VARIABLE RATE N AND P MANAGEMENT FOR HIGH-VALUE VEGETABLE CROPPING SYSTEMS

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ABSTRACT

The Lower Colorado River Region (LCRR) of Arizona and California and their environs produce more than 90% of the nation's cool-season vegetables during the fall-winter-spring period. Large amounts of N and P fertilizers are currently utilized for maximum yield and quality. Phosphorus fertilizers are applied pre-plant based on a soil test of a composite field sample. Nitrogen is applied by side-dress based on a plant midrib or petiole N analysis, or soil nitrate-N test, from a composited field sample. The current practice is a single prescribed rate of P and then N over a large production block. The prospect of variable rate applications across a production block had not been evaluated. Studies conducted from 2014 to 2016 evaluated variable rate pre-plant P applications and studies conducted from 2018 to 2022 evaluated variable rate side-dress N applications compared to standard practices. Studies included lettuce (*Lactuca sativa*), broccoli (*Brassica oleracea italica*), and cauliflower (*Brassica oleracea botrytis*), the most common winter vegetable crops in the low desert. Conductance surveys were the principal basis for delineating management zones in all studies. However, we also evaluated 3-band active reflectance sensing implemented on-the-go as a potential tool in fertilizer decisions. The results show that zone management generally resulted in reductions in N and P fertilizer, compared to existing practices, with no positive or negative effects on marketable yield. Reflectance measurements showed trends associated with plant vigor but were highly dependent on the size of the crops at the time of side-dressing N fertilizer. Reflectance measurements alone were not consistent as a basis for driving variable rate fertilizer decisions, but it leaves ample room for the integration of other sources of information to increase accuracy. Zone management sometimes produced results inferior to high-resolution grid soil sampling, but the latter is not economically feasible

INTRODUCTION

The Lower Colorado River Region (LCRR) of Arizona and California and their environs produce more than 90% of the nation's cool-season vegetables during the fall-winter-spring period. Large amounts of N and P fertilizers are currently utilized for maximum yield and quality. In studies, we have shown most cool-season vegetables produced in the desert will respond to P fertilizers up to a sodium bicarbonate P soil test level of 30 to 35 mg/kg. As pre-plant soil tests approach these critical soil test P levels, the probability of crop response to P fertilizer drops dramatically. However, P fertilization based on a composite soil sample from a production unit assumes relatively uniform fertility within the unit, which is inconsistent with our findings. In high-resolution sampling of vegetable production fields in the desert, we have found large in-field variability in soil test P levels within production units (CVs from 18 to 90% usually exceeding 50%). It is reasonable to assume that a P fertilizer rate based on a composite soil sample results in parts of the field being under-fertilized and parts over-fertilized.

Nitrogen is applied by side-dress based on a plant midrib or petiole N analysis, or a pre-side-dress soil nitrate-N test, from a composite field sample. We have also found considerable variation in soil nitrate-N across a field before side-dressing. The prospect of variable rate applications across a production block had not been evaluated. The objective of these studies was to evaluate variable rate (VR) pre-plant P application and VR side-dress N applications for the economically important vegetable crops in Arizona.

METHODS

Studies conducted from 2014 to 2016 evaluated variable rate pre-plant P applications and studies conducted from 2018 to 2022 evaluated variable rate side-dress N applications compared to standard practices Studies included lettuce (*Lactuca sativa*), broccoli (*Brassica oleracea italica*), and cauliflower (*Brassica oleracea botrytis*), the most common winter vegetable crops in the low desert. For the P studies, we compared grid and zone-based P management to the current grower's practice. However, for the N evaluations, we only compared zone management to current practices due to the economic limitations of high-resolution grid sampling schemes.

Conductance Surveys

Prior to planting, fields were surveyed using a Geonics Dual-dipole EM38 meter mounted on a mobilized assessment platform with an integrated sub-meter accuracy GNSS (Global Navigation Satellite System) receiver, with all survey and GNSS position data logged into an on-board portable computer. These pre-plant conductance surveys were performed for both P and N studies. These data were analyzed using the ESAP software package (https://www.ars.usda.gov/pacific-west-area/riverside-ca/us-salinity-laboratory/docs/esap-model/) and the spatial response surface sampling algorithm in the ESAP-RSSD program. At each sampling location, a single 1.2 m soil core was extracted using automated soil auguring equipment and split into four depth-specific 30 cm samples. The soil samples collected from each core were bagged, labeled, and subsequently used for chemical and physical analyses. Subsets of all soil samples were oven-dried to determine soil moisture content. The results of these surveys were used as a basis for defining management zones (Figure 1).

