On-farm evaluation of boron response in corn

Year 3 (Final) Report: AFREC PO 18947, PO 22923, PO 27027

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2016-2018 Research Summary Points

- Hot water extractable soil test boron was correlated to soil organic matter concentration.
- When applied, B almost always increased the concentration of B in the upmost fully developed corn leaf sampled at V10.
- Corn grain yield was increased by B at 5 locations and decreased yield at 3 locations. However, the differences with and without B are likely attributed to spatial variation in yield due to variation in soil chemical and physical properties within a field. To use commercial equipment for research with large strips, need to be established which make it difficult to find completely uniform areas of fields for research. Care should be taken when interpreting strip trial data to account for spatial variation in the field and ensure differences in yield are attributed to treatments and not how the treatment strips are randomized in the field.
- Soil test or V10 corn leaf tissue B showed a general correlation with corn yield but could not be used to predict where B responses would occur in a field.
- There was no correlation between soil and plant tissue B concentration.
- Sugarbeet leaf blade B concentration was seldom impacted by the application of B while tonnage and recoverable sugar were not increased by B when applied on a fine textured soil with organic matter concentration greater than 4.0% in the top six inches.

Implications for management – The data suggests that there should be little concern that B is limiting the yield of corn and sugarbeet across Minnesota. Soil tests for B were relatively low at a few irrigated corn locations but yield responses could not be tied to a specific concentration or B in the soil (a critical level could not be determined). More research is being conducted to determine if there is a concentration of B in the soil where a response to B in corn would occur. Care should be taken when interpreting soil and plant tissue test results as critical levels have not been established for either test based on yield response data. The data suggests that soil tests as low as 0.08 ppm and tissue tests as low as 4 ppm should provide adequate B to maximize corn grain yield.

Introduction

Reports of low boron concentrations in corn plant tissue have been common in recent years. There are no established guidelines for boron application for corn in Minnesota. With higher crop yield farmers are continually being marketed boron as a way to further increase yield. Plant analysis has become an increasingly larger tool used to promote the sales of boron. Critical plant tissue sufficiency levels can be easily manipulated to ensure B concentration are considered "low". Research identifying crop response as related to soil test and plant tissue boron concentration is needed to identify whether there is a direct correlation to crop yield response to the given variables. On-farm research can be useful for correlation studies to gauge the impacts of fertilizer management across varying soil properties within and across fields.

The specific objectives are to:

1. Scale up research from small plots to on-farm replicated large plots.
2. Develop and establish field and data protocols for on-farm research using boron as a test variable to evaluate corn tissue and grain yield response to boron application.
3. Use an on-farm program to validate current and new nutrient application guidelines and management suggestions (particularly for boron).

Materials and Methods

Field strips (60, 66, or 90' in width) consisting of no boron and 2-3 lbs of boron (applied as a 15% B product) per acre broadcast pre-plant or after planting on the soil surface were established in six corn fields across Minnesota in 2016, 2017, and 2018 (Table 1). Boron was applied using a calibrated spinner spreader mounted on the back of an ATV. Individual strips were 1200' long at each site and were large enough to encompass variation in soil properties or elevation at each location. Three locations were irrigated and the concentration of boron in the irrigation water is summarized in Table 2. Soil and plant samples were collected in June when the majority of corn in each field was at the V10 growth stages. Soil samples were collected to a depth of 0-6" from non-fertilized strips with one composite sample (10 cores) sampled every 120 feet along the strips. Each composite sample was analyzed for organic matter concentration and hot water extractable boron. Plant tissue samples were collected from applied and non-applied strips at the same intervals soil samples were collected and tested for boron concentration.

Yield data was collected using a combine equipped with a yield monitor. Yield data for each sampling area was calculated using the center one or two passes with the combine. Individual yield data points within 20' of the start and end of each sampling area were buffered and removed. The remaining points were used to generate an average yield for the center of each of the ten sampling areas within a strip. Yield surface maps were generated using the center one or two passes from each strip prior to buffering the data.

Table 1. Summary of soil test (0-6”) values for 30 individual soil samples collected in June from check strips without boron applied for eighteen study locations conducted from 2016 to 2018.

						B		
Year	Location	P	K	pH	OM	Avg.	Min.	Max.
		------ppm-----			---%---	------------ppm------------		
2016	Cannon Falls	39	260	5.5	2.6	0.28	0.09	0.43
	Clarkfield	11	158	6.8	4.8	1.09	0.50	2.33
	Hastings	43	233	5.8	2.6	0.30	0.09	0.52
	Rice	22	161	6.0	1.3	0.19	0.11	0.33
	Stewart	22	168	6.9	5.6	0.92	0.11	1.32
	Waseca	18	144	6.3	5.6	0.97	0.70	1.45
2017	Benson	17	137	6.6	4.3	0.99	0.32	1.51
	Cannon Falls N	37	259	6.2	3.2	0.38	0.10	0.60
	Cannon Falls S	26	260	5.6	3.6	0.41	0.21	0.78
	Clarks Grove	12	132	5.5	5.8	0.80	0.37	1.32
	Rice	24	150	6.3	1.7	0.24	0.16	0.45
	Stewart	17	161	6.6	6.8	1.15	0.83	1.71
2018	Benson	29	168	6.3	3.9	0.89	0.32	1.43
	Cannon Falls	50	305	5.7	3.5	0.43	0.29	0.81
	Danvers	25	108	6.5	2.5	0.59	0.26	1.51
	Farmington	18	191	5.7	3.5	0.41	0.26	0.52
	Rice	16	123	6.1	1.7	0.15	0.10	0.26
	Stewart	17	166	6.8	5.2	0.94	0.34	1.64

P, Olsen soil test P; K, ammonium acetate K; OM, soil organic matter by loss on ignition; B, average (Avg.), minimum (Min.), and maximum (Max.) hot water extractable soil boron concentration.

