Evaluation of Commercial Aerial Imagery to Assess Variability of Height and Yield in Cotton (*Gossypium hirsutum* L.) Fields

Monti Vandiver
Texas Agrilife Extension Service, Friona, TX
Terry A. Wheeler[1]
Kevin F. Bronson
Ben G. Mullinix Jr. [2]
Texas Agrilife Research, Lubbock, TX 79403

ABSTRACT

Variable rate application of products can be applied based on the identification of vigor zones in cotton fields. Companies exist which acquire imagery, create vigor zones, and provide application maps for products based on the vigor zones. The accuracy of using commercially obtained vigor zones in semi-arid cotton growing areas, such as the southern High Plains of Texas was investigated, and compared with the value obtained by digitized soil maps, that are obtained at no charge by the Soil Survey Geographic Data Base of the USDA Natural Resources Service. Commercial aerial imagery was taken of nine cotton fields (six in 2006 and three other fields in 2007) by Wilbur-Ellis, using AgFleet version 3.0 in 2006 and by In Time Inc. in 2007. Vigor maps based on three zones were created by these companies and used to test whether the zones accurately represented differences in plant height in nine fields, and yield in five fields. Soil maps were overlaid over the imaged fields, and plant height and yield were compared among the different soil types. In general, yield differences were not adequately predicted by height differences in the fields. Vigor maps did adequately represent yield differences in 3 of 5 fields. Soil maps were related to yield differences in 3 of 5 fields. However, it was not intuitive which soils would be more productive based on their properties. There were several instances where soils with a shallow petrocalcic horizon yielded higher than areas of deep, calcium free soils. The use of commercially available imaging to identify vigor zones was successful in some fields, but in a number of situations it was not reliable. Producers should evaluate the technology on a case-by-case basis before using recommendations based on imagery for variable rate applications. Plant height was not necessarily a reliable method to identify vigor zones, so the use of a yield monitor may be the best method of identifying consistent management zones.

KEY WORDS: imagery, precision agriculture, variable-rate application

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[1] Corresponding author.

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INTRODUCTION

Variability in cotton growth can occur due to soil physical characteristics, soil chemical differences, and biotic factors. Variable rate application of agricultural products can be utilized if differences in fields are consistent over years (Guo and Maas, 2005), or if variability can be measured timely during the season through remote sensing. Imagery can be used to calculate a vegetation index which can represent plant vigor. One of the most commonly used vegetation indices is called the normalized difference vegetation index (NDVI) which is calculated by light reflected at the (near-infrared wavelength – red wavelength) / (near-infrared wavelength + red wavelength) (Tucker, 1979). The near infrared wavelength is approximately 700 to 900 nm, and the red wavelength is approximately 600 to 700 nm. This vegetation index has been correlated with cotton yield (Jayroe et al., 2005; Plant et al., 2000). There are commercial enterprises which collect imagery, transform them with NDVI, and sell them to producers for crop management (www.gointime.com).

Variable rate applications are conducted with almost all farm inputs including seed density (Shanahan et al., 2004), nitrogen and phosphorus rates (Bronson et al., 2003; Bronson et al., 2005), plant growth regulators (Lewis et al., 2002; Nelson et al., 2005), nematicides (Wheeler et al., 1999), and harvest aids (Nelson et al., 2005). Producers using some of these inputs in a variable rate system can take advantage of in-season remote sensing imagery.

In cotton, the connection between aerial imagery and commercial variable rate applications was primarily developed in Mississippi, with a project under the NASA Ag 20/20 program. At that time, it was difficult for producers to obtain a commercial product that both obtained imagery and assisted them with application maps. The company In Time (www.gointime.com) was created as a result of the collaborative efforts of this project (www.gointime.com/about_history.jsp). Over the years there have been some large companies that have also tried to tie-in remote sensing services with variable rate applications (Wilbur-Ellis and John Deere). There are also some consultants who offer imagery plus the ability to create application maps as part of their consulting services. There were a number of on-farm experiments conducted in California, Louisiana, and Mississippi to demonstrate that multispectral remote sensing could be used to generate accurate plant growth maps, and these could be used to generate application maps (Bethel et al., 2003; Leonard et al., 2003; Lewis et al., 2002). However, the ability of companies to use imagery to create management zones related to plant vigor in the semiarid region of West Texas has not been demonstrated. This area produces deficit-irrigated cotton, that may develop into a much smaller plant as well as other differences related to the climate. The objectives of this project were to take commercially developed three-zone vigor maps, and relate them to plant height taken at a time appropriate for application of plant growth regulators; to relate yield to these three-zone vigor maps; and to relate yield and plant height to digitally available soil maps.

MATERIALS AND METHODS

In 2006, imagery represented as three vigor zones was obtained from Wilbur-Ellis (AgFleet version 3.0, a part of ZedX Inc., Bellefonte, PA) from six cotton fields on 17 July (Fig. 1). Soil maps were obtained for each field from the Soil Survey Geographic

Data Base from the USDA Natural Resources Conservation Service and overlaid on the images (Fig. 1).

