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Planet Labs' monitoring solution in support of precision agriculture practices

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Abstract. Satellite imagery is particularly useful for efficiently monitoring very large areas and providing regular feedback on the status and productivity of agricultural fields. These data are now widely used in precision farming; however, many challenges to making optimal use of this technology remain, such as easy access to data, management and exploitation of large datasets with deep time series, and sharing of the data and derived analytics with users. Providing satellite imagery through a cloud computing based platform offers an operationally successful method to enable timely and efficient access to important field information and crop analytics.

Planet's Monitoring for Agriculture solution leverages the high-frequency revisit schedule and collection capacity of the PlanetScope and RapidEye satellite constellations. It provides access to an enormous pool of multi-temporal, multispectral, orthorectified high-resolution imagery collected throughout the growing season, as well as archive imagery from previous seasons. Subscribers and their end-users benefit from this unique information source for extracting accurate and timely information on crop indicators.

As an example, derived vegetation indices can efficiently map and display the different levels of greenness in crop fields, providing a basis for managing different parts of the fields according to their productivity levels. Additionally, trend analysis on temporally and spatially consistent high frequency time series data improves the ability to monitor crop health, identify stress factors, and provide more actionable and timely information for field management decision support.

Another key feature of these image collection programs is the cloud-based technology supporting them. Planet's imagery dissemination and analytics platform empowers users with fast and easy access to imagery collected shortly after acquisition using Application Programming Interfaces (APIs). It also allows users to run processing workflows more efficiently, by bringing their proprietary algorithms that derive information about agricultural fields closer to the enormous pool of imagery. Clients are thus able to accelerate their image analytics, as well as reduce capital and operational expenses needed to build and maintain custom systems.

Together, collection programs and cloud-based services, integrated with localized application software, respond to worldwide demand for managing crop production, potential, and problems more effectively than blanket field applications. The results are optimized costs and improved yields, while reducing the burden on the environment.

Finally, the provision of high-resolution, high frequency satellite imagery through a cloud solution allows Planet's customers to focus more on their core expertise: data analytics and applications.

Keywords. *Satellite imagery, Precision Agriculture, Agricultural Monitoring, High Resolution, In-Field Detail, PlanetScope, RapidEye, Vegetation Indices, Application Programming Interface*

Introduction

Last year saw the highest global mean temperatures ever recorded with many agricultural regions affected by thermal and precipitation anomalies, along with an increasing number of severe weather events. If historical prevailing farming conditions are changing, it will be necessary for both large agri-businesses and small producers to better manage associated risks by investing in improved or adapted production technologies to sustain and optimize yields. Thus, growers throughout the world are constantly searching for ways to maximize their returns. A way of achieving this is through the adoption of more cost effective agricultural practices, which ultimately need to be based on a solid knowledge of the conditions of the crops as they are being grown and managed.

Precision Agriculture Practices

In conventional agriculture practices, fields subject to farming are considered to be uniform and thus treated with uniform rates of agrochemicals and fertilizers, whereas precision agriculture refers to the management of in-field variability, such as soil nutrients, pest control, water supply, and other environmental factors. Accordingly, one of the main areas of application and decision-making for information derived from satellite imagery are Variable Rate Applications (VRA). VRAs refers to the application of inputs (seed, agrochemicals, fertilizers, water) based on the exact location and needs, identified by means of geospatial information overlay (management zones). Unlike traditional practices that simply apply fertilizers and pesticides homogeneously across the entire field regardless of the specific needs of different areas, VRA optimizes the application and consumption of crop inputs thus reducing unnecessary application and therefore reducing costs and emissions of potentially pollutant substances to the soil, ground water, and air.

Cost-effectiveness

Precision agriculture practices require a more detailed knowledge of variations within a field. Traditional methods of assessing crop and soil properties or plant chlorophyll content are based on ground direct sampling. Ground sampling tends to be labor intensive and costly if a spatially representative depiction of field variability needs to be obtained. Also, sampling costs and efforts drastically increase with crop monitoring, because the sampling needs to be repeated several times during the growing season.