Table 2. Summary of boron concentration in irrigation water applied for studies conducted from 2016 to 2018.

Year	Location	Water B Concentration
		oz B/ac per inch of water applied
2016	Cannon Falls	<0.07†
	Hastings	<0.07†
	Rice	<0.07†
2017	Cannon Falls N	<0.07†
	Cannon Falls S	<0.07†
	Rice	<0.07†
2018	Cannon Falls	<0.07†
	Danvers	0.39
	Rice	<0.07†

† Concentration values were below the detection limit of the ICP (0.02 ppm).

The percentage of yield produced by the non-fertilized strip will be correlated to soil and plant tissue tests to determine if there is any correlation between yield and the soil and plant tissue. If the boron is being taken up by the corn plant the applied strip will allow us to gauge whether the sufficiency levels used are too high or too low which is critical since plant tissue tests are being used to promote the use of boron even though small plot research trials have not shown a positive yield response.

Table 3 Summary of soil test data collected in 2016, 2017, and 2018 from sugarbeet trials prior to treatment application. Samples were collected from the 0-6" and are a composite of 12 separate cores per location.

Year	Location	Soil Type	Soil Test†				B‡
			P	K	pH	OM	Avg
			--ppm--			-%-	---ppm---
2016	Clara City	Bearden	10	150	7.8	6.4	1.5
2017	Clara City	Bearden	15	316	7.8	7.9	1.1
	Crookston	Wheatville	12	194	7.9	4.4	0.7
	Redwood Falls	Havelock	39	544	7.7	6.7	1.5
2018	Clara City	Bearden	15	189	7.7	6.6	2.1
	Crookston	Wheatville	11	91	8.1	2.9	0.8
	Redwood Falls	Amiret	20	198	5.6	4.1	0.7

† P, Olsen phosphorus; K, ammonium acetate extractable potassium; pH, soil pH; OM, organic matter.

Sugarbeet trials were conducted from 2016 to 2018 (Table 3). The sugarbeet research differed from the corn trials in that traditional small plot trials were used as the technology was not available to measure yield and quality on a large scale basis. Boron rates of 0, 2, 4, and 6 lbs B per acre were hand applied on the soil surface after planting to plots measuring 11' in width (6 rows 22" wide) and 40' in length. Each treatment was replicated six times. A single composite soil sample was collected at a depth of 0-6" before fertilizer application. Boron concentration in the leaf blade was measured from each plot by sampling the newest fully developed leaf in early July.

Results and Discussion – Corn Trials

A summary of the mean, minimum, and maximum boron (B) soil test (hot water extractable) from the surface 0-6" for corn locations is located in Table 1. Locations were selected to contain a significant range in the boron soil test values. The sandy sites (Cannon Falls, Danvers, Hastings, and Rice) contained less B than the rain-fed soils which contained a greater concentration of organic matter. The sandy sites tended to have less variation between the minimum and maximum soil test boron concentration values. Figure 1 shows the relationship between the hot-water extractable B concentration in the soil and soil organic matter. There was a clear relationship between the two variables but the best fit curve was not linear indicating that the increase in soil B is not the same per every increase in soil organic matter concentration. The data did indicate some potential differences between the sandy irrigated sites and the rain-fed sites. In general, the relationship between soil organic matter and soil test B was more linear and the points followed closer to the best fit line for the irrigated locations while there was more scatter in the data for the rain-fed sites. The exception for the irrigated sites was the Danvers location which had higher STB concentrations which deviated and were general greater than the best fit line. The only difference between Danvers and the remaining irrigated sites was the amount of B in the irrigation water which was detectable at Danvers compared to the remaining irrigated locations where the concentration of B was under the detection limit for the ICP used to analyze the water samples (Table 2).