In 2007, imagery represented as seven vigor zones (called scout maps) was obtained from In Time Inc. (www.gointime.com) from three cotton fields on 16 July (Fig. 2 Byrd, Herr07, Watson). The scout maps were also transformed into application maps with three zones by In Time Inc. Soil maps were obtained for each field similarly as in 2006.

Plant height in 2006 was taken at these six sites between one and three times depending on the site. In 2006, plant height locations taken in early July were selected by representative sampling of soil types for all six fields. Plant height taken in late July (Clark and Saylor fields only) and August (Clark and HH fields only) were selected by representative sampling of vigor zones. In 2007, a relatively even spacing of locations or height measurement was made on all fields, and the same locations sampled three times for all three fields. At each location that plant height was measured, 10 consecutive plants were measured and the height was averaged for that point (in both years).

Yield maps were obtained with an AgriPlan yield monitor attached to the burr extractor of a John Deere 7445 cotton stripper, at two sites in 2006 (Clark on 17 Nov., and HH on 1 Nov.) and three sites in 2007 (Byrd on 24 Oct., Herr on 22 Oct., and Watson on 26 Oct). At each site, a minimum of six, six row areas were stripped and monitored for yield. Within each six row area, two rows were harvested at a time, so that a minimum of 18 2-row strips were obtained. Yield was collected at 1 sec intervals.

Aburto. This field consisted primarily of two soils, an Arch loam and Portales loam (0-1% slope), with 3% of the field in a Drake soil (1-3% slope) (Fig. 1). There were 10 locations per soil measured for height on 13 July, 2006 (30 total measurement points). These locations corresponded to nine, 10, and five measurements in the high, medium, and low vigor groups, respectively.

BAM. This field consisted primarily (91%) of an Amarillo loamy fine sand (0-1% slope, and 1-3% slope), with a small percentage of the field in three other soil types (Acuff loam, 1-3% slope; Arvana fine sandy loam, 0-1% slope; and Posey fine sandy loam, 1-3% slope) (Fig. 1). Plant height was measured in all five soils on 13 July, 2006 with the highest number of measurements (24) occurring in the Amarillo loamy fine sand with 1-3% slope. Plant height measurements were taken at 24, 25, and 20 locations in the high, medium, and low vigor groups, respectively.

Byrd. Plant height was taken on 12 July, 26 July, and 8 Aug in 2007. This field was predominantly a Portales loam (81%) with 0-1% slope, with an Acuff loam (0-1% slope) as the only other soil with at least 10% area (Fig. 2). There were 38 locations where plant height was measured, and there was at least 10 locations measured for height in each vigor group. Height measurements were predominantly located on the Portales loam (31 locations), with five locations on the Acuff loam, and one location each on the other two soils.

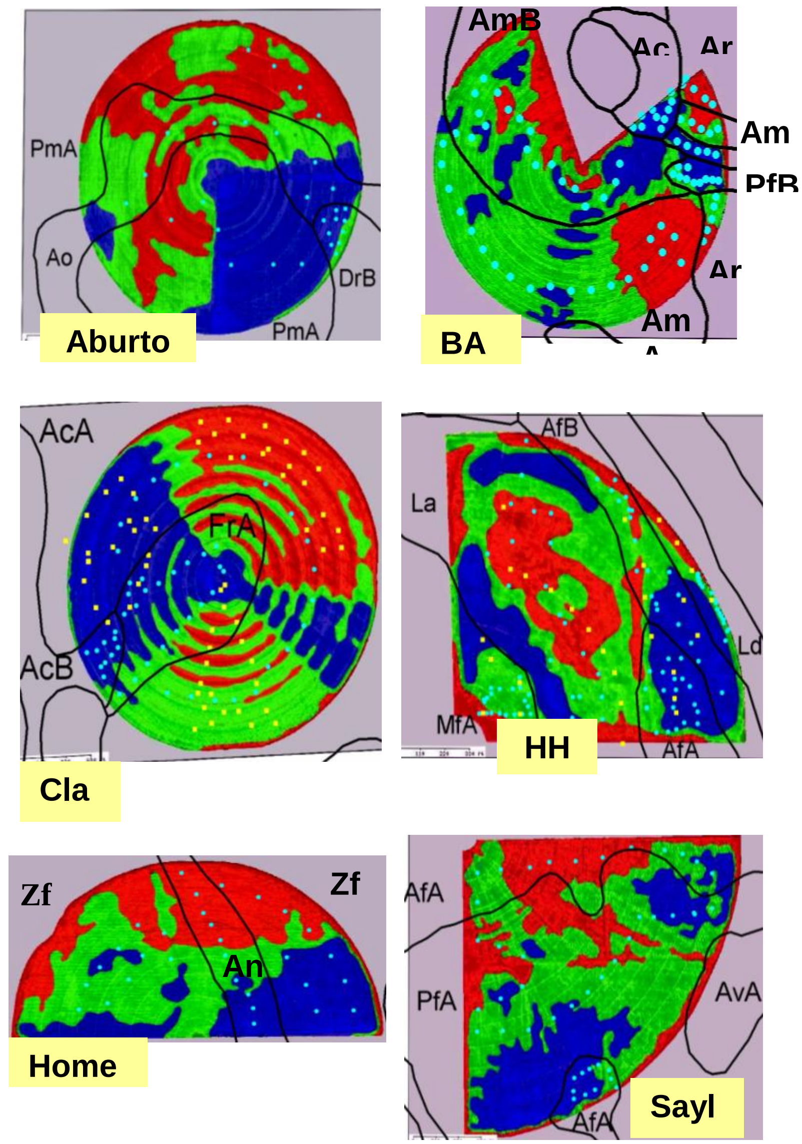

Figure 1. Vigor categories obtain from images taken on 17 July, 2006, which were group was colored green, and the lowest vigor group was red.

