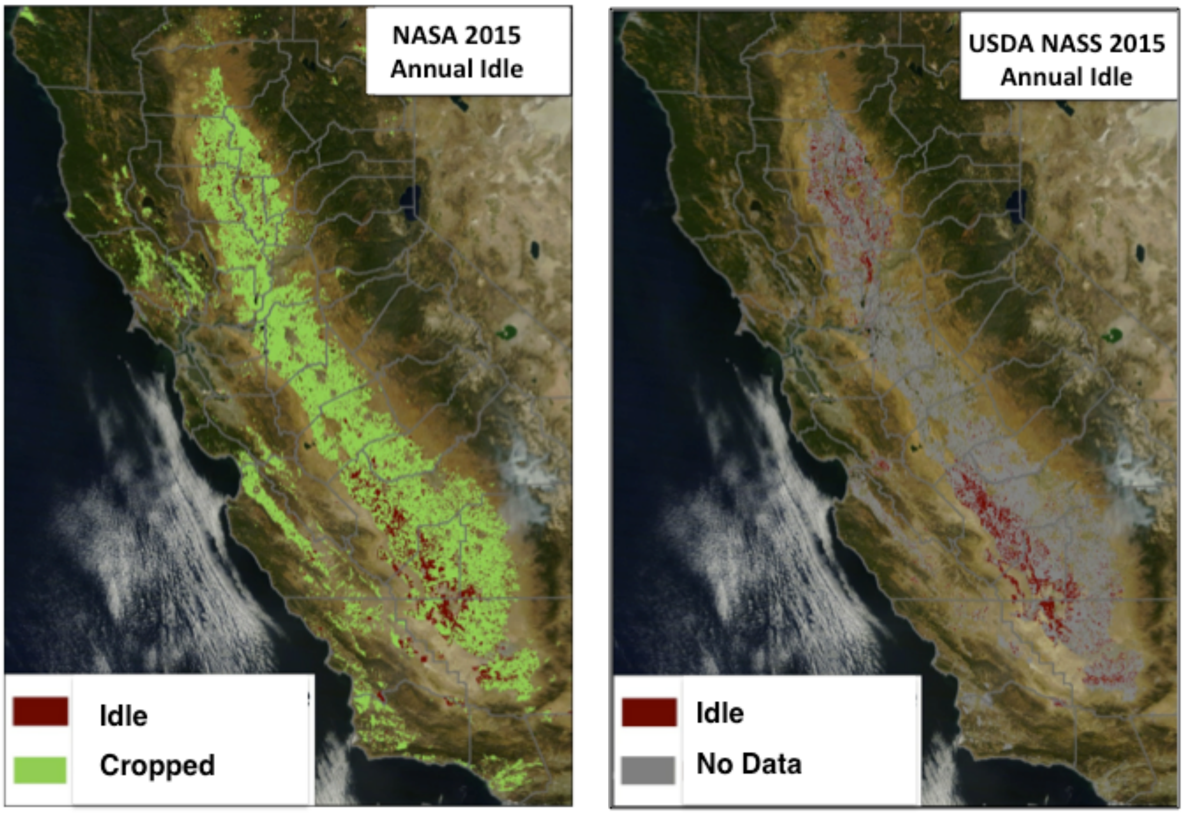


Figure 2. Comparison of spatial patterns in fallow areas in the NASA and USDA NASS data products. Data shown are for September, 2015. Only data for the "idle lands" class is available from USDA NASS prior to the end of the year, so other regions associated with agricultural production are indicated with "NoData".