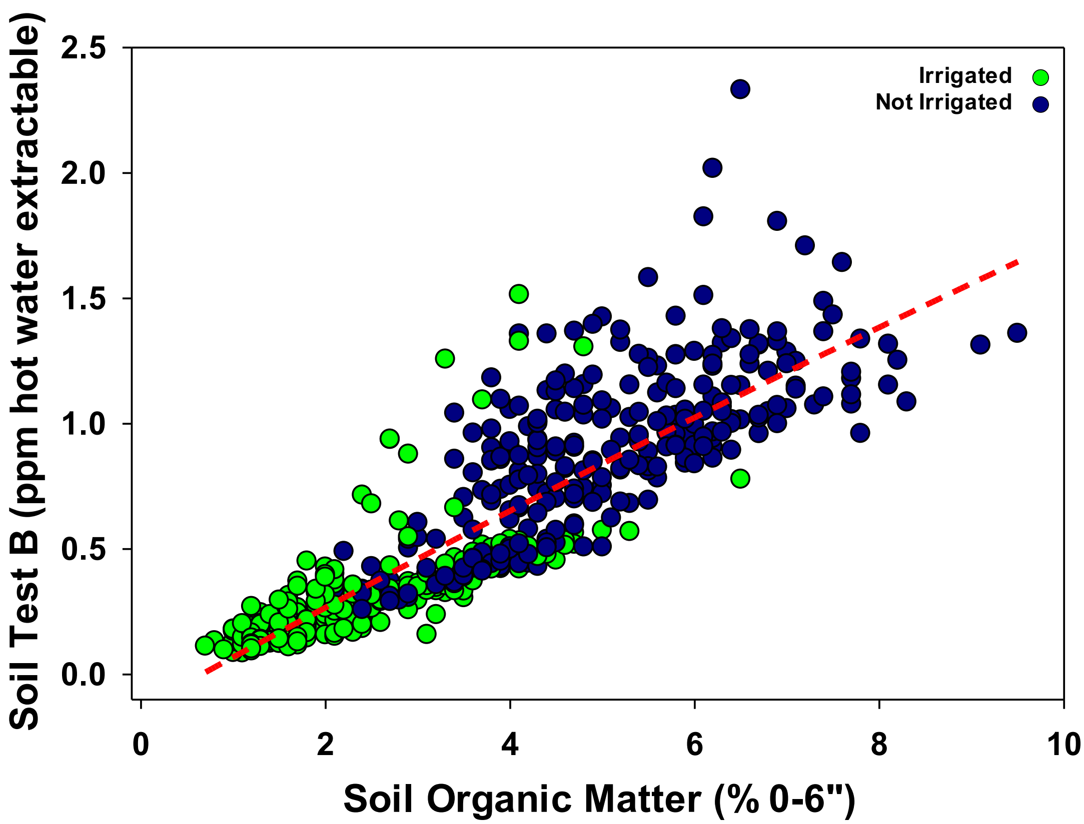

Figure 1. A summary of the relationship between the hot-water extractable B soil test and soil organic matter. Each circle represents an individual sampling point at each location. The dashed line represents the best fit curve for the combined data.

There was more noise in the data collected from rain-fed locations which could represent variation in soils and the ability of soil to release and retain B. Soil moisture measurements were determined for the soils collected at sampling but did not explain the greater variation in soil B relative to organic matter for the rain-fed locations. Release of B in the soil can be related to soil moisture. In the case of the rain-fed sites, there may be some effect that soil texture has on retention of soil test B which may be a result of the grater deviation from the best fit line. It is clear that there is a relationship between soil organic matter concentration and soil test boron and increasing soil organic matter concentration should decrease the potential for a yield response to B to occur.

Table 4 summarizes the increase in corn leaf tissue B at V10. Leaf tissue samples were collected in order to determine if the B applied was solubilized and was available to the corn plant. Across individual locations for 2016, corn leaf B concentration was increased at five of the six locations. Leaf tissue B was not directly related to soil test B measured at the time the leaf samples were taken (data not shown). The increase in leaf B concentration following application of B was greatest in the sandy irrigated locations. In the case of the location at Rice, MN, the average concentration of B for the control (no B applied) was greater than the other locations. Past research has shown that hybrids can vary in the concentration of nutrients among similar leaf tissue measured. Hybrid variation would explain the majority of the variation B concentration not matching with soil test B concentration.

Table 4. Summary of effect of the application of 2 lbs of B per acre on the boron concentration of the upper most fully developed corn leaf collected at V10. Data are summarized for three replications in each field. Effects are considered significant when $P \leq 0.05$.

Year	Location	No B	With B	Significance
		------------------ppm B	------------------	*P*>F
2016	Cannon Falls	6.0b	10.4a	<0.001
	Clarkfield	10.2b	11.7a	0.03
	Hastings	7.0b	14.1a	<0.001
	Rice	10.4b	18.7a	<0.001
	Stewart	8.6b	9.1a	<0.001
	Waseca	7.8	9.8	0.41
2017	Benson	12.5b	20.5a	<0.001
	Cannon Falls N	6.1b	9.1a	<0.001
	Cannon Falls S	6.1b	8.4a	<0.001
	Clarks Grove	5.8b	9.4a	<0.001
	Rice	6.0b	17.0a	<0.001
	Stewart	11.5b	15.1a	<0.001
2018	Benson	5.5b	20.2a	<0.001
	Cannon Falls	4.1b	7.8a	<0.001
	Danvers	6.6b	31.2a	<0.001
	Farmington	3.4b	7.4a	<0.001
	Rice	4.1b	14.0a	<0.001
	Stewart	4.8b	8.5a	<0.001

Leaf tissue B concentration was increased when B was applied at all of the 2017 and 2018 locations (Table 4). Field which had the lowest organic matter concentration in the top six inches tended to have less B in the plant tissue when boron was or was not applied. In 2017, the greatest increase in B concentration was at Danvers followed by Benson. If we assume 4 ppm is a sufficient B concentration in the leaf tissue all sits should have had an adequate supply of B. In 2018, the greatest increase in B concentration was at Rice followed by Benson. If we assume 4 ppm is a sufficient B concentration in the leaf tissue all sits should have had an adequate supply of B except for the Farmington location in 2018.