Soil testing

Pre-plant soil samples, the basis of pre-plant P fertilization, were collected by a management zone or on a grid sampling scheme to a 30 cm depth. The soil samples were bagged, labeled, and subsequently processed using a sodium bicarbonate extraction and colorimetric determination of P. Prior to N side-dress applications, multiple soil cores were collected to a 30 cm depth and composited within a zone. Soil samples were air-dried and extracted with 2N KCl. Total ammonium and nitrate N were determined colorimetrically. Ammonium was determined using the indophenol blue method, and nitrate was determined using Griess-IIosovay method after reduction with copperized cadmium. These both were measured using an ALPKEM RFA2 automated colorimeter.

VR Application

The application rig consisted of a CAT-II tractor with a 3-point hitch and conventional electric/hydraulic power ports. Trimble FMX (Sunnyvale, CA) GNSS equipment of RTK (real-time kinematics) correction level was installed in the power unit to provide the VR controller with real-time geographic position data. Both VR and GNSS displays were mounted inside the tractor cab. The application implement was built using a 20 ft wide (6-row), 3-bar frame of 4x4 inch steel bar. This frame supported the tank, hydraulic drive, pump, distribution lines, and injection shanks. Prior to field application events, this system was calibrated and tested to confirm the accuracy of controlled fertilizer delivery rates and field-ready conditions.

Spectral Sensing

A 3-point hitch tractor-mounted frame holding three ACS-430 active spectral sensors manufactured by Holland Scientific (Lincoln, NE). This array allowed surveying every-other row of the entire field. These sensors were fitted with three filters for the simultaneous acquisition of reflectance in the red (670nm), red-edge (730nm), and near-infrared (780nm) bands. Sub-inch precision GNSS equipment was used to geo-locate the sensor output while scanning the crops. At the vehicle speed and sensor refresh rate, this system recorded one data point every 11 inches in the direction of travel. This instrument setup provided high-spatial-resolution data (i.e. 10k georeferenced 3-channel spectral data points per acre).

N Tissue Testing

Tissue samples were collected within management zones two to three weeks after side-dressing and irrigation to track the impacts of variable rate application and for correlation to final yield. All tissue samples were oven-dried and ground. These samples were extracted to measure nitrate and digested using hydrogen peroxide and sulfuric acid to determine the total N. Nitrate in the tissue was determined using the method noted above for soils. Total N was determined using the indophenol blue method noted above.

Yields

We collected yields for this study a day before the commercial harvesters entered the field. Mature heads were cut, graded, and weighed in the field following a GNSS-referenced sampling protocol established to provide meaningful yield assessments in both the variable rate plots and the grower control.

Maps and Data Visualization

All geo-referenced data layers collected in this study from pre-plant to yield were mapped using contouring options and algorithms embedded in Trimble Ag Software. For variables with high spatial resolution such as soil conductance and 3-channel active spectral surveys, we employed the Average Method algorithm with a cell size of 125 ft. and maximum smoothing. For variables sampled on a point basis, we employed the Inverse Distance algorithm with a search radius ranging from 60 to 75 ft. and a cell size of 125 ft. with maximum smoothing (Figures 2, 3, and 4). Geographic mapping of soil/plant variables provides a framework for geostatistical analyses and a digital template to implement VR through the generation of output prescription (esri shape) files.

RESULTS

Over ten sites, yields were not significantly different between variable rate P management and current practices (GSP). In a few situations, variable rate-based applications resulted in a higher net P application rate than the grower standard practice (GSP) but not for most sites. The net fertilizer savings over all sites was 20% for grid and 12% for zone-based sampling schemes, compared to the GSP. However, the fertilizer cost savings often did not cover the additional costs involved in surveys, sampling, and sample analysis. Grid management was seldom economically feasible, even with the current high fertilizer process. The zone management was often not economically beneficial for the fertilizer prices that existed back in

2013 to 2017 period when we did this work. However, a more recent economic evaluation using current fertilizer prices shows more consistent positive economic outcomes to variable rate P management. This strategy may be immediately applicable where environmental issues restrict P fertilization rates.

The variable rate N studies are on-going, but results processed to date indicate consistent fertilizer savings with no reduction in yield. The vegetable industry is very competitive and uniformity, as well as yield, are sought-after objectives as multiple harvests increase costs to the shippers. Thus, growers often fertilize the entire field for the weak area of a field to achieve uniformity. This approach not only results in inefficient N use it potentially has other consequences. In fact, on one lettuce site, the excess fertilizer applied by standard practice resulted in high tissue N content and reduced yield in a management zone that called for a much lower N rate (see Figure 5 below). We are finding about a 20 to 30% saving in N fertilizer use by variable rate management compared to the current practice. At current fertilizer prices, the costs of soil survey and additional sampling are covered by these savings. The data we have collected suggest variable rate technologies provide a means of achieving optimal yield and uniformity with desirable economic and environmental outcomes.