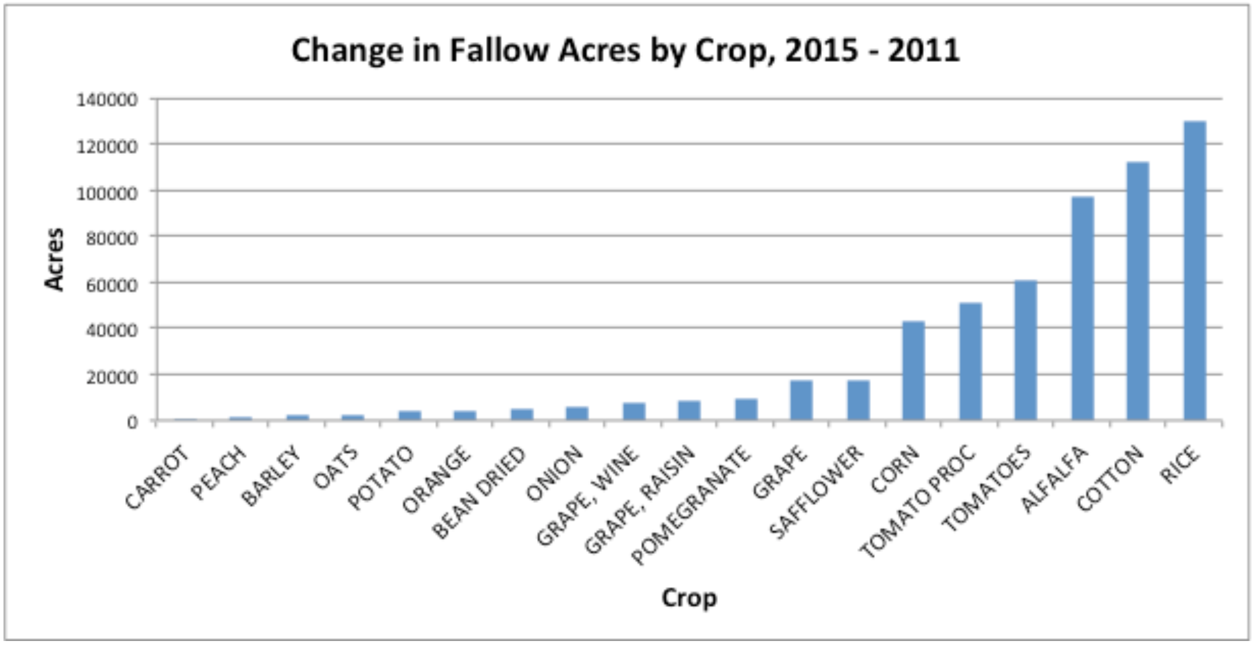
Many of California's higher value crops are grown during the summer production season, and these crops are typically more labor intensive to harvest and process than the winter grains and vegetable crops that constitute much of the cultivated acreage during the winter. In addition, many of the perennial crops grown in California ripen and are harvested during the summer season. As such, we focus on the summer production season for our analyses of land fallowing by county and by crop type. Table 2 summarizes the amount of fallowed acreage by county during the summer season, and also summarizes the change in fallowed acreage from 2011 to 2015. The top six counties in 2015 by total fallowed acreage were Fresno, Kern, Kings, Tulare, Merced and Yolo counties, and the rankings by total fallowed acreage were the same in both the summer and winter season. Importantly, both Fresno and Kings recorded increases in fallowed acreage of more than 95,000 acres relative to 2011.

Table 2. Fallowed acreage in the California Central Valley by county (all values in acres)

Summer 2015 (Jun. 1 - Sept. 30)				Summer 2011 (Jun. 1 - Sept. 30)			Change in Fallowing
County	**Cropped**	**Fallow**		**Cropped**	**Fallow**	**Total**	**2015 - 2011**
FRESNO	773,235	418,584		897,707	294,112	1,191,819	124,472
KERN	648,911	335,262		686,746	297,427	984,173	37,835
KINGS	293,626	258,635		390,610	161,651	552,261	96,984
TULARE	506,122	174,827		537,403	143,546	680,949	31,281
YOLO	223,183	115,236		253,437	84,983	338,419	30,253
MERCED	358,516	104,151		402,419	60,248	462,668	43,903
COLUSA	233,537	73,943		277,301	30,179	307,480	43,764
GLENN	204,751	61,979		235,234	31,496	266,729	30,483
SAN JOAQUIN	417,252	60,595		420,723	57,124	477,847	3,471
SUTTER	200,736	58,544		235,627	23,653	259,280	34,891
MADERA	290,788	53,634		293,284	51,139	344,422	2,495
SOLANO	111,235	46,700		115,870	42,066	157,935	4,635
BUTTE	202,836	32,100		226,395	8,541	234,936	23,558
SACRAMENTO	108,466	30,672		104,928	34,210	139,137	-3,538
STANISLAUS	287,807	30,222		298,828	19,201	318,029	11,021
PLACER	18,569	18,327		18,761	18,135	36,895	192
YUBA	84,993	15,158		87,102	13,049	100,151	2,109
TEHAMA	46,762	12,823		48,613	10,972	59,585	1,851
ALAMEDA	2,861	4,721		2,970	4,612	7,582	110
SHASTA	23,634	4,108		25,236	2,506	27,742	1,602
CONTRA COSTA	29,990	3,958		30,026	3,922	33,948	36
CALAVERAS	1,410	1,635		1,513	1,532	3,045	103
AMADOR	4,126	1,187		4,716	597	5,313	590
MARIPOSA	62	57		112	8	120	50
EL DORADO	322			322		322	0
Grand Total	**5,073,730**	**1,917,058**		**5,595,882**	**1,394,906**	**6,990,788**	**522,152**