For a baseline, growers want to see areas of poor crop performance and areas of high output. In the field a grower can simply not get such an overview to make the informed decisions required to maximize crop production and quality. It requires a source of data that provides an overview of entire fields, has enough in-field detail to show variability within the field, as well as match equipment to apply the correct management strategies.

Secondly, the solution needs to be cost effective with a return on investment to make the technology and platform a worthwhile endeavor. This can be viewed from various angles such as increased yield, decreased inputs, land health and overall sustainability.

Last, consistency, if one is taking the time and money to invest in a technology like satellite imagery, it needs to show demonstrable yield/cost benefit, or economic gain per acre farmed. This can only be achieved with consistent data provision in terms of availability and output product quality to permit accurate field performance analysis over time.

Scalability

For precision agriculture technologies, the demonstrated ability to deliver true economic gain across diverse farming conditions and methods is the ultimate challenge. From scouting fields and consulting with growers, to supporting the work of large global retail operation requires a scalable solution. When it comes to monitor and analyze large areas in a short time frequently, the effort to go to different locations, take the time to walk the fields, make measurements or deploy a drone is just neither practical nor affordable. This is where the use of satellite imaging technology becomes a fundamental resource.

Satellites with high spatial and temporal resolution capability, such as Planet's constellations, are suitable for obtaining detailed information about the distribution of crop field properties in space and time. Therefore, satellite imagery represents an alternative to traditional ground-based or proximal sensing assessments of crop and soil status, providing consistent recurring information at larger scales while reducing costs, time and labor.

Satellite Imagery

Over the last three decades the remote sensing industry has overpromised and under-delivered to the agriculture market. The right combination of spatial resolution, temporal resolution, quick access, price and coverage never occurred, and therefore the expectations were never fulfilled. Daily global coverage, typically from single wide swath satellites, has only been available at a very low spatial resolution. On the other hand, higher resolution imagery from satellite tasking was provided with only low coverage and high cost. In addition, whereas there is a number of options free of charge, such as Landsat 8 and Sentinel-2, availability of suitable high spatial resolution imagery to cover large regions on a frequent basis during the growing season is still a challenge.

Both, traditional tasking and fixed less frequent acquisition schedules would miss important field events, and more importantly, the ability to detect in-field crop changes on a frequent basis to adapt input levels in the field at the right time. Thus, limited coverage, low revisit rates and slow and inefficient access prevented many users from monitoring at scale.

Today, Planet serves customers across the globe with a monitoring solution that major companies and organizations in the precision agriculture industry have already adopted. This is being achieved by taking a different approach all together, where Planet operates many satellites (PlanetScope and RapidEye constellations), which allows for full global land coverage at a very high revisit rate (daily in 2017).

Planet launches satellites regularly, contributing to a larger constellation of satellites. Therefore, its on-orbit capacity is constantly growing, with technology improvements deployed at a rapid pace. The result is the largest constellation of earth-imaging satellites in history providing an unprecedented combination of high frequency, high-resolution broad-coverage becoming an operational solution for small local to large enterprise businesses in agriculture.

Planet's Broad-Area Agriculture Monitoring

Planet Monitoring for Agriculture and its associated business model is increasing efficiency by providing a constant broad acquisition plan for all agricultural areas and facilitating access to the full archive of imagery collected over the course of a season. Thus, the ordering, tasking and acquisition process becomes more streamlined. Essentially, the satellites are always on acquiring imagery as they passed overhead, also creating a larger archive of data to draw from. The second improvement is increased efficiency in the discovery and delivery of data. As the imagery can be searched and accessed through web interfaces and protocols, it can be accessed shortly after acquisition. To feature the solution in more detail:

- **Field-to-global coverage:** Emphasis is put on reliability of imagery provision at different scales: from fields to countries to major cropping regions to global coverage. Currently worldwide there are more than 11 million km^2 of farmland (Americas, Europe, Asia and Australia) under Planet's in-season satellite monitoring. See Figure 1 (left) for an illustration of the North America monitoring footprint as an example.

