

DIRECTED R_x: A NEW METHOD FOR VARIABLE RATE NITROGEN PRESCRIPTION IN COTTON

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Abstract

Directed R_x is a method developed by Clemson researchers in an effort to optimize zone delineation and assignment of inputs for spatially variable prescriptions. Currently employed methods of variable rate prescription development generally overlay rates or products (e.g. hybrids) on pre-defined yield management zones, with a number of studies focused on how to best define these management zones. In cotton, algorithms for variable rate nitrogen prescriptions have been developed on the basis of normalized difference vegetation index (NDVI), which is used to calculate in season estimated yield (INSEY). The Directed R_x method uses strip tests to integrate yield and therefore profitability effects with site-specific foundation (e.g. soil EC, elevation, irrigation) polygons, seeking to optimize prescriptions, specific to a field and input. In this study, one site showed no potential benefit from variable rate nitrogen in cotton and at the other site the Directed R_x system for variable rate nitrogen showed a \$15/ac and 47.4 lb/ac benefit over the best performing, uniform nitrogen rate, while maintaining a higher fertilizer nitrogen use efficiency.

Introduction

Variable rate prescription capabilities exist for most of today's inputs used in row crop production. Several methods exist for assigning rates, the most common of which involves development of spatially classified yield management zones, followed by assignment of a product type or rate of product by zone based on the assignor's expected performance of that zone. The underlying goal and premise of variable rate nutrient prescriptions is a desire to optimize nutrient application rates to increase profitability and increase utilization efficiency. If a uniform nutrient rate is applied, over-application may result in under-performing areas of the field and under-application may result in superior performing areas of the field. Over application of nitrogen represents a waste of product, which may result in surface- or ground-water contamination and in cotton may result in excessive growth and maturity delays. Under-application of nitrogen in cotton results in loss of yield potential and therefore reduced profitability.

Conventionally, and in the absence of variable rate application capabilities, nitrogen is applied for cotton production as a blanket rate for each field, generally based on a yield goal and a Cooperative Extension recommendation. For South Carolina, Clemson University Extension recommends nitrogen rates for cotton of 70 lb/ac for 500 lb/ac lint yield with a nitrogen rate increase of 6 lb/ac for each 100 lb/ac increase in lint yield. Using these recommendations, if zone management were employed, yield goals could be set for each zone based on historical yield records, which could be coupled with Extension recommendations to assign a blanket nitrogen rate for each zone.

Porter (2010) discusses development and testing of NDVI sensor-based algorithms for calculation of an in-season estimation of yield (INSEY), which is used along with a response index (RI) and nitrogen use efficiency (NUE) to calculate a recommended nitrogen rate. The Clemson work was in part based on prior work by Arnall et al. (2008) to develop an OSU algorithm. Both algorithms are based on work demonstrating that INSEY can be calculated from NDVI measurements within a particular range of days after emergence. An advantage of NDVI sensor-based nitrogen prescriptions is the ability to assign a nitrogen rate based on in-season estimates of expected nitrogen use. These sensor-based nitrogen algorithms have not been widely implemented, possibly due to complexity of executing, cost of sensor systems required, grower reluctance, or some combination of these factors. Furthermore, with today's rapidly advancing plant technologies, these INSEY algorithms may require refinement with time and by variety.

The Directed R_x system tested in this project involves application of uniform rate nitrogen strips and yield data collection across these strips. Soil property data (e.g. soil electrical conductivity, elevation, texture, etc.) is collected and contoured to divide the field into soil foundation zones. As demonstrated in this study, the system allows for layering of soil property data. The cotton yield for each nitrogen rate is then averaged as a function of each soil property. This method allows for determination of the nitrogen rate that maximized yield or profitability within each soil property division, which defines the prescription to be applied in the subsequent year.

An advantage of the Directed R_X system is that it requires no investment in technology beyond that currently being employed by many growers. Furthermore, it puts a grower's yield data to work, using data from their field, conditions, and management practices to develop the variable rate prescription. Because the Directed R_X system does not involve "generic" data or data from another variety and site, it may produce more relevant results than other prescription development methods. A drawback of the method is that it uses this year's results for next year's prescription, and differences in environmental conditions between years may constitute differences in optimum input rates. If the system proves to be beneficial in increasing profitability of variable rate prescriptions, its adoption success will be in part dependent on its ease of implementation.

This report summarizes results from a two year study evaluating the Directed R_X system for variable rate nitrogen in cotton on two fields in Barnwell County, S.C. First year objectives in 2016 were to characterize yield and profit effects from different nitrogen rates as functions of soil properties. Comparisons of these yield and profit effects were then used to develop a Directed R_X variable rate nitrogen prescription for the 2017 cotton production year on the same two fields. A secondary objective of both years of study was evaluate yield and profitability of Porter's (2010) NDVI sensor-based nitrogen prescription with respect to yield and profitability for uniform nitrogen rates and the Directed R_X prescription.