Using data obtained from County Agricultural Commissioner offices on crop type, we are also able to provide an initial assessment of drought impacts by crop type. While the data on crop types used in our analysis are from calendar years 2012-2013, it provides an assessment of crops recently grown for each parcel of land associated with fallowing in 2015. Figure 3 summarizes the results of this analysis for the top 20 crops by change in fallowed acreage in 2015. Most of these crops are annual crops, indicating that impacts to perennial crops to date have largely been avoided, and most of the observed fallowing is associated with land that was recently used to produce annual crops, with cotton, rice and alfalfa all associated with increases in fallowing of more than 95,000 acres in 2015. Furthermore, with the exception of pomegranates and grapes, the perennial crops showed little overall change in fallowed acreage relative to 2011, indicating that overall fallowed acreage is still in line with normal turnover associated with replacement of older orchards, though there have been concentrated impacts in some regions of the Central Valley.

Figure 3. Change in fallowed acreage in the California Central Valley by crop



Comparison with Other Published Estimates

Previously, estimates of fallowed agricultural acreage from different sources have varied widely and have been difficult to reconcile. This has been due, in part, to the fact that there is not a single definition of "fallow" agricultural land that is used by all entities, and estimates of land fallowing from different sources can vary based on the geographic extent and time period considered in the analysis. For example, official estimates produced by USDA NASS focus on annual fallowing, consistent with national products produced by USDA, while estimates produced by UC Davis and the California Department of Food and Agriculture (CDFA) for California have focused on the higher value summer season only. Estimates from other sources for individual counties or regions often do not specify how they are defining fallow. One contribution of this project has been to serve as a reference that can be used to evaluate estimates of land fallowing produced by different sources, and to explain and reconcile the estimates produced by UC Davis and USDA NASS.

On August 17, 2015, the UC Davis Center for Watershed Sciences released the Economic Analysis of the 2015 Drought for California Agriculture (Howitt et al., 2015). This report described the economic impact of the drought on the California agricultural sector. The analysis used multiple models to quantify a range of impacts of the drought, including estimated increases in drought-related land fallowing in the Central Valley. The report leveraged datasets produced by NASA for this project for 2011 to estimate fallowing during 2011 as the baseline year. The estimates of land fallowing in the Central Valley in the UC Davis report were focused on the summer production season when many higher value crops are produced and harvested, and totaled an increase of 540,000 acres in 2015 relative to summer fallow acreage in 2011. The estimates from Howitt et al. (2015) agree well with our estimates of summer fallowing for the Central Valley of 522,000 acres, and the difference between these estimates is less than 3.5%. However, estimates produced by NASA are for all counties with agricultural production within the Central Valley and California Delta region, whereas the UC Davis report uses the boundaries for the Central Valley Management Plan (CVMP) regions. Applying these boundaries to the NASA dataset reduces our estimate of increased land fallowing slightly to 509,500 acres, and the difference between the estimates is still less than 6%. In addition, the estimates provided in the UC Davis report fall within our estimate range for increased land fallowing in the CVMP boundaries of 448,000 to 540,000 acres based on the accuracy assessment described below.

In January 2016, USDA NASS is expected to release the official Cropland Data Layer (CDL) for 2015. Information contained in the full CDL is considered market sensitive and the full CDL itself cannot be publicly released during the growing season. As part of this project, USDA NASS has been able to release the "idle lands" class only from the CDL throughout the growing season. The USDA CDL idle lands class is also produced using data from multiple satellites, and applies a series of decision tree algorithms to perform a classification for each pixel.