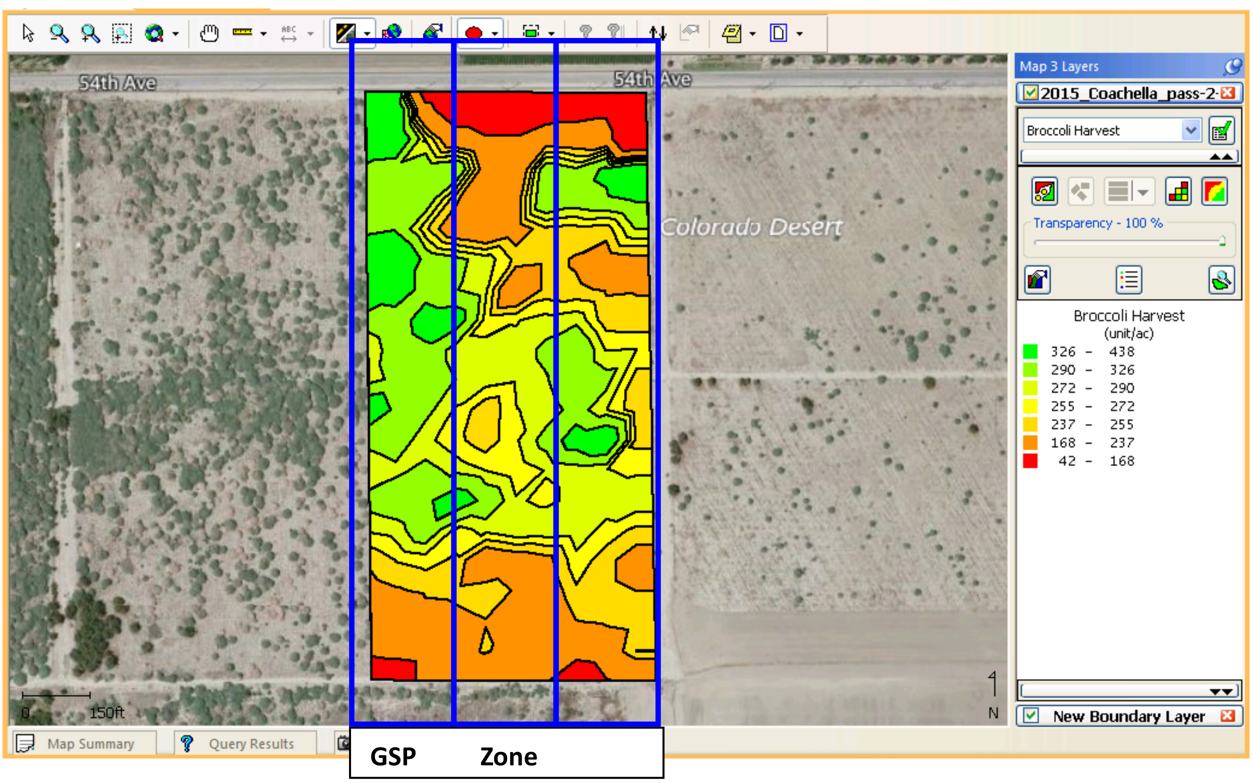

Figure 1. Broccoli field in the Coachella valley California split into Grid, Zone, and growing practice management areas.

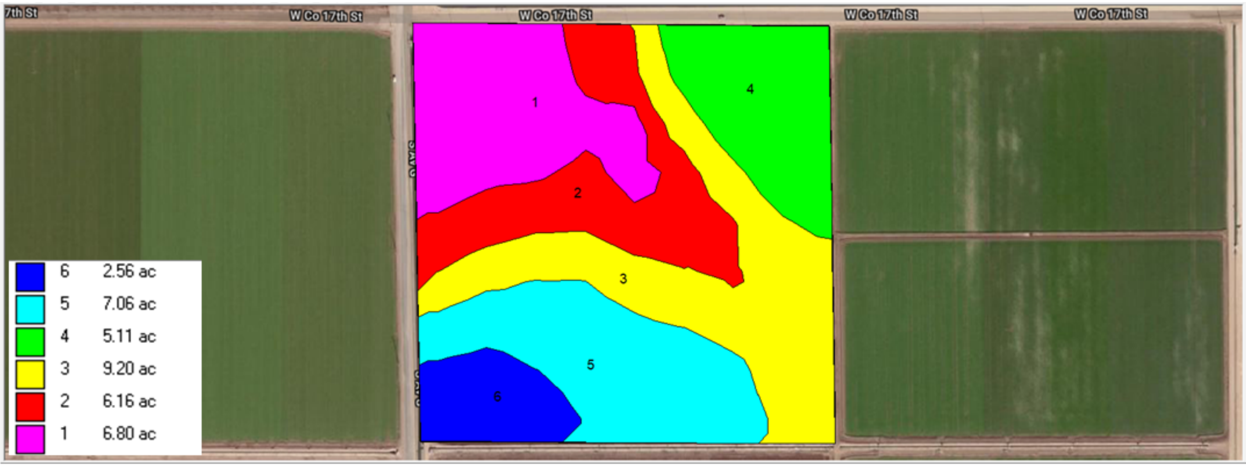

Figure 2. Management zones defined for lettuce production in an irrigation district south of Yuma, Arizona.