- **Frequent revisit:** Frequent information is critical to get the full picture of fields at each of the growth stages. Many field management decisions are dependent upon timely information with high locational accuracy for in-field precision. Planet provides a high imaging frequency (daily acquisition in 2017) with new imagery available and accessible in near real time. See Figure 1 (left) for an illustration of the North America RapidEye imaging frequency for 2009 through 2015.

- **In-field detail:** Multispectral data are collected at high resolution to provide high in-field detail with a high positional accuracy of less than 10 m RMSE worldwide - ground controlled through very high resolution imagery. Absolute and relative radiometric calibration across all satellites is performed. See Figures 1 (to the right) for the level of in-field detail that is derivable from 5 meter RapidEye multispectral data. See Figure 2 for a comparison of color-infrared composites of 3-4 meter PlanetScope imagery and RapidEye data.

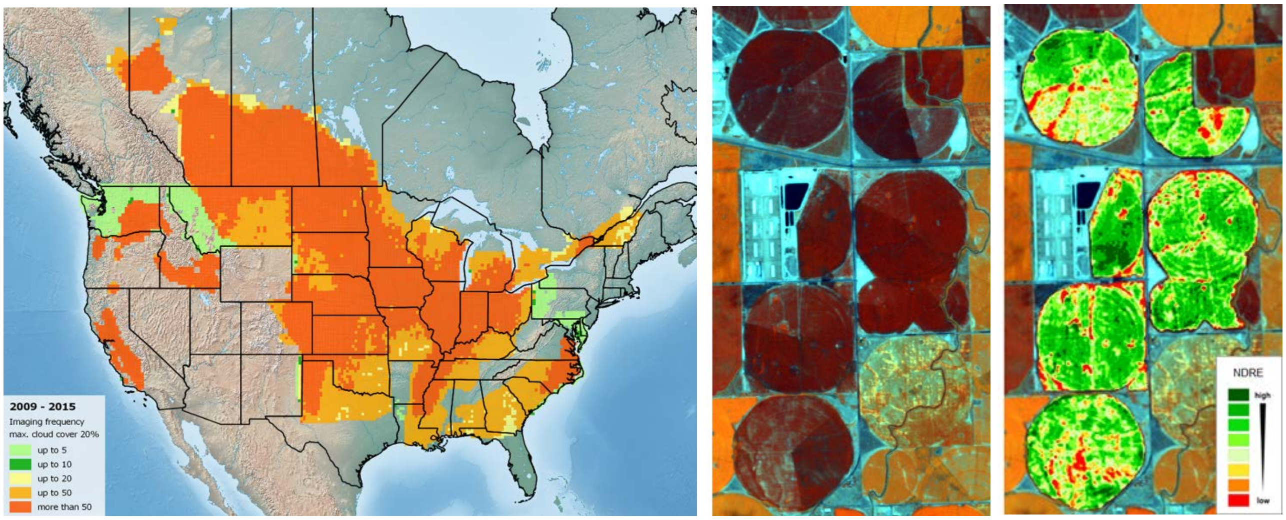


Fig 1 Left: Broad coverage and frequent revisit: North America monitoring area and RapidEye archive content for the monitoring period May 15th to Sep 15th for 2009 – 2015 (Note: green areas have only processed out for two seasons). Right: RapidEye false-color composite (NIR-RE-R) and derived Normalized Difference Red-Edge (NDRE) index showing in-field variability of corn fields.

Fig 2. Left: Color-infrared composite (NIR-R-G) of PlanetScope data, acquired 18th of April 2016. Right: Color-infrared composite (NIR-R-G) of RapidEye data, acquired 2nd of May 2016. PlanetScope on-orbit capacity is constantly growing to provide global land mass coverage on a daily basis from 2017 onwards.