Soil classes included Arch loam (Ao), Drake soils with 1-3% slope (DrB), Portales loam with 0-1% slope (PmA), Acuff loam with 1-3% slope (AcB), Amarillo loamy fine sand with 0-1% slope (AmA), Amarillo loamy fine sandy with 1-3% slope (AmB), Arvana fine sandy loam with 0-1% slope (ArA), Posey fine sandy loam with 1-

3% slope (PfB), Friona loam with 0-1% slope (FrA), Amarillo fine sandy loam with 0-1% slope (AfA), Amarillo fine sandy loam with 1-3% slope (AfB), Bippus clay loam with 0-2% slope (Ld), Likes-Arch complex that is hummocky (La), Mansker fine sandy loam with 0-1% slope (MfA), Arch fine sandy loam (An), Zita fine sandy loam with 0-1% slope (ZfA), and Midessa fine sandy loam with 0-1% slope (PfA)

Clark. Plant height was measured on 13 July, 19 July, and 10 Aug, 2006. An Acuff loam was the predominant soil (78%), with some variation in slope (0-1% versus 1-3%), and 22% of the field in a Friona loam with 0-1% slope (Fig.1). On the first sampling date, 20 locations were measured on each of the Acuff loam with 0-1% slope and the Friona loam, and nine locations on the Acuff loam with 1-3% slope. On the second sampling date, 32 samples were taken on the Acuff loam with 0-1% slope, and three samples on the Friona loam. On the third sampling date, 47 samples were taken on the Acuff loam with 0-1% slope, one sample on the Acuff loam with 1-3% slope, and 10 samples on the Friona loam. Plant height measurements were taken at a minimum of nine locations in each vigor group for all three sampling times.

HH. There were five soils in this field, an Amarillo fine sandy loam (0-1% and 1-3% slope), Bippus clay loam with 0-2% slope, a Likes-Arch complex that is hummocky, and a Mansker fine sandy loam with 0-1% slope (Fig. 1). Plant height measurements were taken on 7 July and 10 Aug, 2006. Plant height measurements ranged from 18 to 20 locations for each soil type on 7 July, and 5 to 10 locations for each soil type on 10 August. Locations measured for height within vigor groups ranged from 21 to 52 on 7 July, and 7 to 9 on 10 August.

Herr. There were primarily two soils in this field, an Arvana fine sandy loam with 0-1% slope (38% area) and a Mansker fine sandy loam with 0-1% slope (56% area) (Fig. 2). A small portion of the field had a Zita fine sandy loam with 0-1% slope. Plant height measurements were taken on 11 July, 26 July, and 9 Aug, 2007. At least 11 locations were sampled for plant height in the two main soil types at each of the measurement times. Sampling locations in the high, medium, and low vigor groups consisted of 7, 15, and14 for the first sampling time; 5, 10, and 13 for the second sampling time; and 12, 11, and 13 for the third sampling time, respectively.

Home60. There were two soils in this field, an Arch fine sandy loam (17% area) and a Zita fine sandy loam, with 0-1% slope (83% area) (Fig. 1). Plant height was measured on 13 July, 2006 at 30 locations (10 in the Arch and 20 in the Zita fine sandy loam soils). Plant height was measured at 9 to 11 locations in each of the vigor groupings.

Saylor. This field had primarily two soils, an Amarillo fine sandy loam with 0-1% slope (24% area), and a Midessa fine sandy loam with 0-1% slope (75% area) (Fig. 1). On 13 July, plant height was measured at 23 locations in the Amarillo fine sandy loam and 20 locations in the Midessa fine sandy loam, and on 19 July, plant height was measured at nine locations in the Amarillo fine sandy loam and at 24 locations in the Midessa fine sandy loam. On 13 July, plant height measurements were taken at 10, 17, and 7 locations in the high, medium, and low vigor groups. On 19 July, plant height measurements were taken at 10, 15, and 10 locations in the high, medium, and low vigor groups.