Materials and Methods

Testing commenced for this project during the 2016 crop year. Two irrigated fields in Barnwell County, SC were included in the tests, both of which were planted in cotton for both the 2016 and 2017 crop years.

E7 Experimental Design and Site Description

One site was a 9.5 ac field (approximately 8 ac under irrigation), E7, at Edisto Research & Education Center in Blackville, SC. DeltaPine 1538 B2XF was planted at a rate of 41,000 seeds per acre on June 4, 2016 and May 18, 2017. One June 5, 2016, Edisto REC experienced an intense rainfall event in excess of 2 inches and the resulting germination/emergence was poor at best with a substantial amount of gully and sheet erosion. The first planting of 2016 was killed on June 15 with a field cultivator and the DP 1538 B2XF was re-planted at 41,000 seeds per acre on the same date. Liquid nitrogen was applied uniformly as 25-S at the first planting in both years at a rate of 15 gal/ac (40 lb-N/ac) in 2016 and 7.5 gal/ac (20 lb-N/ac) in 2017. The field was divided into 8-row strips in 2016, providing six replications of five uniform rate nitrogen treatments, randomized within each replication. In 2017 the field was divided into 4-row strips, providing ten replications of seven treatments: five uniform nitrogen rates, a Directed R_X treatment based on the 2016 test results, and a NDVI based prescription treatment, all randomized within each replication. Two of the replication blocks in 2017 were outside of the irrigation boundaries, reducing the effective number of replications to eight.

In 2016 the second liquid nitrogen application of 25-S for E7 was knifed in on July 8 at uniform rates of 20, 40, 60, 80, and 100 lb-N/ac (Figure 1). As discussed in the results, yield data from 2016 was used to develop a Directed R_X prescription for 2017 selecting the nitrogen rates from 2016 that maximized profit in each of seven divisions of true deep EC; true deep EC is defined in a later section. Because E7 was replanted in 2016, the side-dress nitrogen application had to be applied prior to the time when NDVI for INSEY could be reliably obtained and an NDVI sensor-based nitrogen prescription for E7 was therefore not applied in 2016. NDVI was measured in 2017 with a model 505 Greenseeker on June 29 and used to develop a variable rate nitrogen prescription using the Clemson algorithm (Porter, 2010). In 2017 the second liquid nitrogen application of 25-S was knifed in on July 6 at fixed rates of 20, 40, 60, 80, and 100 lb-N/ac in addition to the rates dictated by the prescriptions. Treatments assigned in 2017 by strip can be seen in Figure 2. Soil electrical conductivity was measured on January 13, 2017 using a Veris model 3100 and soil samples collected on a 150 ft grid were analyzed for soil texture using a hydrometer method.

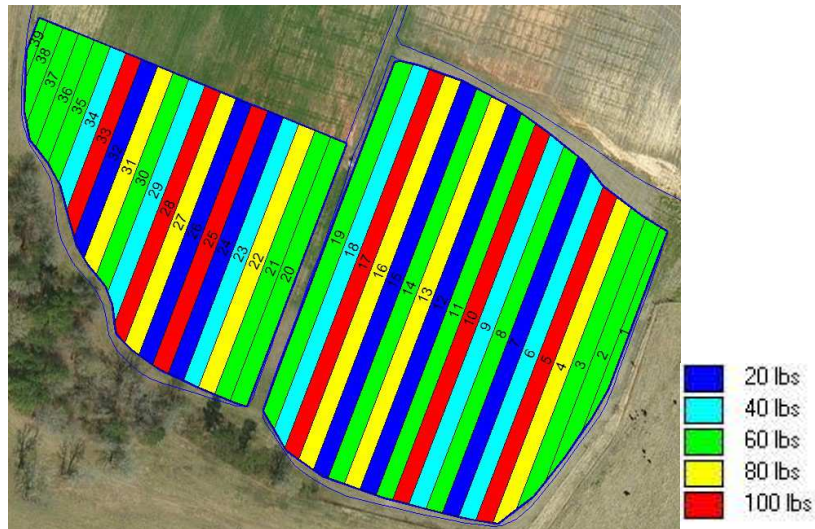


Figure 1. Nitrogen rates (lb-N/ac) applied in E7 at second application in 2016.