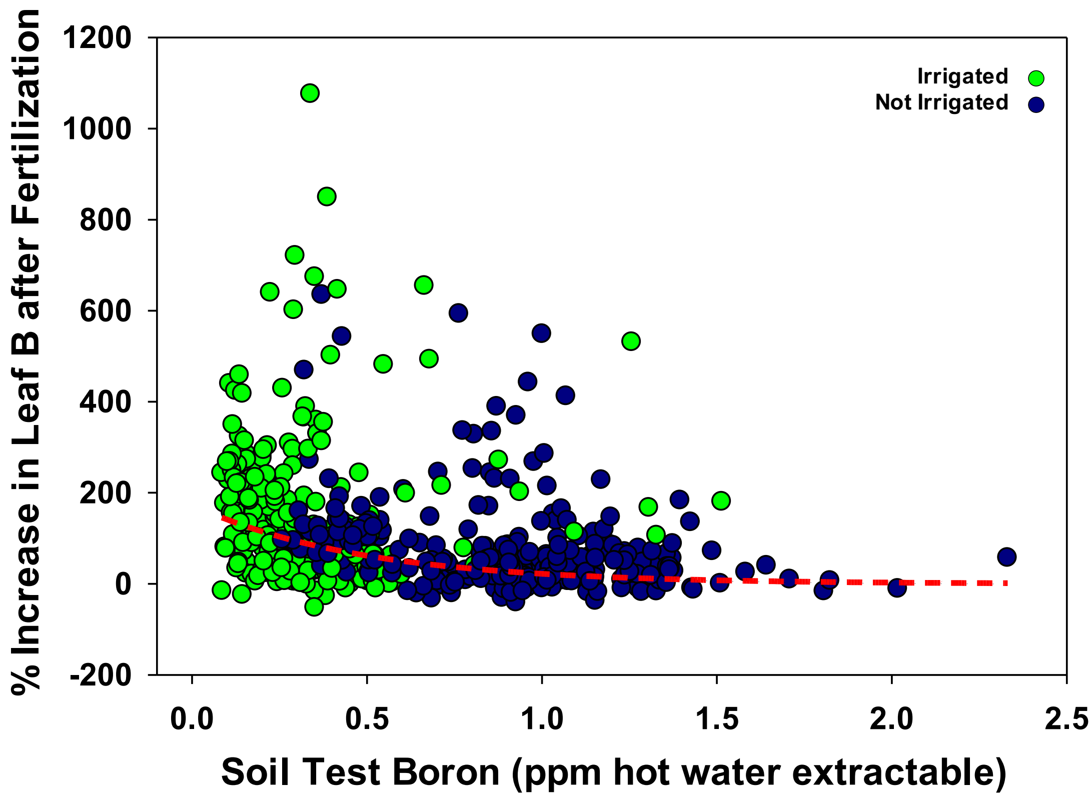

Figure 2. A summary of the relationship between the hot-water extractable B soil test and the percent increase in plant tissue B concentration when 2 lbs of B was applied. Each circle represents an individual sampling point at each location. The dashed line represents the best fit curve for the combined data.

While there was no direct relationship between soil test B and plant tissue B, the relative increase in plant B concentration did appear to be related to soil test B (Figure 2). There was always a general increase in the concentration of B regardless of the B soil test concentration. Data for individual sampling points is summarized for each location in the Appendix in Figures 7-24. The increase in corn leaf tissue B was relatively constant when the soil test was near 1.0 ppm. The greatest increases in tissue B concentration occurred when soil test B concentration was 0.25 ppm or less. This increase could be indicative of a situation where B in less available and the plant will readily take up more B. Born content of the irrigation water was measured at all locations but the total amount applied was non-detectable at eight of the nine irrigated locations (Table 2). The small quantity of B in the irrigation water would indicate that, if deficient in the soil, B applied through irrigation may not be sufficient to cover the need of a high yielding corn crop.

Table 5. Summary of effect of the application of 2 lbs of B per acre on corn grain yield (reported at 15.5% moisture). Data are summarized for three replications in each field. Effects are considered significant when $P \leq 0.05$.

Year	Location	No B	With B	Significance
		------------------bu/ac------------------		*P*>F
2016	Cannon Falls	222b	225a	0.05
	Clarkfield	236a	229b	0.05
	Hastings	238	240	0.50
	Rice	225	224	0.30
	Stewart	183	189	0.20
	Waseca	237	239	0.59
2017	Benson	244	245	0.33
	Cannon Falls N		*	
	Cannon Falls S		*	
	Clarks Grove	205b	209a	0.02
	Rice	245	246	0.40
	Stewart	215	212	0.36
2018	Benson	217	214	0.09
	Cannon Falls	259b	263a	0.03
	Danvers	193	192	0.72
	Farmington	203a	197b	0.04
	Rice	212a	209b	<0.01
	Stewart	192	195	0.14

The average corn grain yield for strips with and without B is summarized in Table 5. Yield significantly differed when boron was applied at two of the six locations in 2016. Corn grain yield was 3 bu/ac greater on average in strips which received boron while yield as 7 bu/ac less in strips where boron was applied at Clarkfield.