- **Multi-year archive:** Another crucial part of the solution is Planet's extensive RapidEye archive of imagery dating back to 2009 (see Figure 3). It contains more than 8 billion km^2 of imagery across the world representing a valuable source of information for determining historical field performance for predictive analytics.

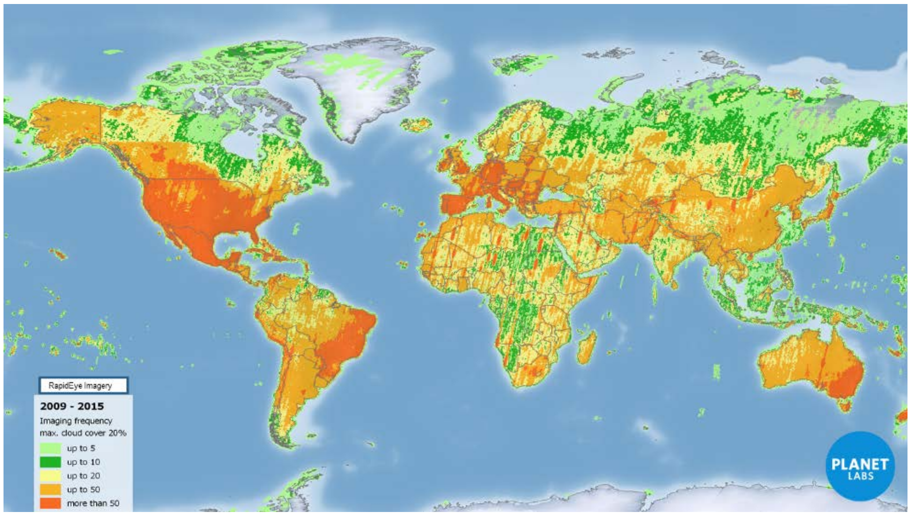


Fig 3. RapidEye image archive dating back to 2009. Colors indicate imaging frequency (number of images taken) with 20% of cloud cover or less.

- **Easy and efficient platform access:** Great field management decisions are dependent upon timely and accurate information. It can mean the difference between a healthy crop and one that's in distress, helping growers to identify problems before they impact yield. Planet delivers data in near real time and in easy-to-use formats allowing users to spend less time waiting for decision making inputs and more time taking action. Access to image products is through Planet's platform via a Graphical User Interface (GUI) or via an Application Programming Interface (API) for more programmatic usage.

- **Integrated Imagery:** The solution provides access to ortho image products from RapidEye and Planet constellations – RapidEye imagery in 5 meter detail with 5 spectral bands including RGB, near-infrared and a red-edge band. In 2017 the fully deployed Planet constellation with RGB and near-infrared bands will achieve daily coverage of earth's landmass. All imagery goes through radiometric calibration and orthorectification. In addition, Planet provides access to third-party imagery such as Landsat-8 (or Sentinel-2 once available), daily ingested for the area of interest. Planet ortho products are provided in GIS-ready GeoTIFF format. Third-party data are co-registered to higher positional accuracy Planet products for the best possible combined use of the multiple sources. Figure 4 summarizes Planet's platform-based integrated imagery offering.

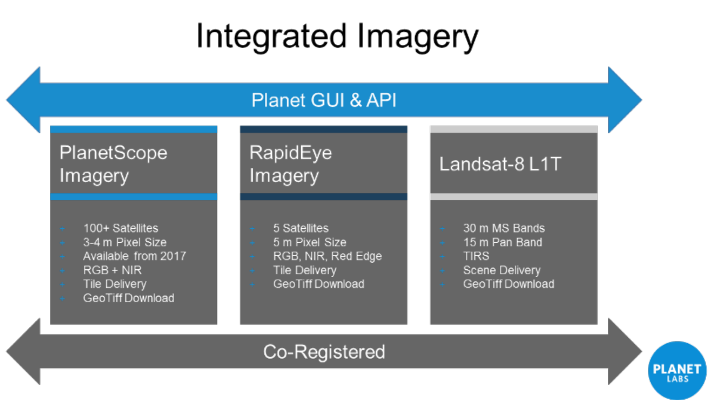


Fig 4. Planet's platform integrates multiple imagery sources, suited to precision farming applications, and accessible through API