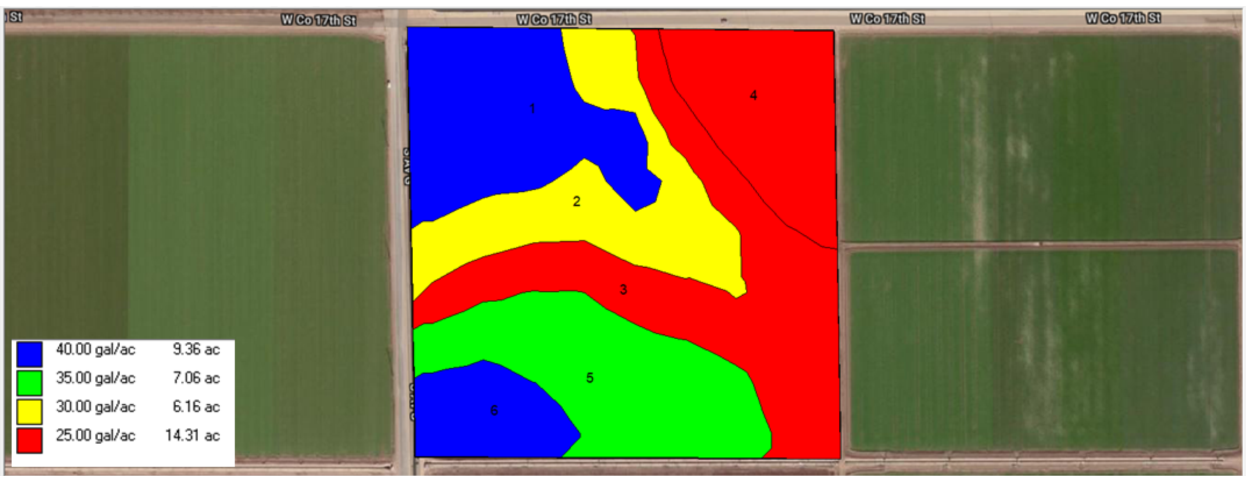

Figure 3. Nitrogen side-dress prescription map for lettuce field above. The grower used 60 gallons UAN 32 over the standard practice half of the field.

Figure 4. Nitrogen side-dress prescription map for lettuce in an irrigation district north of Yuma, Arizona.

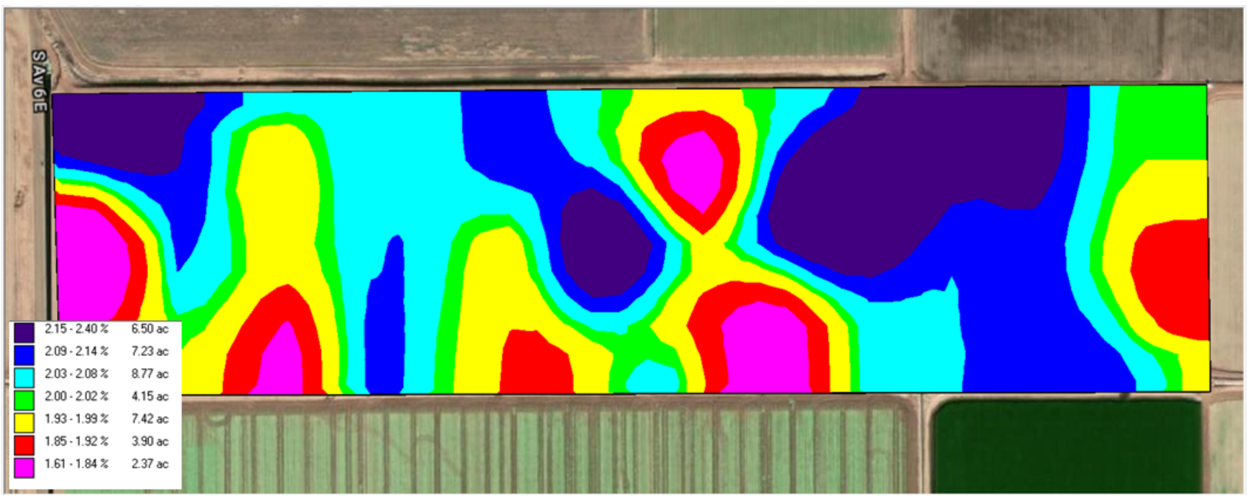

Figure 5. Measured leaf N content after side-dress for the site above.