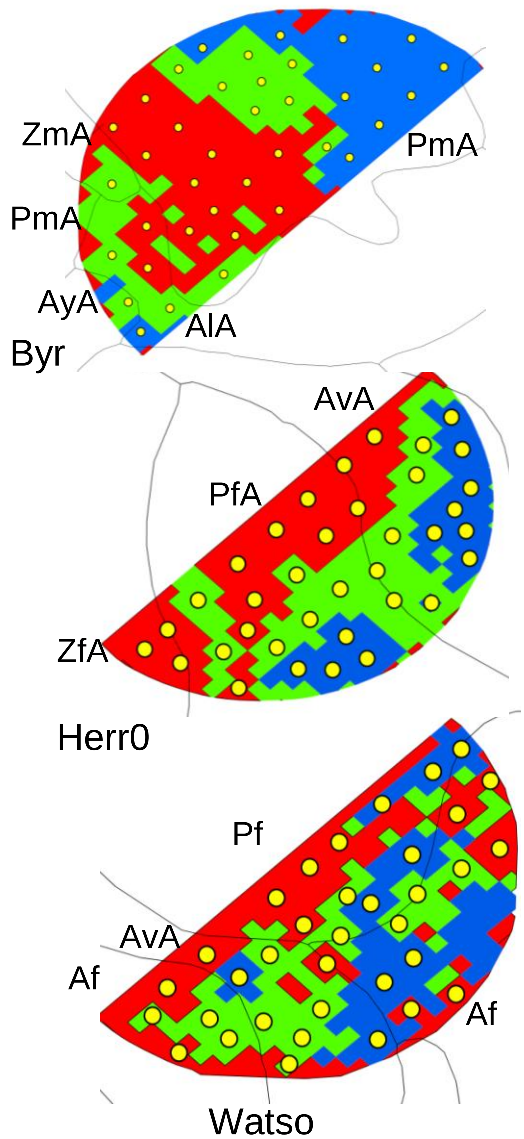

Figure 2. Vigor groups obtained from imagery taken on 16 July, 2007 and overlaid on soil maps.

The highest vigor group was colored blue, the intermediate vigor group was colored green, and the lowest vigor group was red. Soil classes included Acuff loam with 0-1% slope (AcA), Friona-Acuff loams with 0-1% slope (AyA), Portales loam with 0-1% slope (PmA), Zita loam with 0-1% slope (ZmA), Arvana fine sandy loam with 0-1% slope (AvA), Mansker fine sandy loam with 0-1% slope (MfA), Zita fine sandy loam with 0-1% slope (ZfA), Amarillo fine sandy loam with 0-1% slope, and Midessa fine sandy loam with 0-1% slope (PfA)

Watson. This field had three soil types, an Amarillo fine sandy loam with 0-1% slope (48% area), an Arvana fine sandy loam with 0-1% slope (22% area), and a Midessa fine sandy loam with 0-1% slope (30% area) (Fig. 2). Plant height measurements were taken on 11 and 26 July, and 9 August. Plant height measurements ranged from 9 to 17 locations for each of the soil types, and 12 to 13 locations for each vigor group at all measurement times.

Cochran's test of homogeneity was used to determine if variance was similar between vigor groupings, both on an individual field level and combined across all fields. Variances were not similar between vigor groupings at all levels tested (unequal number of samples, unequal variances). A T-test was used to compare vigor groupings to height and yield on all fields combined, and individual fields, and for vigor group comparisons from soil types within fields where all three vigor classifications were found for yield only. Comparisons between low versus moderate vigor, low versus high vigor and moderate versus high vigor were made, with $P \leq 0.05$.

RESULTS AND DISCUSSION

Plant Height Taken Close to Time of Images. In 2006, plant height was significantly different between vigor groupings across all six sites, with low, medium, and high vigor groupings averaging 37.6, 42.7, and 46.7 cm, respectively. In 2007, only the highest vigor grouping (27.7 cm) separated out from the other vigor groupings (24.4 and 25.1 for low and medium vigor groupings respectively). However, weather conditions were much cooler in 2007 compared to 2006, (Fig. 3) resulting in slower growth, shorter plants and smaller differences between fastest and slowest growing plants.

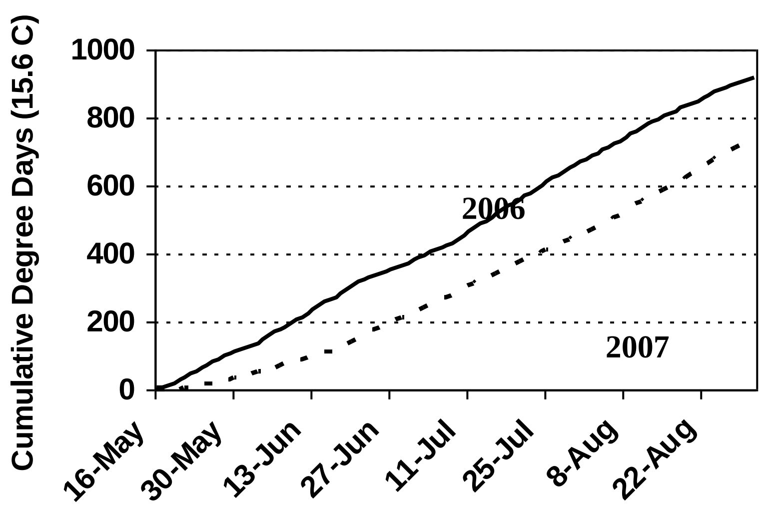

Figure 3. Degree days accumulated near the test locations during 2006 and 2007.

When comparing plant height for individual fields in 2006, all the sites but the Saylor field had at least some significant height differences between vigor groups with the tallest plants always associated with the better vigor groupings (Table 1). In 2007, the high vigor groupings had taller plants than the medium and low vigor groupings for the Byrd field (Table 1).