In 2017, yield statistically differed at three of the six locations when boron was applied. Data for two of the locations, Cannon Falls N and S, were omitted from Table 5 as the average differences were large, but yield maps shown in Figures 14 and 15 clear spatial patterns in yield follow topographical differences and variation among soil map units which may have resulted in yield differences due to specific strips lining up on higher yielding areas. Plots at Cannon Falls were laid out such that strips for the applied treatments encompassed more of the higher yielding areas so we could not determine if the yield increases were a sole result of treatments or were related to variation in soil and landscape position. Yield means for the individual replicates are summarized in Table 6B. Yield was greater for the strips with B applied for two of three replications but was less for the third. It is likely that all yield effects which occur are mostly related to soil differences in the plot and not the treatments. This point illustrates issues with strip trial data and type I errors in research. Soil series, elevation, and spatial X and Y coordinates were considered in the analysis of the data and all showed to be significant at the two Cannon Falls locations as well as Clarks Grove indicating significant spatial structure to the data.

Corn grain yield differed at three of the six locations in 2018 (Table 5). Boron appeared to increase grain yield at Cannon Falls and decrease yield at Farmington and Rice. Similar to 2018, analysis of covariates such as elevation and slope did indicate some correlation in yield with soil specific factors. Therefore, some of the differences again may be a result of how the strips fit over higher or lower yielding areas of the field. Further analysis is needed to clean some of the spatial variation in yield due to soil factors to get a better estimate of yield effect from boron.

At this time there is no overwhelming evidence that boron was required at any of the field locations in to achieve maximum corn grain yield. Figure 3 summarizes leaf B concentration and corn grain yield summarized for irrigated and non-irrigated location. Leaf B concentration was affected regardless of irrigation. Corn grain yield was not impacted by boron regardless whther the site was irrigated or rain-fed. The two locations from Cannon Falls which the yield was not summarized in Table 5 was not included in the yield averages. If included the two sites would result in the analysis indicating a significant impact of B on corn yield. While yield was significantly different at two locations according to the statistical analysis, additional data does not support an increase in yield across locations. If yield would be impacted it would be more likely to encounter differences for sandy irrigated soils. Further analysis of the data may help determine specific soil conditions necessary to increase the potential for a corn yield response to B.

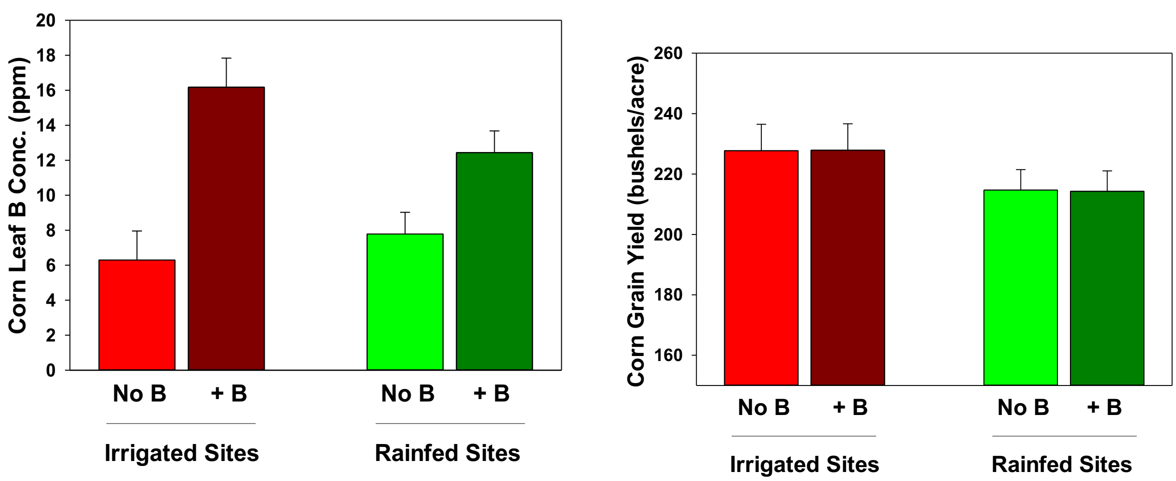

Figure 3. Summary of leaf B concentration and grain yield averaged across nine irrigated and nine rainfed locations in Minnesota conducted from 2016 to 2018 for treatments with and without boron applied.