The USDA NASS CDL algorithms are trained against data provided by farmers to the Farm Services Agency (FSA), and assign land to the "idle lands" class only if it is fallow throughout the year. As part of this project, team members at NASA also developed algorithms to separate winter and summer fallowing. To ensure consistency between the two products, we compared the year-to-date or "annual" fallowing results from the two different data products. To facilitate comparison between the USDA NASS "idle lands" class and the estimates of fallowing produced by NASA, we first applied a mask of field boundaries for the Central Valley to both data products to eliminate farm roads and non-ag lands that may be included in the USDA NASS data products but omitted from the datasets produced by NASA. As of September 30th, 2015, USDA NASS estimated total annual fallowed acreage for the Central Valley at 1,034,205 acres, and the NASA algorithms estimated 1,035,794 million acres, a difference of less than 1%.

ACCURACY ASSESSMENT

At the beginning of the project, team members at CDWR provided an accuracy requirement of 75% or better in all months, and indicated that an error of up to +/- 25% in the estimates of land fallowing was acceptable.

The accuracy assessment for the USDA NASS idle lands data product was conducted by comparing results from the satellite-based classification against information reported by growers to the FSA. The information provided by growers is considered confidential and is only available to analysts within USDA. Based on comparison with data reported to FSA, the accuracy of the USDA NASS algorithms was better than 75%, meeting the accuracy target specified by CDWR.

To assess the accuracy of the satellite-derived estimates of fallowed acreage provided by NASA and CSUMB, the project team conducted monthly surveys of field conditions in the Central Valley. The surveys followed eight east-west transect routes across the Central Valley that were spaced along north-south axis of the Central Valley, and one north-south transect through the west side of the San Joaquin Valley where impacts on agricultural production have been heavily concentrated during the drought. The field survey transects included 670 sites, and covered a mix of vegetable crops, winter grains, alfalfa, perennial crops including vineyards and orchards, and a number of sites that were fallow throughout the winter and/or summer growing seasons. The transects were surveyed monthly from March to September in 2014 and 2015, and data collected included information on crop presence or absence, crop type, crop height, visual estimates of canopy cover, soil condition, and observations of evidence of irrigation, weed control, or other field maintenance. Digital photographs and GPS readings were also collected at each field survey site.

Monthly field observations for each site were used to assign a code to each site indicating whether the field was cultivated or fallow. Monthly data were also compiled into a seasonal classification: if a field had clear evidence of cultivation and crop development approaching maturity in one or more months, it was considered cultivated or "cropped" for the season regardless of final crop quality or yield. If, however, a crop was observed to be newly emergent in one month but was then abandoned or tilled under in the following month, the field was considered "idle" for the remaining months and fallow for the season as a whole. If a field was observed to be bare, uncultivated, or covered by weeds or sparse volunteer crop growth in all months, it was also considered to be fallow for the season.

Our accuracy considered the overall percent of fields in each class (cropped and fallow) that were correctly classified by the algorithm applied to the timeseries of satellite data, and also calculated the producer's and user's accuracy for each of the two classes. Seasonal results for winter and summer 2015 are included in Table 3, and similar accuracies were observed for each month from March to September in both 2014 and 2015, with accuracies slightly lower in June when the transition from winter to spring crops presented challenges in comparing field observations and results from the satellite-based classification. The producer's accuracy provides a measure of errors of omission, and the user's accuracy provides a measure of errors of commission. We used these accuracy measures to calculate the upper and lower bounds respectively for our monthly and seasonal estimates.

Table 3. Accuracy Assessment for the NASA Algorithm

Season	**Overall% correct**	**Cropped% correct**	**Fallow% correct**		**Cropped, producer's accuracy**	**Cropped, user's accuracy**		**Fallow, producer's accuracy**	**Fallow, user's accuracy**
Winter	95%	97%	88%		97%	97%		88%	88%
Summer	96%	96%	95%		99%	96%		95%	88%

The overall accuracies for the NASA algorithms were better than 90% in all months, and both the producer's and user's accuracies exceeded 85% in all months, comfortably meeting the accuracy requirements established by CDWR.

The primary sources of error for the NASA algorithms were recently planted perennial crops and errors associated with field boundaries or partially planted fields. When viewed from directly overhead, young perennial crops have very low leaf area with vegetated fractional cover values that are often 10% or lower. Since many perennial crops are now irrigated with drip or microjets, the fraction of wetted soil surface is often only 25% or less. As a result, recently planted perennial fields are frequently difficult to distinguish spectrally from fallow fields with a few sparse weeds. This confusion represented the largest source of error in the algorithms developed by team members at NASA and CSUMB. The second source of error occurred in cases where the field boundaries used as inputs to the NASA algorithms included multiple sub-blocks that were planted at different times, or where the grower opted to only plant a small portion of the field. The project team is currently working on improvements to the algorithm to calculate the percent fallow for fields that are partially planted.