Relationship Between Imagery and Plant Height at Two to Five Weeks After Imagery Acquisition. In 2006 only two fields were monitored for plant height in late July and August, so these will be presented separately. At the Clark field, the high vigor grouping had significantly taller plants than the medium or low vigor grouping at all additional measurement times (Table 2). In the HH field, the high vigor grouping had significantly taller plants than the medium or low vigor grouping in August (Table 2). At the Saylor field, the high, medium and low vigor areas all had significantly different plant heights (Table 2).

In 2007, when the combined ratings for high, medium, and low vigor were examined for late July and mid August, the groupings were significantly different in each case, and positively related to vigor (47.0, 43.7, and 40.4 cm in late July, and 60.2, 56.9, and 51.8 cm in mid August, for high, medium, and low, respectively). For individual field vigor ratings in 2007, there were significant differences between plant height in the low and high vigor areas in late July and mid-August for all three fields (Table 2). However, in the Herr and Watson fields, the high and medium vigor areas had similar plant heights in late July. In mid-August, at the Herr field, the medium vigor area had taller plants than the high vigor area and at the Watson field, the medium and low vigor areas had similar plant height (Table 2). As time passed after imagery was taken, in general the vigor relationships, as defined by plant height, were accurate in most cases.

Relationship Between Vigor Groupings and Yield. In the combined analysis (five fields), yield was positively related to vigor grouping, with the low, medium, and high vigor grouping having significantly different ($P \leq 0.01$) yields (3777, 4174, and 4412 kg/ha, respectively). Yield in this case reflects the combination of lint, seed, and trash that was recorded by the yield monitor. For the individual field analysis, the Clark, HH, and Herr fields had yields that separated out into three significant groups that corresponded with the three vigor ratings (Table 3). The Byrd field separated into two groupings with the high and medium vigor grouping having similar and higher yields than the low vigor grouping (Table 3). The Watson field however was quite different than the other fields, where the low and medium vigor groupings had higher yields than the high vigor grouping (Table 3). Height measurements correlated fairly well with vigor groupings at this site, so it was surprising that the yields were poorer in the high vigor areas compared to other parts of the field.

Relationship Between Soil Types and Plant Height. Soils in this region are generally more productive when the calcic horizon is deeper. The $CaCO_3$ nodules that form in the calcic horizon are associated with poor root growth; however, they do not completely restrict root growth. There is also the existence of a petrocalcic horizon that can form in some soils, and this layer is so hard that it will almost completely restrict root growth. Soil series that have deep calcic horizons that were present in the test fields are Acuff (76-152 cm depth) and Amarillo (76 to 152 cm depth) (Soil Survey Staff, 2008). Soils that may have shallower calcic horizons include Zita (51 to 102 cm depth), Midessa (51 to 102 cm depth), Posey (30 to 58 cm depth), Mansker (15 to 51 cm depth), Arch (25 to 51 cm depth), Drake (25 to 102 cm depth), and Portales (13 to 38 cm depth) (Soil Survey Staff, 2008).

Table 1. Relationship between vigor grouping obtained by imagery[a] and plant height (cm) taken within one week of the imagery in 2006 and 2007.

		Vigor groupings		
Year	Field	Low	Medium	High
2006	Aburto	34.5 b[b]	37.1 ab	40.4 a
2006	Bam	34.8 c	37.3 b	41.4 a
2006	Clark	48.5 b	47.5 b	57.7 a
2006	HH	35.3 b	42.7 a	45.2 a
2006	Home60	28.7 b	38.6 a	37.6 a
2006	Saylor	50.8	52.3	52.1
2007	Byrd	22.1 b	22.4 b	25.1 a
2007	Herr	22.1	23.1	23.9
2007	Watson	30.0 ab	30.0 b	32.0 a

[a]Aerial imagery was obtained from Wilbur-Ellis (AgFleet version3.0, a part of ZedX Inc., Bellefonte, PA) on 17 July, 2006, and In Time Inc. (www.gointime.com) on 16 July in 2007. The vigor zone rating was determined from the company based entirely on their broad band, multispectral imagery.
[b]Different letters in a row indicate that means are significantly different based on a t-test at $P \leq 0.05$.

Table 2. The relationship between vigor groupings obtained from imagery[a] taken in mid July, and plant height (cm) taken in late July and mid August in 2006 and 2007.

		Plant height (late July)			Plant height (August)		
Year	Field	Low	Medium	High	Low	Medium	High
2006	Clark	51.6 b	46.7 b	67.3 a[b]	63.5 b	60.7 b	74.7 a
2006	HH				54.9 b	56.4 b	64.0 a
2006	Saylor	45.2 c	59.2 b	66.0 a			
2007	Byrd	38.1 c	40.6 b	45.5 a	49.0 c	54.6 b	61.7 a
2007	Herr	38.4 b	41.7 a	44.2 a	52.6 c	59.9 a	56.6 b
2007	Watson	45.2 b	47.8 ab	49.8 a	54.4 b	56.1 b	63.2 a

[a]Aerial imagery was obtained from Wilbur-Ellis (AgFleet version3.0, a part of ZedX Inc., Bellefonte, PA) on 17 July, 2006, and In Time Inc. (www.gointime.com) on 16 July in 2007. The vigor zone rating was determined from the company based entirely on their broad band, multispectral imagery.
[b]Different letters in a row and within a month indicate that means are significantly different based on a t-test at $P \leq 0.05$.