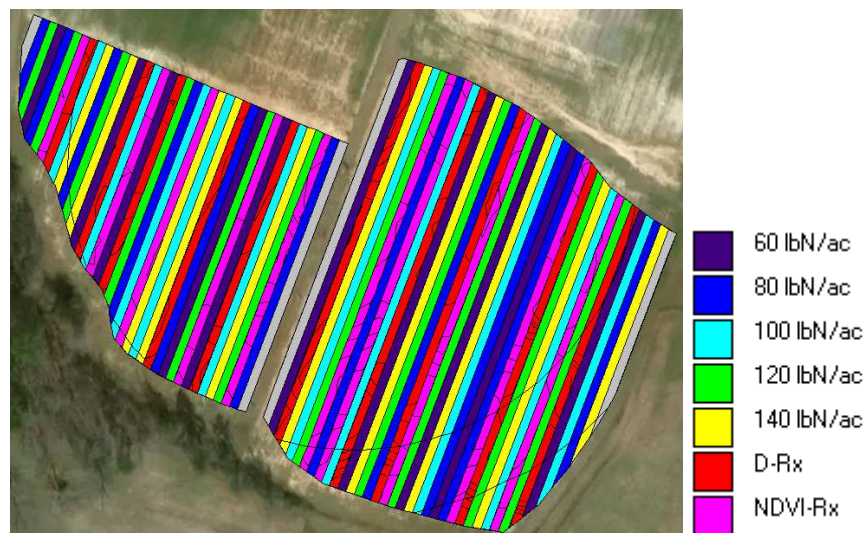


Figure 2. Treatments assigned to the 4-row strips in 2017. Legend entries where nitrogen rates are defined were for continuous rate strips, where rates specified are as total nitrogen for the season.

Bates Place Experimental Design and Site Description

The second site was a 31 ac field (approximately 21 ac under irrigation), Bates Place, in Elko, SC, farmed by a cooperating grower. Planting of DeltaPine 1538 at a rate of 35,000 seeds per acre was on May 11, 2016 and May 20, 2017 with granular applications of urea in both years at rates of 40 lb-N/ac at planting. Stand counts collected on a 150 ft grid on May 27, 2016 showed an average population of 26,000 plants per acre. Stand counts were not measured in 2017.

NDVI was measured with a model 505 Greenseeker on June 27, 2016 and used to develop a variable rate nitrogen prescription using the Clemson algorithm for the 2016 crop year (Porter, 2010). In 2016 the field was divided into 16 row strips, providing five replications of five treatments, which were randomized by block. The 2016 treatments included side-dress uniform rates of 35 lb-N/ac, 55 lb-N/ac, 75 lb-N/ac, and 95 lb-N/ac, along with an additional treatment where the NDVI-based variable rate nitrogen prescription was applied (Figure 3); this sidedress plan was applied as granular urea on June 30, 2016. The sidedress nitrogen rate applied to the area outside of the irrigation

endgun boundary was alternated in uniform strips of 35 and 55 lb-N/ac, although data from these areas was not analyzed as a part of this report.

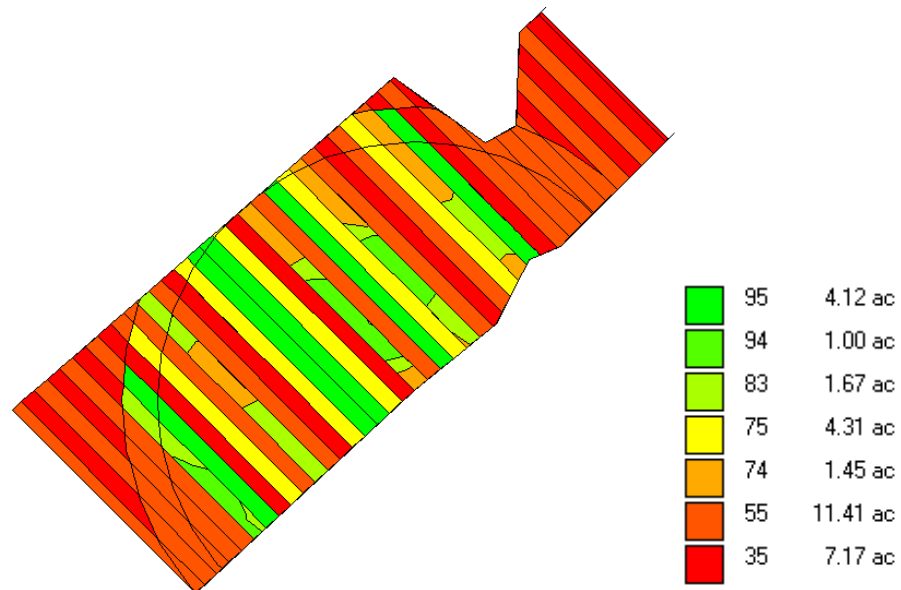


Figure 3. Sidedress nitrogen rates (as lb-N/ac) applied at Bates Place on June 30, 2016.

The Directed R_X prescription for 2017 was based on profit response from 2016 uniform nitrogen rate strips, assigning the most profitable nitrogen rate for each of seven divisions of deep soil EC. Development of this prescription is discussed in the results section. Also using a model 505 Greenseeker, NDVI was measured on June 28, 2017 and used to develop a variable rate nitrogen prescription using the Clemson algorithm for the 2017 crop year. In 2017 the field was divided into 16-row strips, providing six replications of six treatments: four uniform nitrogen rate treatments, a Directed R_X treatment based on the 2016 test results, and a NDVI based prescription treatment, all randomized within each replication (Figure 4). Sidedress nitrogen was applied as granular urea on July 3, 2017. Soil texture samples for Bates Place collected on a 150 ft grid were processed using a hydrometer method to define sand, silt, and clay contents and an electrical conductivity map was acquired using a Veris model 3100.