Platform & API

In the era of big data, making the most out of the enormous existing and growing imagery archives and collection capacity of satellite systems requires a powerful IT infrastructure able to handle, process and provide all those data efficiently. On the other hand, extracting valuable information from all the existing data requires sound algorithms and workflows that have evolved and continue to evolve (e.g. machine learning).

Unlike one or two decades ago, today there is more available data than ever providing regular satellite imagery-derived information over agricultural areas during the growing season. However, most of these sources are completely disconnected from one another and gathering imagery from different sources is challenging and inefficient. No matter what quantity of imagery data are available, the value is low if the data are not easily accessible. This is a challenge for precision farming, as imagery from multiple platforms is typically preferred.

Planet has deployed a scalable cloud-based infrastructure to handle and exploit large volumes of its satellite imagery and improved access to multiple imagery sources, suited to precision farming applications, by offering them through APIs.

Planet's best-in-class automated pipeline and online tools help users find and access data in near real time allowing for faster decision making. The platform API provides anytime access, and on demand / self-serve capabilities. More importantly, it can be used to programmatically automate process or work flows since it exposes all the attributes of the imagery as search parameters and can be queued with several concurrent connections for multiple data transactions at a time.

Data Analytics

Before being able to unlock the significant value of information embedded in satellite images, an understanding of data acquisition and provision is key. With frequent Planet coverages from in-season programs, users can look for relative gains or issues by monitoring the crop growth through the season. The ability to continuously measure in-field properties (based on daily to weekly to monthly imaging frequency) helps guide scouting activities and strategies better, particularly in case of field events.

Connecting instantaneous in-season data with the cumulative historical baseline helps in a deeper management zone understanding to see where field output is on track. This guides the management practices to apply more input in high performance zones and start to pull back in defensive zones (and all at the right time), thus maximizing yield and minimizing cost.

In-field crop properties are typically derived from the imagery by means of vegetation indices.

Vegetation Indices (VI)

Spectral vegetation indices (VI) are arithmetic combinations of selected spectral bands especially designed to emphasize specific vegetation related properties or characteristics. Most VIs take advantage of the difference between the lower reflectance in the red visible (caused by chlorophyll absorption) and the high reflectance NIR region (caused by the refraction of energy due to leaf cellular structure). The basic assumption is that the reduction of spectral information in one index value provides more useful information about vegetation characteristics compared to the pure individual spectral bands.

Several VIs were successfully developed over the past decades in order to improve the relationship to specific vegetation parameters such as biomass, leaf area index (LAI) and chlorophyll content, and to suppress other details such as soil background noise and atmospheric effects. Substantial efforts were made in designing vegetation indices sensitive to only one particular parameter of interest such as the chlorophyll content or LAI. A portion of these indices was developed using hyperspectral and narrow bands supposedly to be more sensitive to particular vegetation properties compared to broad band indices. Eitel et al. (2007) and Schelling (2010) showed that the red edge band, as used in the RapidEye sensors is suitable for obtaining information about the chlorophyll and nitrogen content of plants.

The following example (see also Figure 5) utilizes time series of productivity measures derived from RapidEye imagery for historical productivity assessment turned into productivity benchmarking for predictive analysis using newly acquired in-season data.

Productivity Maps

Crop yield strongly depends on an adequate supply of nitrogen (N). Therefore, knowledge about N-status represents an important factor for agricultural management. Since N-status cannot be directly measured through remote sensing, an indirect indicator is needed. The N-status of crops can be assessed through chlorophyll measurements, given the strong correlation between the two in several major crop types (Daughtry et al. 2000).