Soils in the test fields with the more impervious petrocalcic layer include Arvana (50 to 100 cm depth) and Friona (51 to 89 cm depth) (Soil Survey Staff, 2008). While $CaCO_3$ is not the only soil property involved with productivity of soils, it is an important one in this region. Soil moisture holding capacity, slopes, and location near to playa lake basins are also important properties.

Table 3. Relationship between vigor groupings obtained by imagery[a] and yield (kg/ha of seed + lint + trash) in five cotton fields.

		Vigor grouping		
Year	Field	Low	Medium	High
2006	Clark	4299 c	4696 b	4930 a[b]
2006	HH	4265 c	4598 b	5018 a
2007	Byrd	3601 b	3727 a	3730 a
2007	Herr	2420 c	3179 b	3335 a
2007	Watson	3632 a	3698 a	3530 b

[a]Aerial imagery was obtained from Wilbur-Ellis (AgFleet version3.0, a part of ZedX Inc., Bellefonte, PA) on 17 July, 2006, and In Time Inc. (www.gointime.com) on 16 July in 2007. The vigor zone rating was determined from the company based entirely on their broad band, multispectral imagery.
[b]Different letters in a row indicate that means are significantly different based on a t-test at $P \leq 0.05$.

There was no relationship between soil types and plant height in the Aburto, Byrd, Home60, and Watson fields (Table 4). In the Bam field at the first height evaluation, plants in the Acuff loam were taller than plants in the Amarillo loamy fine sand, Posey fine sandy loam and Arvana fine sandy loam (Table 4). At the Clark field and only during the evaluation in late July, plants in the Friona loam were taller than plants in the Acuff loam, which is surprising because the Acuff loam is considered much more productive than the Friona soil, which has a petrocalcic horizon. In the HH field during the first evaluation and in mid-August, plants in the Amarillo fine sandy loam with 0-1% slope were taller than plants in the Mansker fine sandy loam and Likes-Arch complex. Plants in the Bippus clay loam were initially similar in height to plants in the Amarillo fine sandy loam with 0-1% slope, but by August they averaged 8 cm shorter than plants in the Amarillo fine sandy loam. In the Herr field, plants were taller in the Arvana fine sandy loam compared with the Midessa fine sandy loam, but only when measured in late July, not in early July or August. In the Saylor field, plants were taller in the Midessa fine sandy loam compared with the Amarillo fine sandy loam in late July, but they were similar in height in early July. Overall, for a combination of 19 field/height measurement times, six had significantly different height measurements between soil types. When using imagery to compare height difference, 17 of the 19 field/height measurements had significant differences between vigor classes. So, plant height differences were captured more readily with imagery defined into vigor groupings than using soil types based on digitized soil maps. However, better vigor (taller plants) was not always associated with what would be predicted as the better soil type.

Relationship Among Soil Types, Yield, and Imagery. In the Byrd field, the highest yields were in the Zita loam (4144 kg/ha), followed by the Portales loam (3708 kg/ha), Acuff loam (3322 kg/ha), and Friona-Acuff loam soil (2974 kg/ha) (Table 5). These results were surprising because the Acuff loam would be considered a more productive soil for cotton than the Zita and Portales soils, which have a shallower calcic horizon. Within the Portales loam, which covered 81% of the field, the low vigor areas had lower yield (3611 kg/ha) than the medium (3751 kg/ha) or high vigor areas (3790 kg/ha) (Table

5). With imagery alone, the difference in average yield between the low and high vigor areas was 3.5%.

Table 4. Relationship between soil type[a] and plant height for nine fields.

			%	% Land	Plant height (cm) at		
Year	Field	Soil	Slope	area	Early July	Late July	August
2006	Aburto	Ah l		26	38		
2006	Aburto	Dr	1-3	3	38		
2006	Aburto	Pt l	0-1	71	38		
2006	Bam	Ac l	1-3	2	43 a[b]		
2006	Bam	Am lfs	0-1	47	38 b		
2006	Bam	Am lfs	1-3	44	38 b		
2006	Bam	Av fsl	0-1	<1	35 c		
2006	Bam	Po fsl	1-3	3	38 b		
2007	Byrd	Ac l	0-1	13	22	39	55
2007	Byrd	FA l	0-1	2			
2007	Byrd	Pt l	0-1	81	23	42	55
2007	Byrd	Z l	0-1	4			
2006	Clark	Ac l	0-1	75	50	55 b	66
2006	Clark	Ac l	1-3	3	54		
2006	Clark	F l	0-1	22	56	81 a	72
2006	HH	Am fsl	0-1	10	47 a		65 a
2006	HH	Am fsl	1-3	16	37 c		60 ab
2006	HH	B cl	0-2	5	46 ab		57 bc
2006	HH	LA		58	38 c		53 c
2006	HH	Ma fsl	0-1	11	41 b		58 b
2007	Herr	Av fsl	0-1	38	23	43 a	53
2007	Herr	Mi fsl	0-1	56	23	39 b	56
2007	Herr	Z fsl	0-1	6	23	39 ab	55
2006	Home60	Ah fsl		17	34		
2006	Home60	Z fsl	0-1	83	35		
2006	Saylor	Am fsl	0-1	24	51	48 b	
2006	Saylor	Mi fsl	0-1	75	53	60 a	
2007	Watson	Am fsl	0-1	48	31	48	56
2007	Watson	Av fsl	0-1	22	30	48	60
2007	Watson	Mi fsl	0-1	30	30	46	57