Figure 4 summarizes corn grain yield response versus the soil B concentration tested at V10. There was a clear clustering of data points for the sandy irrigated locations versus the rain-fed sites due to greater soil B concentration for the rain-fed sites. There was greater variation in yield with the majority of points plus or minus 20% from the average for the rain-fed sites compared to plus or minus 10% for irrigated sites. What the data indicates is that the B soil test does not predict where yield responses will occur and it is more likely that the majority of the differences in yield between treatments with or without B were due to soil moisture and not due to a limitation of B to the corn crop. Since the relative yield average was 100% regardless of soil test B, the data indicate that a yield response is unlikely even when soil B concentration was near 0.1 ppm. It should be noted that the regression model was significant indicated a very weak relationship between soil test B and relative corn grain yield. However, the model indicated that variation in soil test B could predict less than 5% of the variation in yield. This indicates that there is more a coincidence that both are related and does not prove variations in soil test B would explain variation in yield. If a critical level needed to be identified from the data, it would be more likely that a yield response would occur when soil test B is 0.4 ppm or less. However, there would likely be only a 25% chance or less that a response would occur when soil test B is less than 0.4 ppm assuming there was no significant effect for when relative yield was 95% or greater.

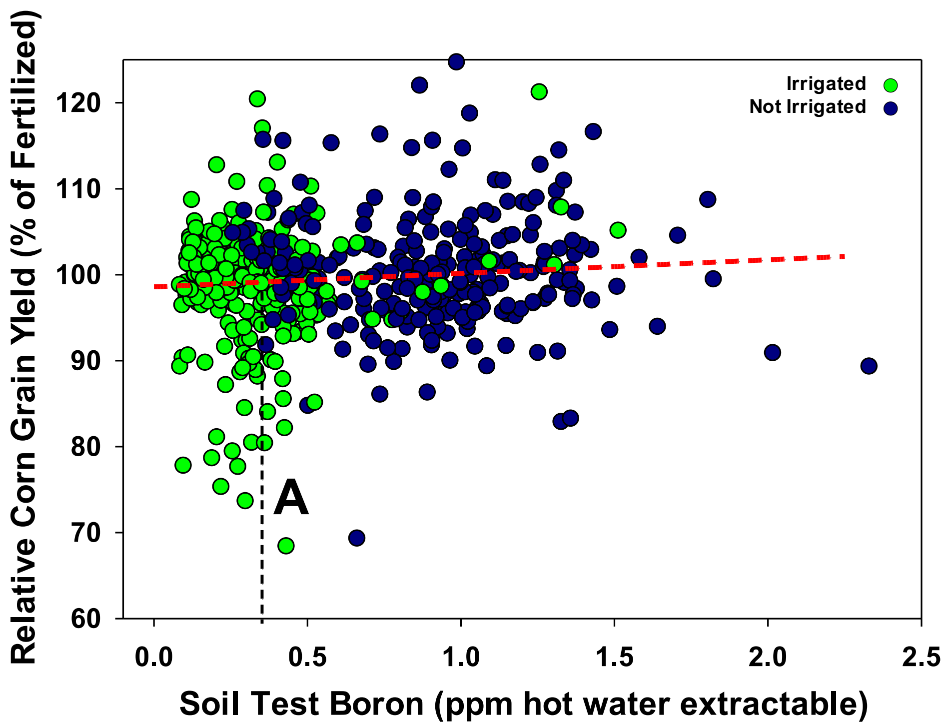

Figure 4. A summary of the relationship between the hot-water extractable B soil test and the percentage yield produced by the no B control compared to the adjacent strip where B was applied. Each circle represents an individual sampling area each location. The horizontal red dashed line represents the best fit curve for the combined data which includes 2016-2018 locations. Vertical dashed lines represent general critical level based on (A) eyeballed fit.

Similar to the B soil test, the B concentration in the plant tissue was not a good predictor of yield response. Similar to soil test B, there was a general relationship where yield increased with increasing leaf B concentration. The ability to predict yield based on a model developed between leaf B and yield was poor with an R^2 value less than 0.05. I would hesitate to use a plateau value from the relationship for a critical level as it does not appear likely that yield would be decreased when B is limiting as the relationship between yield and leaf B was more of a cloud of points versus the relationship between soil B and yield. The lowest concentration of B in the plant tissue were near 4 ppm so all I can say at this time with this data that yield should not be limited by B if leaf tissue B concentration is 4 ppm or greater.