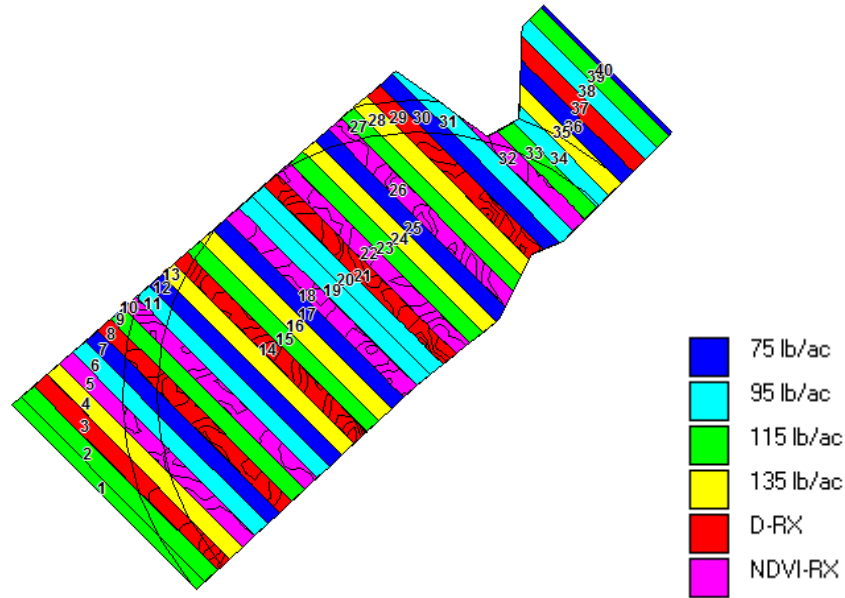


Figure 4. Treatments assigned to the 16-row strips in 2017. Legend entries where nitrogen rates are defined were for continuous rate strips, where rates specified are as total nitrogen for the season.

Yield Data Collection and Analysis

Yield data was collected for E7 using an Ag Leader optical yield monitor on a 4-row Case picker in 2016 and using a John Deere microwave yield monitor harvesting four rows per pass with a John Deere 9986 picker in 2017. Yield data for Bates Place in both years was collected using a John Deere microwave yield monitor on a 6-row John Deere 9986 picker. For the Bates Place field, 6-row yield data for passes that intersected two nitrogen rate strips were omitted from the analyzed dataset. Yield data for both sites was analyzed as discussed below in the same manner. Yield data was post-process calibrated using known basket or module weights from the test sites.

The calibrated yield point data (csv file) from each year and site was appended with several attributes using Clemson University's Point-Polygon Merge Utility (PPMU) software. The PPMU software merges a polygon shapefile with a point (csv) dataset, adding a column to the csv dataset indicating the polygon in which each point resides. As an example, merging the yield dataset with the shallow EC contour shapefile would result in addition of a column to the yield dataset indicating the shallow EC for each yield data point. Seven divisions of each soil foundation property available (0-12" EC, 0-36" EC, 12-36" EC, elevation, bare soil pixel brightness, sand content, silt content, and clay content) were used to create the contoured shapefiles in Farmworks. Throughout this report, the 0-12" soil EC is referred to as shallow EC, the 0-36" soil EC is referred to as deep EC, and the 12-36" soil EC is referred to as true deep EC. The true deep EC value was calculated as $1.5 * (\text{deep EC}) - 0.5 * (\text{shallow EC})$, an equation derived as a part of an ongoing, unpublished Clemson Precision Agriculture Program research effort. Each soil property contour was further split by an irrigation attribute as: under pivot, under endgun, and non-irrigated. Analysis for this study only included the "under pivot" area. Figure 5 shows true deep EC maps of the two fields as examples of the soil property maps used for appending yield data via PPMU.