[a]Soil abbreviations were Ah = Arch, l=loam, Dr = Drake soils, Pt = Portales, Ac = Acuff, Am = Amarillo, lfs = loamy fine sand, Av = Arvana, fsl = fine sandy loam, Po = Posey, FA = Friona-Acuff, Z = Zita, F = Friona, B = Bippus, cl = clay loam, LA = Likes-Arch complex, hummocky, Ma = Mansker, Mi = Midessa.
[b]Different letters within a column and for the same field indicate that means are significantly different based on a t-test at $P \leq 0.05$.

With soil type, differences in average yield between the Zita loam and Friona-Acuff loam averaged 28.2%, though neither of these soils covered more than 4% of the field. The Portales loam (81% of the field) averaged 10.5% higher yield than the Acuff loam (13% of the field). No height differences were measured within these two soils. Plant height was not a good predictor of yield within this field. Variable rate management of this field might be more effective if soil types are utilized rather than vigor zones based on imagery.

With the Clark field, yield was similar for the Acuff loam with 0-1% slope (4663 kg/ha) and Friona loam (4640 kg/ha) compared with the Acuff loam with 1-3% slope (4030 kg/ha) (Table 5). Within both the Acuff loam with 0-1% slope and the Friona loam, yields separated well by vigor grouping (Table 5). The average difference in yield by soil type alone was 14% and image grouping differed by 13%, while differences when combining soil type and imagery vigor grouping were 10 to 14%. Management based on vigor groupings would allow for more variable rate applications than soil types, because 97% of the soils yielded similarly, yet within each soil type there was a range of yield. Plant height by soil type indicated large differences between the Acuff loam and Friona loam in late July, but no yield differences. Plant height was different based on vigor groupings, though still a poorer predictor of yield than vigor grouping. NDVI provided a good indicator of yield differences and could be used in a variable rate management program for this field. Soil type was not useful for variable rate management.

In the HH field, yield was different between soil types, with the highest yields associated with the Amarillo fine sandy loam (4838 and 4801 kg/ha for 0-1 and 1-3% slope), followed by the Bippus clay loam (4682 kg/ha), and with the lowest yields associated with the Likes-Arch and Mansker fine sandy loam soils (4573 and 4649 kg/ha, respectively). These differences are also what would be expected based on soil properties, where the Bippus soil does not have a calcic horizon, and the Amarillo soil has a very deep calcic horizon.

The Mansker and Arch soils can have very shallow calcic horizons. The maximum difference in yield between poorest and best yielding soil was 5.5%. Imagery combined with soil type did result in significant differences between vigor classes for all soil types (Table 5). The differences in yield within a soil type and between vigor classes ranged from approximately 11% for the Amarillo fine sandy loam with 0-1% slope and Bippus clay loam, to approximately 16% for the Amarillo fine sandy loam with 1-3% slope, Likes-Arch complex, and Mansker fine sandy loam. The average yield difference between low and high vigor groups was 15%. Vigor groupings based on imagery was a better predictor of yield differences than soil type. Plant height was a reasonable good predictor of yield in the different soil types as was plant height in image groupings to yield in image groupings.

Yields in the Herr field were highest in the Arvana fine sandy loam (3069 kg/ha), followed by the Midessa fine sandy loam (2922 kg/ha) and the Zita fine sandy loam (2076 kg/ha) had the lowest yields. The Arvana soil has a petrocalcic horizon, also referred to as an impervious calieche layer. However, the depth of the calieche layer may have been deep enough to allow for good root growth. The Zita fine sandy loam fell completely into the low vigor grouping. Within the Arvana fine sandy loam, yields were similar in the medium and high vigor group and better than the low vigor group. Within the Midessa fine sandy loam, yield was significantly and positively associated with vigor grouping. At this site more than any other in the test, there were large differences between soil types, where cotton in the Zita soil yielded 32% less than in the Arvana soil. Yield differences between low and high vigor groupings within a soil type differed by 27 to 35%. Height ratings based on soil types and vigor groupings were not particularly good predictors of yield differences. Vigor groupings alone or combined with soil types were useful in differentiating between high and low yielding areas of the field, and should be useful in a variable rate management system. However, because the differences in soils were not intuitive, based on their expected properties, it would be important to look at yield relationships over several years with a yield monitor, before using soil type for variable rate applications.

Table 5. Affect of soil type and vigor grouping[a] on yield for five cotton fields.