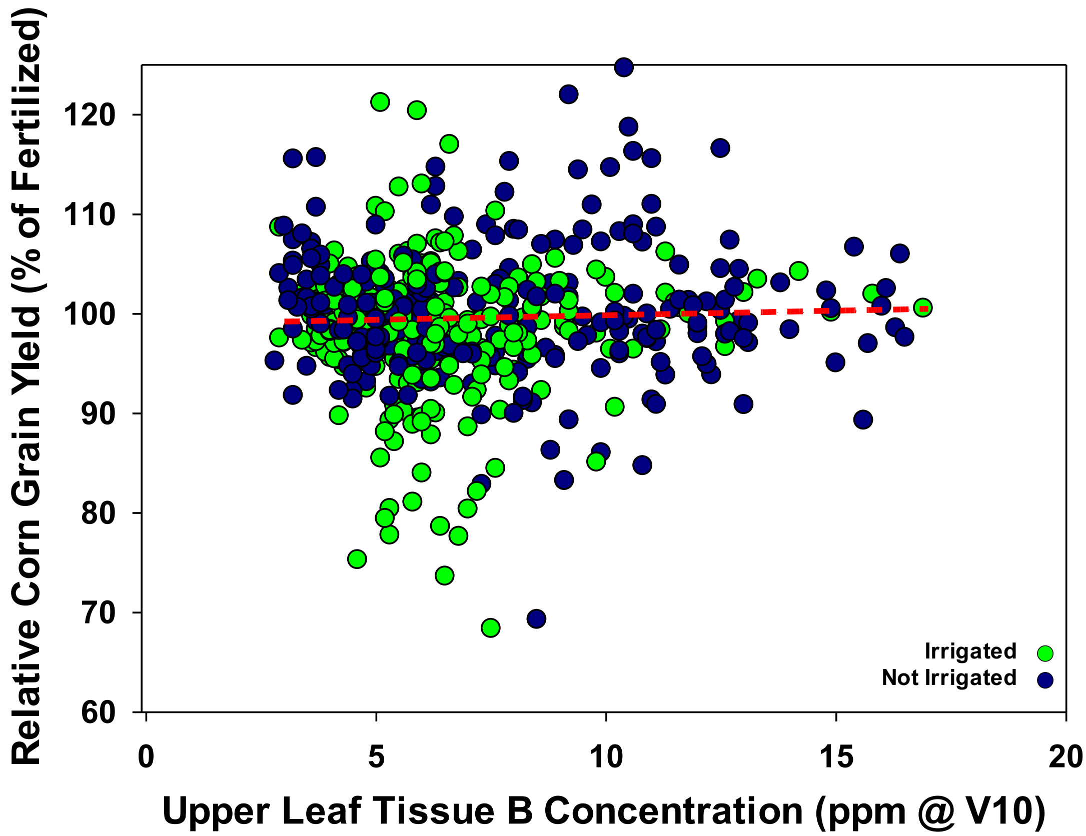

Figure 5. A summary of the relationship between corn upper leaf B concentration at V10 and the percentage yield produced by the no B control compared to the adjacent strip where B was applied. Each circle represents an individual sampling area each location. The dashed line represents the best fit curve for the combined data.

It was previously stated that it is doubtful that the significant yield effects may be due explicitly to the application of B. Table 6a and 6b summarize the mean yield for each strip for each replication at all locations. In the case of the sites were a response was determined (Cannon Falls and Clarkfield), Average yield for two of the three replications were almost identical but yield for the strip with boron in one of the replications was much greater than another at Cannon Falls and was less at Clarkfield. If a treatment has no effect on yield it does not mean that the yield of the strip with will yield the same as the strip without B applied. In that case it is unlikely that yield will be the same due to the size of the strips and variation in soil across the plot. It would be expected that the chance that the yield of one of the strips was greater than another is the same as they are exactly the same. Examination of the data by replication is important in strip trials to determine if one of the replications is skewing the results of the study.

Table 6a. Average yield summarized for each strip at each 2016 location summarized by replication number and strips with (+B) and without (-B) boron applied.							
		Location					
Replication	Treatment	Cannon Falls	Clarkfield	Hastings	Rice	Stewart	Waseca
	------------------------------bushels per acre------------------------------						
1	-B	220	244	243	227	190	237
	+B	220	225	238	227	180	226
2	-B	225	231	235	226	179	239
	+B	227	232	237	222	201	250
3	-B	220	235	236	223	182	235
	+B	227	229	244	222	187	240

Table 6b. Average yield summarized for each strip at each 2017 location summarized by replication number and strips with (+B) and without (-B) boron applied.							
		Location					
Replication	Treatment	Benson	Cannon Falls N	Cannon Falls S	Clarks Grove	Rice	Stewart
	------------------------------bushels per acre------------------------------						
1	-B	245	235	241	205	246	211
	+B	251	261	274	209	244	218
2	-B	240	225	252	204	248	225
	+B	243	235	246	210	246	208
3	-B	246	226	251	204	244	210
	+B	243	245	270	208	244	210

Table 6c. Average yield summarized for each strip at each 2018 location summarized by replication number and strips with (+B) and without (-B) boron applied.							
		Location					
Replication	Treatment	Benson	Cannon Falls	Danvers	Farmington	Rice	Stewart
	------------------------------bushels per acre------------------------------						
1	-B	214	258	201	201	216	185
	+B	214	260	192	195	212	191
2	-B	221	262	191	208	212	196
	+B	215	264	191	201	210	197
3	-B	214	260	184	199	207	195
	+B	215	265	190	192	204	198

Yield maps for the individual sites are included in the Appendix as Figures 7 through 24. It is likely that the yield differences determined with the statistical analysis were due to yield variations due to soil properties which followed replications. For Cannon Falls, Figure 6, a spatial patter due soil differences was not completely evident. The yield difference at Cannon Falls was due to the large difference in yield for the applied strip in the third replication. Three was a high spot in the field near plot 1006 and a low spot near 106 where yield was less which may have resulted in the large difference in yield between the two strips in the third replication at Cannon Falls. At Clarkield the decrease in yield was due to the large difference in yield between the two strips in the first replication. It is easier to see patters in yield due to soil series differences at Clarkfield (Figure 8). While the data indicates and effect soil spatial variation needs to be taken into effect. The majority of evidence currently suggests no effect of B on corn grain yield regardless of soil or plant tissue test.