METHODS

Both the USDA NASS and NASA classifications apply decision tree algorithms to timeseries of satellite data. The USDA NASS algorithms for the CDL are trained against data provided by farmers to the FSA and an overview of the methods and satellite data inputs is provided in Boryan et al. (2015).

Since the FSA data is considered confidential, the NASA algorithms were developed using ground-based observations of field conditions collected across ~1,000 field sites in the Central Valley that were surveyed in 2012. The project team evaluated multiple satellite indices and classification approaches and found that decision-tree algorithms based on timeseries of Normalized Difference Vegetation Index (NDVI) data performed as well, or better, than other indices and more complex approaches. NDVI is a well-established remote sensing index of vegetation condition, and can be calculated from multiple satellite that collect data in the visible and near-infrared wavelengths.

The NASA estimates are based on timeseries of data from Landsat 5, 7, and 8, with the best available observations in each 8-day period mosaicked into a statewide composite. During periods with multi-week gaps due to cloud cover during Landsat overpasses, daily surface reflectance data products from MODIS were also used to calculate NDVI values for the pixels that were fully contained within each field boundary and used to fill these gaps.

Datasets on field boundaries were compiled from publicly available sources and used to create a dataset that included more than 220,000 fields statewide. Timeseries of NDVI data were extracted from each field in the state, and data were filtered to remove as many cloud-contaminated data values as possible from each timeseries.

Decision tree algorithms were then applied to assign fields to one of 20 classes associated with different types of cultivated or fallow fields. The algorithms evaluated information on the maximum, minimum and average monthly NDVI, as well as the slope, number of changes in the slope, range between maximum and minimum, and change relative to previous years to assign each field to a class. The algorithm accounted for crop type for key crop categories when known. For example, perennial crops and rice tend to be cultivated on the same fields year after year, and additional algorithms were run for these fields. This also allowed the algorithms to assign special codes for these fields in the winter season to account for the fact that evidence of cultivation is often not detectable until May or June, as perennial crops leaf out or flooding of rice fields begin.

The classifications for each 8-day period were then compiled to calculate seasonal classifications. If evidence of crop production was observed in multiple periods, the field was assigned to a "cropped" class on a seasonal basis. If the field was fallow throughout, the field was assigned to a "fallow" class on a seasonal basis. Since emergent crops can be similar to emergent weeds and grass early in the year, for a field to be considered cropped on a seasonal basis, the field condition was required to advance from emergent to a "cropped" class. Fields that never advanced beyond an emergent condition were considered to be failed crops, volunteer regrowth following a harvest in the previous season (common with alfalfa and wheat), or weeds. Fields that had extensive crop cover in early June but were harvested within the first two weeks of June or senesced throughout June were considered to be a winter crop. If no evidence of a second planting was detected, the field was considered to be fallow for the summer season.

Details of the NASA algorithm and data processing are currently being prepared for publication. Links to the full article will be added to this report when available, and added to:

https://nex.nasa.gov/nex/projects/1372/.

Data Access and Metadata

Datasets for winter, summer, and annual fallowing are available for download in GeoTIFF format at https://nex.nasa.gov/nex/resources/370/. Data are posted for 2011 and 2015. Data for additional years are available upon request. For additional information about the data, please contact Forrest Melton (forrest.s.melton@nasa.gov).

The full classification has been consolidated into a simplified classification in these datasets:

Class	Value
Crop present	2
Fallow	10
Crop not detected yet (winter season only)	13 (perennial), 15 (rice)
Non-ag or rangeland	NoData

Information on the dataset projection and datum is also included below.

Projection:	Lambert_Azimuthal_Equal_Area
False_Easting:	0.00000000
False_Northing:	0.00000000
central_meridian:	-120.00000000
latitude_of_origin:	37.00000000
Linear Unit:	Meter

Geographic Coordinate System:	GCS_North_American_1983
Datum:	D_North_American_1983
Prime Meridian:	Greenwich
Angular Unit:	Degree

For more information, please contact Forrest Melton (forrest.s.melton@nasa.gov).

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