				Yield (lint + seed + trash) kg/ha			
			%	Image classification			
Year	Field	Soil[b]	Slope	Low	Medium	High	Average
2007	Byrd	Ac l	0-1	3261	3324	3452	3322 y
2007	Byrd	FA l	0-1		3362 a	2678 b	2974 z
2007	Byrd	Pt l	0-1	3611 b[c]	3752 a	3790 a	3708 x
2007	Byrd	Z l	0-1	3938 b	4475 a	3315 c	4144 w
2006	Clark	Ac l	0-1	4295 c	4726 b	5014 a	4663 y
2006	Clark	Ac l	3-Jan			4030	4030 z
2006	Clark	F l	0-1	4314 c	4606 b	4806 a	4640 y
2006	HH	Am fsl	0-1		4457 b	4979 a	4838 x
2006	HH	Am fsl	3-Jan	4202 c	4677 b	4973 a	4801 xy
2006	HH	B cl	0-2	4290 b	4787 a	4806 a	4682 yz
2006	HH	LA		4289 c	4538 b	5163 a	4573 z
2006	HH	Ma fsl	0-1	4072 b	4766 a	4832 a	4649 z
2007	Herr	Av fsl	0-1	2135 b	3217 a	3264 a	3069 x
2007	Herr	Mi fsl	0-1	2553 c	3153 b	3515 a	2922 y
2007	Herr	Z fsl	0-1	2076			2076 z
2007	Watson	Am fsl	0-1	3423 ab	3501 a	3328 b	3407 z
2007	Watson	Av fsl	0-1	3658 b	3962 a	4083 a	3893 x
2007	Watson	Mi fsl	0-1	3756	3724	3637	3718 y

[a]Aerial imagery was obtained from Wilbur-Ellis (AgFleet version3.0, a part of ZedX Inc., Bellefonte, PA) on 17 July, 2006, and In Time Inc. (www.gointime.com) on 16 July in 2007. The vigor zone rating was determined from the company based entirely on their broad band, multispectral imagery.

[b]Soil abbreviations were Ac = Acuff, l = loam, FA = Friona-Acuff, Pt = Portales, Z = Zita, F = Friona, Am = Amarillo, fsl = fine sandy loam, B = Bippus, cl = clay loam, LA = Likes-Arch complex, Ma = Mansker, Av = Arvana, Mi = Midessa.

[c]Different letters indicate that means are significantly different based on a t-test at $P \leq 0.05$. If the letters start with a, b, etc., then the comparisons are within a soil type for the three image classifications. If the letters end with z, then the comparisons are down a column and among the soil types that are present within a field.

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Yields in the Watson field were highest in the Arvana fine sandy loam (3893 kg/ha), followed by the Midessa fine sandy loam (3718 kg/ha), with the lowest yields associated with the Amarillo fine sandy loam (3407 kg/ha) (Table 5). It is unusual to have higher yields associated with an Arvana fine sandy loam than an Amarillo fine sandy loam, since the calcic horizon would be deep in the Amarillo soil. Amarillo soils are among the most productive for this growing region. Vigor groups at this site were misleading, with the highest vigor group having the lowest yield. When vigor group was examined within soil type, there was no relationship between vigor and yield in the Midessa fine sandy loam. However, the high and medium vigor groups associated with the Arvana fine sandy loam did have higher yields (4083 and 3962 kg/ha) than the low vigor group (3658 kg/ha). With the Amarillo fine sandy loam, the high vigor group had the lowest yield (3328 kg/ha), and the medium vigor group had the highest yield (3501 kg/ha) with the low vigor group intermediate (3423 kg/ha) (Table 5). These results are so unusual, that there may have been some other significant factor that occurred at this site, and affected the Amarillo soil more than the other soil types. Cotton in the different soils had up to 12.5% yield differences while yield associated with the vigor groups were misleading and only averaged a maximum difference of 4.5%. Imagery based vigor groups were not useful for management decisions at this site, though it is questionable whether soil differences would be consistent over years.

Imagery taken in mid-July was used to differentiate each field into three vigor classifications. At the time that this project began, the choice of how many zones a field should be broken into was dictated to the end user. However, In Time Inc. now offers a service that selects the appropriate number of zones based on the variability within the image, called Vari-Scout Plus™ (www.gointime.com/ProductsScout.jsp). This would address one of the problems identified in this project, namely that three vigor zones were not necessarily appropriate for each field. In general, vigor zones were more closely associated with yield differences than plant height. Soil types were associated with significant yield differences in the Byrd and Watson fields, while vigor zones based on imagery were better indicators of yield potential in the Clark and HH fields. In the Herr field there were significant yield differences using both vigor groupings and soil type. In the three sites where yield differences were significant and of large magnitude between soil types, there was poor agreement between what would be considered the best soils and the highest yields. In many of the sites, the soils that were deep and basically free of a calcic horizon, the yields were lower than in soils that had very shallow calcic horizons. This makes it difficult to use soil type without years of monitoring yield in different soils for each site. The vigor classifications did not require any prior knowledge of the field, but vigor grouping was not reliable across all the sites tested. Producers should evaluate the technology on a case-by-case basis before making variable rate applications. Plant height was not necessarily a reliable method to identify vigor zones, so the use of a yield monitor rather than imagery may be the best method of identifying consistent vigor zones that require variable rate applications.

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