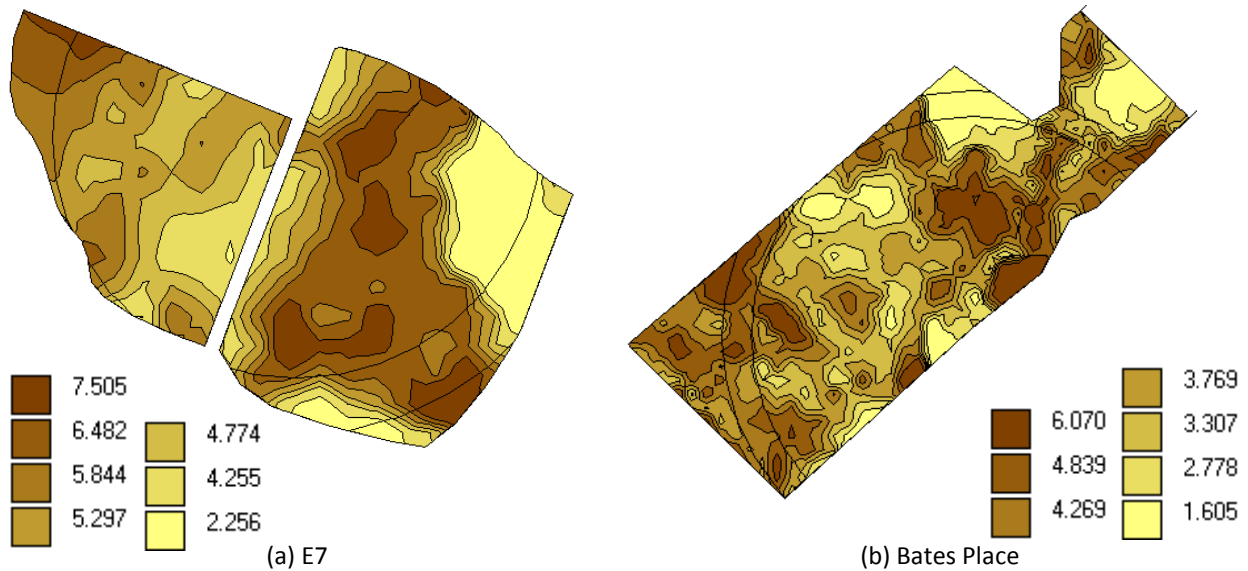


Figure 5. Seven division true deep EC (mS/m) contour map for E7 (a) and Bates Place (b) with indication of pivot and endgun boundaries.

Determination of the Directed Rx Prescription

After classifying each yield data point by soil properties defined in the shapefile contour maps, the yield data variable was normalized using a univariate Box-Cox transformation. Independent outlier analyses were performed for each type of soil property classification; yield outliers were removed by treatment using Tukey's method. After removal of outliers, the remaining yield data points were averaged by soil property division and by treatment. Revenue was calculated from lint yield at rates of 0.65 \$/lb for both years and nitrogen costs were calculated from nitrogen application rates at a rate of 0.359 \$/lb for both years. From the revenue and nitrogen cost for each treatment and soil property division, "returns above nitrogen costs" (hereinafter referred to as returns) values were calculated as \$/ac. This allowed for identification of the highest yielding and highest profiting nitrogen rates for each soil property division, representing the "Directed Prescription" for each soil property classification.

There were occasional average yield and return response averages as a function of soil property division by nitrogen rate that were divergent from the general trends exhibited within that nitrogen rate. There were also some combinations of soil property division and nitrogen rate for which there was no yield data. Because of these occasions, yield as a function of soil property division within each nitrogen rate was estimated as a second order polynomial regression for identification of optimum nitrogen rates within each soil property division. An example demonstrating this is provided in Figure 6 for 2017 lint yield as a function of deep EC for E7, where the markers represent the actual averages and the curves represent the regression models. In this way, the effect of divergent averages was muted and the absence of data for a given nitrogen rate and soil property division could be interpolated. Hereinafter, these regressed yield values are referred to as "projected yield", which were used to calculate "projected returns".

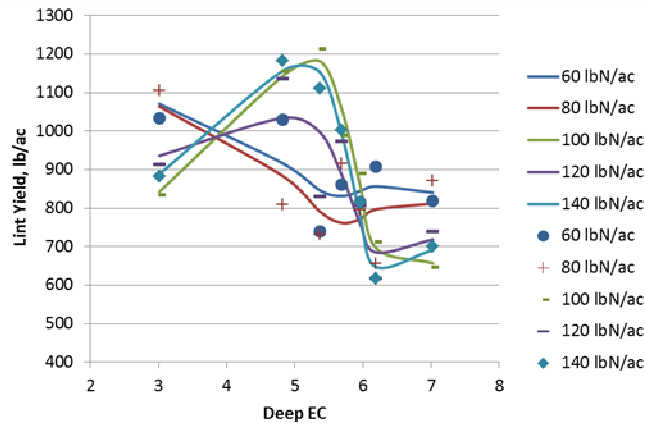
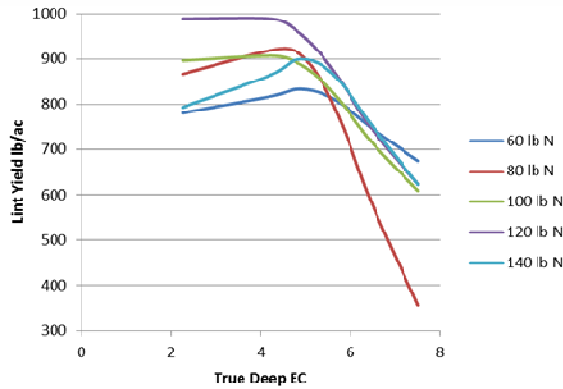


Figure 6. Lint yield as a function of deep EC for 2017 E7 dataset, where markers represent actual averages by nitrogen rate and curves represent regression models for averages by nitrogen rate.