The Productivity mapping algorithm takes advantage of the canopy reflectance measured in the red-edge region of the spectrum, which is found to be the most sensitive spectral region to variations in chlorophyll content (Gitelson et al. 1996). The main advantage of this algorithm is its low susceptibility to saturation (Gitelson and Merzylak, 1994), resulting in increased sensitivity to changes in canopy greenness at higher canopy densities.

The canopy greenness is determined by the product of leaf chlorophyll content and leaf area, which in turn determines the productivity of a crop (Heege and Thiessen 2013). Variations in in-field productivity is the prime parameter of interest to the growers because it determines site-specific yield potential. The map provides accurate and date-specific status information on the relative in-field variability of crop productivity to support efficient field-scouting and crop diagnosis.

The employed Normalized Difference Red-Edge Index (NDRE) has been proven to be sensitive to variations in canopy chlorophyll content (Zillmann et al. 2015), which in turn determines the productivity of a crop and finally its yield. The NDRE requires spectral information measured in the red-edge region of the electromagnetic spectrum which is provided by a few space-borne sensors only. However, in case of lacking red-edge information the same analysis could be performed by substituting the NDRE with the Chlorophyll $\text{Index}_{(green)}$ (Gitelson et al. 2005) which has been proven to be close related to the canopy chlorophyll content of corn and soybean as well.

In Figure 5 the productivity is calculated on a field basis, designed to accentuate on relative differences within the field (from green to red). Therefore, it is not meant for crop growth monitoring but rather for providing information on variations in productivity at critical dates when the farmer usually takes action.

Stable Management Zones

In precision farming, the concept of in-field management zones is widely used. A management zone is a sub-region of a field that expresses a relatively homogeneous combination of yield-limiting factors for which a single rate of a specific crop input is appropriate (Doerge 1999). Useful zones describing common site characteristics can be produced using different sources of information such as yield mapping technology, soil sampling, digital elevation models, and remote sensing imagery. The delineation of management zones based on in-field variation patterns in crop productivity derived from satellite imagery seems to be appropriate because it provides an integrated measure of yield limiting factors. Stone et al. (2007) found remote sensing data collected in season more highly related to yield compared to terrain and soil variables.

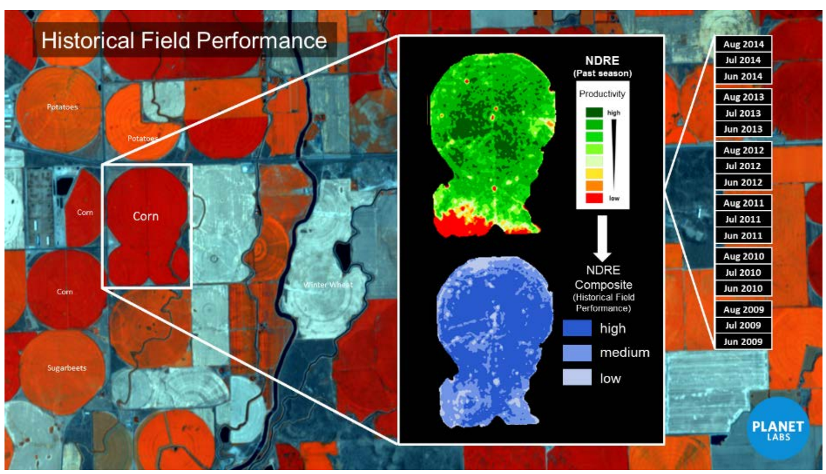
The delineation of management zones from the average of multi-season productivity maps allows for generating zones that are relatively stable over time and help growers to get a better understanding of the performance of their fields in the past. In conjunction with other geospatial information like soil nutrient levels and yield maps, persistent management zones provide a solid foundation for initializing variable rate management.