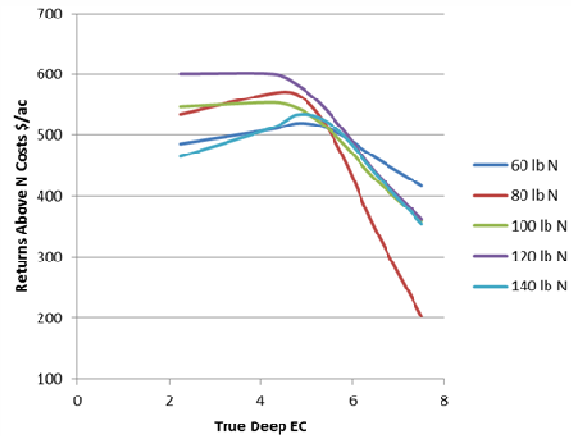
Results and Discussion

Development of Directed R_x Prescriptions

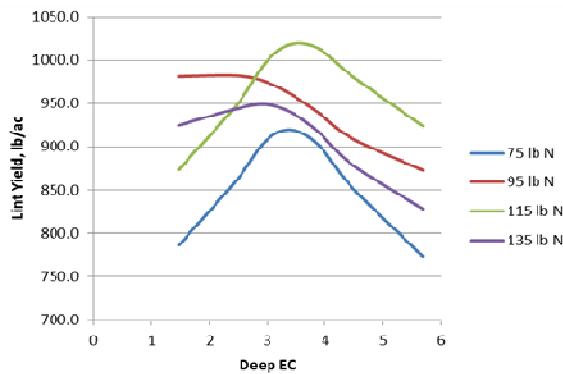
Average yields and returns were calculated for each nitrogen rate and soil classification division; 2016 results for the true deep and deep EC classifications are shown below as examples. For both fields, deep EC and true deep EC more consistently classified 2016 yield as a function of EC than did shallow EC, with yields and returns generally demonstrating a 2nd order polynomial relationship as a function of deep and true deep EC—the highest yielding areas being the low- to mid-range electrical conductivities. These general trends are demonstrated in Figure 7 for the true deep and deep EC classifications. Across all three of the EC classifications for both fields, the 120 (E7) and 115 (Bates Place) lb-N/ac rates were highest yielding and most profitable across the majority of divisions.



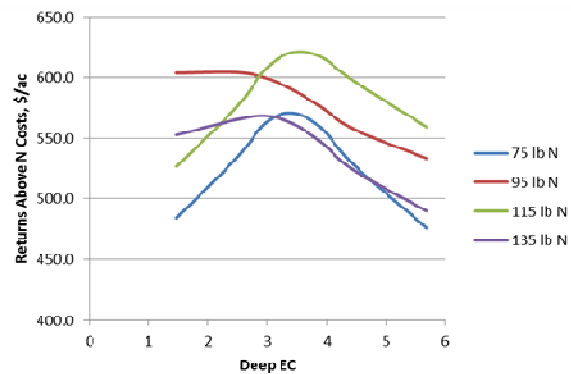
(a) E7, yield



(b) E7, returns



(c) Bates Place, yield



(d) Bates Place, returns

Figure 7. Comparison of nitrogen rates: (a) on projected yield as a function of true deep EC for E7, (b) on projected returns as a function of true deep EC for E7, (c) on projected yield as a function of deep EC for Bates Place, and (d) on projected returns as a function of deep EC for Bates Place. All data are from 2016 crop year.

From Figure 7, the nitrogen rates within each soil classification division resulting in the highest yields and returns represent the optimum nitrogen rates, or the Directed R_x prescription rates for the demonstrated classifications. For example, from Figure 7(d), maximization of returns would have occurred with a nitrogen rate of 95 lb-N/ac at deep EC values less than about 2.75 and a rate of 115 lb-N/ac at deep EC values greater than about 2.75. Figure 8 shows optimum nitrogen rates for maximizing projected 2016 yield and profit in the two fields as functions of true deep EC and deep EC. Optimum nitrogen rates for maximizing yields were generally equal to those for maximizing profits, with few exceptions. At E7, optimum nitrogen rate generally decreased from a plateau of 120 lb N/ac as a function of true deep EC, whereas at Bates Place, optimum nitrogen generally increased to a plateau of 115 lb N/ac as a function of true deep EC. The dissimilarity of these trends in the two fields is supportive of the need for a system such as Directed R_x , which ignores generic relationships and instead seeks to customize recommendations, specific to each field and grower practices. Application of the Directed R_x prescriptions to maximize profit when classified by true deep EC and deep EC resulted in the total nitrogen rate prescriptions applied in 2017; prescriptions developed as a part of this study were only for the irrigated areas of the field. Similar analyses and methods could be used for non-irrigated areas.

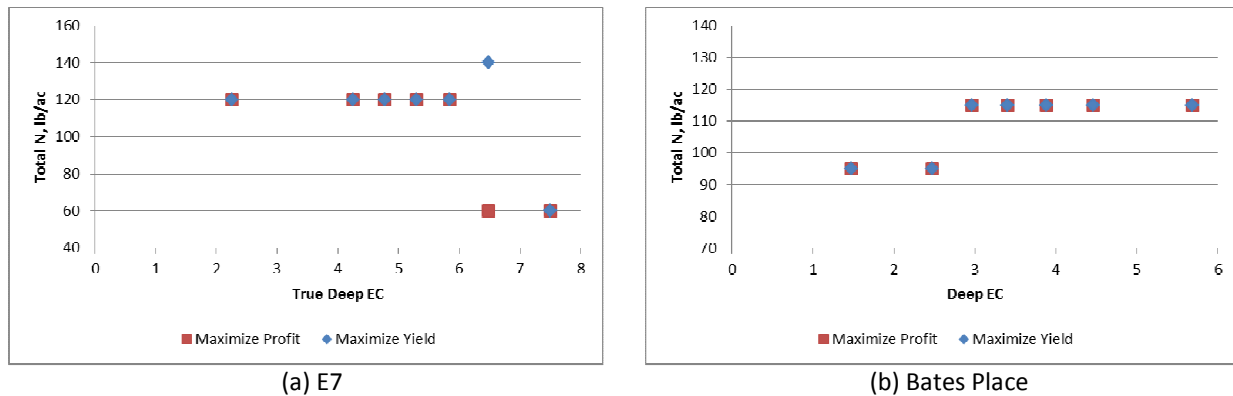
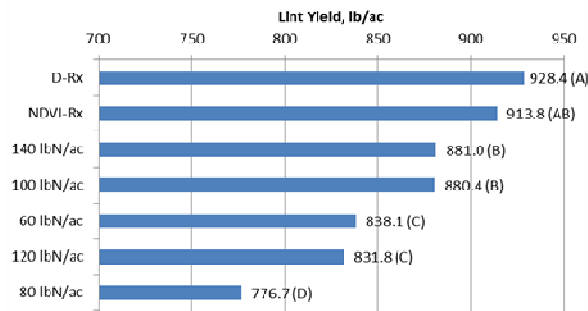


Figure 8. Optimum nitrogen rates as a function of true deep EC for maximization of 2016 projected yield and profit for (a) E7 and (b) Bates Place.

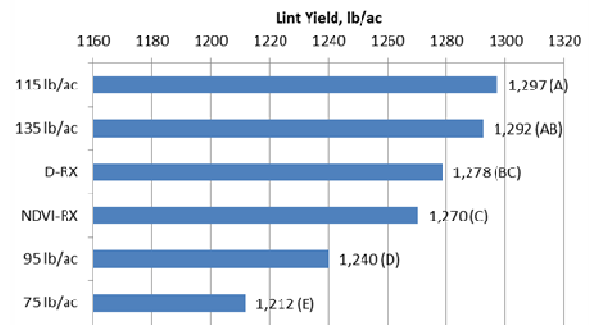
Performance of 2017 Treatments as Applied

As discussed, the 2017 treatments in both fields included Directed R_X prescriptions based on 2016 profit response to nitrogen, NDVI sensor based prescriptions, and uniform nitrogen rates. The Directed R_X nitrogen prescriptions applied to E7 and Bates Place in 2017 were those that maximized profit in 2016 by true deep EC (for E7) and deep EC (for Bates Place). Figure 9 shows the observed yield and returns from the treatments tested. In E7, the highest yielding and most profitable uniform nitrogen rates were 140 and 100 lb-N/ac, with no significant differences between the two rates. Both variable rate nitrogen prescriptions in E7 were numerically more profitable than the most profitable uniform nitrogen rate, but not significantly. The Directed R_X prescription significantly out-yielded the highest yielding uniform nitrogen rate in E7 by 47.1 lb-lint/ac. There were no significant differences in yield or profit between the two variable rate prescriptions in E7. Both variable rate prescriptions used more nitrogen than the most profitable uniform rate (100 lb-N/ac); average total nitrogen applied was 139 lb-N/ac for the NDVI sensor based prescription and 103 lb-N/ac for the Directed R_X prescription. Fertilizer nitrogen use efficiency (in units of pounds of lint per pound of nitrogen applied) in E7 in 2017 was 8.80 for the 100 lb-N/ac uniform rate, 6.29 for the 140 lb-N/ac uniform rate, 6.57 for the NDVI sensor based prescription, and 9.01 for the Directed R_X prescription.