In Figure 5 management zones are shown as NDRE composites and derived from an aggregation of the date specific productivity classes of the NDRE index. The designation of three different zones representing low, medium and high productivity seems to be sufficient for tackling most of the existing in-field variation and allowing for determining corrective management decisions.

In-Season Predictive Analysis

The analysis of historical field performance enables farmers and consultants to make more informed corrective management decisions on fertilizer and fungicide applications based on the current crop conditions. In Figure 5 the in-season productivity is again calculated on a field basis and compared to the historical productivity benchmarking in order to detect issues or predict this year’s productivity.

This map is useful for directed field scouting and diagnostics to identify the causes for the different crop development, which can be manifold. Variations in productivity can be caused by nutrient deficiency, water scarcity and pest infestation. The maps accurately reflect the spatial variation of the crop within the field.



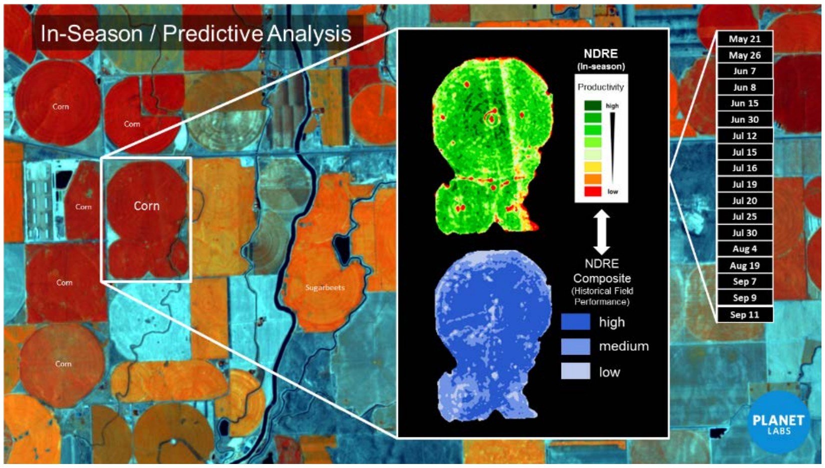


Fig 5. Example for the combined analysis of historical field performance (derived from multi-year archived imagery from 6 years) with in-season imagery. Employed vegetation index is the Normalized Difference Red-Edge Index (NDRE). Instead of providing absolute measurements, relative values of canopy greenness are displayed in a clustered distribution in order to accentuate the in-field variability of productivity.

Conclusions

Precision agriculture is a growing market where satellite imagery is an operational source of information for field management and analysis. The use of high frequency, high spatial resolution satellite data and their applications have passed the development stage and are currently being used operationally for such applications as for variable rate application recommendations. The use of such information in the management of fields is steadily growing and offering sustainable business perspectives for applications that provide end products for empowering field management decisions worldwide.

With an unprecedented global coverage and revisit cycle at high resolution, Planet has overcome the challenges that previously prevented satellite imagery from being a reliable data source for agricultural applications. Planet operates the largest constellation of earth-imaging satellites to date, and is collecting a massive amount of information over agricultural areas every day. With it, Planet's broad-coverage agriculture monitoring solution provides field-to-global information, helping producers manage at the field level and maximize output while being sustainable as well as providing enterprise businesses with actionable intelligence for the global agriculture markets. Its extensive archive can be exploited for setting a true baseline allowing users to create reliable analytics. Frequent revisit gives growers the ability to manage crops efficiently and make the smart calls. Easy access through APIs and an automated process with imagery flowing into the platform gives users the information they need when they need it.

Today, Planet is distributing imagery in over 100 countries and is a leader in the satellite imagery market in support of precision agriculture technologies. Planet's constantly increasing coverage capabilities, advanced data pipeline and easy platform access is fueling a wave of analytics by creating a whole new crop of new geospatial analytics businesses. Interested users are invited to sign up for monitoring demo trials at www.planet.com/ag.

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