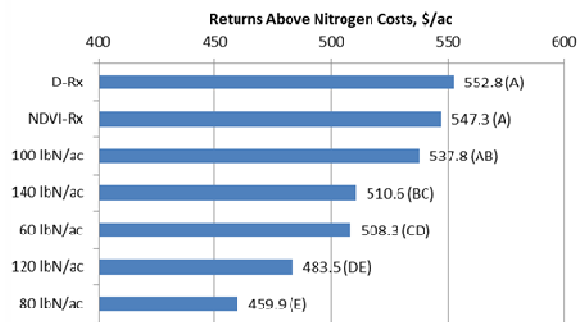
In Bates Place, numerical ranking of treatments on the basis of yield was the same as that for returns, but statistical significance was not the same for yield and returns. Both variable rate prescriptions were significantly lower yielding than the highest yielding uniform rate (115 lb-N/ac) by 19 and 27 lb-lint/ac, for the Directed R_X and NDVI sensor based prescriptions, respectively. Both variable rate prescriptions were also significantly less profitable than the most profitable uniform rate by 10.8 and 20.0 \$/ac, for the Directed R_X and NDVI sensor based prescriptions, respectively. Average total nitrogen applied at Bates Place for the variable rate prescriptions was not substantially different from that for the best performing uniform rate (115 lb-N/ac), at 122 lb-N/ac for the NDVI sensor based prescription and 111 lb-N/ac for the Directed R_X prescription. Fertilizer nitrogen use efficiency (in units of pounds of lint per pound of nitrogen applied) in Bates Place in 2017 was 11.28 for the 115 lb-N/ac uniform rate, 9.57 for the 135 lb-N/ac uniform rate, 10.41 for the NDVI sensor based prescription, and 11.51 for the Directed R_X prescription.



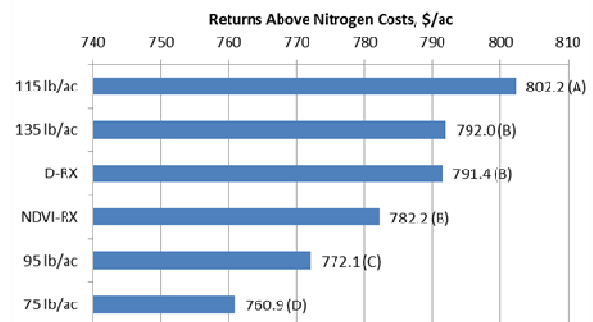
(a) E7, yield



(b) Bates Place, yield



(c) E7, returns



(d) Bates Place, returns

Figure 9. Observed 2017 lint yield (a and b) and returns (c and d) for the treatments applied at E7 (a and c) and Bates Place (b and d). Means with different letters are significantly different (student's t-test, $p < 0.05$).

Conclusions

This study evaluated the potential for using Clemson's Directed R_X method for assigning a variable rate nitrogen prescription for cotton in two fields in Barnwell County, S.C. Conclusions from this work were:

1. In E7, the Directed R_X system demonstrated greater profitability with less nitrogen than the best performing uniform nitrogen rate. As demonstrated in Figure 9, the benefit of variable rate nitrogen using Directed R_X for E7 in 2017 was \$15/ac while using only 3 lb/ac more nitrogen, as compared to the 100 lb-N/ac treatment, which was the most profitable uniform rate treatment. Fertilizer nitrogen use efficiency was also 2.4% higher for Directed R_X as compared to the best performing uniform rate.
2. Not all fields are good candidates for variable rate nitrogen. Bates Place, showed little to no evidence of potential benefit from variable rate nitrogen application. By design, the Directed R_X system is retrospective in seeking to assign the most profitable or highest yielding rates by soil classification zone. So, implication that Bates Place is not a good candidate for variable rate nitrogen is fairly exhaustive in possible combinations of nitrogen rates and soil classification methods.
3. For the fields in this study, deep soil characteristics, such as deep EC and true deep EC, were generally but not exclusively better soil classification bases for application of Directed R_X to nitrogen prescription for cotton than shallow soil characteristics, such as shallow EC and surface soil texture.
4. As applied in this study and based on Porter (2010), the Clemson algorithm for NDVI sensor based nitrogen prescription generally underestimated yield as a function of INSEY and generally overestimated nitrogen applied, as compared to optimum nitrogen rates for maximizing profit.
5. Regardless of whether or not a field demonstrates profit potential from variable rate nitrogen prescription, the Directed R_X methodology requiring use of a grower's yield monitor data to evaluate a test specific to

his field can be economically beneficial. In Bates Place, the farmer's normally applied uniform rate prior to this test was 100 lb-N/ac. There was no 100 lb-N/ac treatment in this test, so it is assumed here that profitability for 100 lb-N/ac would be similar to that for 95 lb-N/ac. It was demonstrated in two consecutive years in this field that the 115 lb-N/ac rate was significantly more profitable than the 95 lb-N/ac rate, a profit increase of \$33/ac in 2016 and an increase of \$31/ac in 2017.

References

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Porter, W. M. 2010. Sensor based nitrogen management for cotton production in coastal plain soils. MS thesis. Clemson, SC: Clemson University, Biosystems Engineering.