Results and Discussion – Sugarbeet Trial

Unlike corn, sugarbeet is considered to be more sensitive to a deficiency of B. A majority of sugarbeet acreage is grown on fine textured soils with organic matter concentrations substantial enough where B should be supplied in adequate quantities. A field study was conducted on a soil with a potential to supply a high concentration of B for the crop. The data in Table 7 shows that there was no effect of B on sugarbeet leaf blade B concentration measured in early July in 2016 and 2017 while all sites showed an increase in leaf blade B concentration in 2018. The lack of an increase in leaf B would be a good indicator of sufficient B availability from the soil in 2016 and 2017. The 2018 growing season was relatively wet (not shown) but there was no indication why leaf blade B concentration would be more responsive to B application in 2018 versus earlier growing season.

Table 7. Summary of boron leaf tissue data collected from a sugarbeet boron field study near Clara City, MN conducted in 2016 where 0, 2, 4 or 6 of B was applied after planting. Variables are considered significant at $P \leq 0.05$.

Year	Location	0	2	4	6	Significance
		------------------%B------------------				*P*>F
2016	Clara City	36.1	35.4	33.2	37.1	0.17
2017	Clara City	23.6	23.5	23.4	24.4	0.44
	Crookston	36.0	35.2	37.1	36.2	0.72
	Redwood Falls	29.2	30.5	31.2	30.5	0.42
2018	Clara City	33b	33b	34b	37a	<0.001
	Crookston	33c	36bc	40b	52a	<0.001
	Redwood Falls	37c	45bc	50b	62a	<0.001

Root yield data are summarized in Table 8. The only difference in sugarbeet root yield occurred at Clara City in 2017 where yield was less for the 6 lb B rate versus 0, 2, or 4 lbs B per acre. Yield decreases due to B have occurred for soybean in Minnesota but it was assumed sugarbeet would be more tolerant of high soil B than soybean. Yield levels varied from around 14 to 39 tons and there was no greater impact of B on high or low yielding situations. Yield was relatively low at Crookston due to a hail event which occurred in the middle of the summer followed by dry weather conditions. Yield data was not collected at the Redwood Falls site in 2018 due to flooding. Crop stand was significantly reduced at Redwood Falls in 2018 to a point which the site was abandoned. Recoverable sucrose was not impacted by the application of B at any location (Table 9).

Table 8. Summary of root yield data collected from a sugarbeet boron field study near Clara City, MN conducted in 2016 where 0, 2, 4 or 6 of B was applied after planting. Variables are considered significant at $P \leq 0.05$.

Year	Location	0	2	4	6	Significance
		------------------ tons per acre ------------------				*P*>F
2016	Clara City	24.6	26.8	25.6	26.4	0.21
2017	Clara City	39.3a	38.2ab	39.6a	37.5b	0.04
	Crookston	24.0	24.4	25.1	25.1	0.37
	Redwood Falls	35.9	36.8	36.9	36.6	0.90
2018	Clara City	21.0	18.0	18.9	19.2	0.22
	Crookston	14.6	15.7	14.0	14.8	0.47
	Redwood Falls	**Site not harvested				

Table 9. Summary of recoverable sugar data collected from a sugarbeet boron field study near Clara City, MN conducted in 2016 where 0, 2, 4 or 6 of B was applied after planting. Variables are considered significant at $P \leq 0.05$.

Year	Location	0	2	4	6	Significance
		------------------ lb per ton ------------------				*P*>F
2016	Clara City	266.6	265.0	264.7	270.6	0.32
2017	Clara City	287.9	288.6	286.6	289.1	0.90
	Crookston	347.3	344.4	346.2	341.3	0.89
	Redwood Falls	303.8	304.2	307.8	305.5	0.68
2018	Clara City	249.0	246.6	246.9	244.1	0.87
	Crookston	332.5	326.4	322.1	328.2	0.58
	Redwood Falls	**Site not harvested				

Preliminary Conclusions

Data was inconclusive as to the benefits of B for corn production in Minnesota. Boron decreased yield at three locations and increased yield at five. However, the use of the B soil or plant tissue test taken at V10 indicated the neither predicted where a yield response would occur, nor was is supported that yield was less as either the soil test or plant tissue B concentration decreased. Boron measured in the soil is correlated to soil organic matter. Thus, soils with low organic matter are more likely to be low in B but yield increases may not be likely even with a B soil test of 0.1 ppm. If boron would be deficient it is more likely that a deficiency would occur in a sandy soil. Irrigation water will not likely supply enough B for corn therefore is the supply of B from the soil would be related to organic matter concentration which is more likely to be low for sandy soils. Data also showed that sugarbeet is unlikely to respond to the application of B when grown on higher organic matter soils. Boron may be deficient and may need to be applied for sugarbeet on sandy soils. However, sugarbeet response in sandy soils was not evaluated in this trial.

Acknowledgments

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APPENDIX – Figures

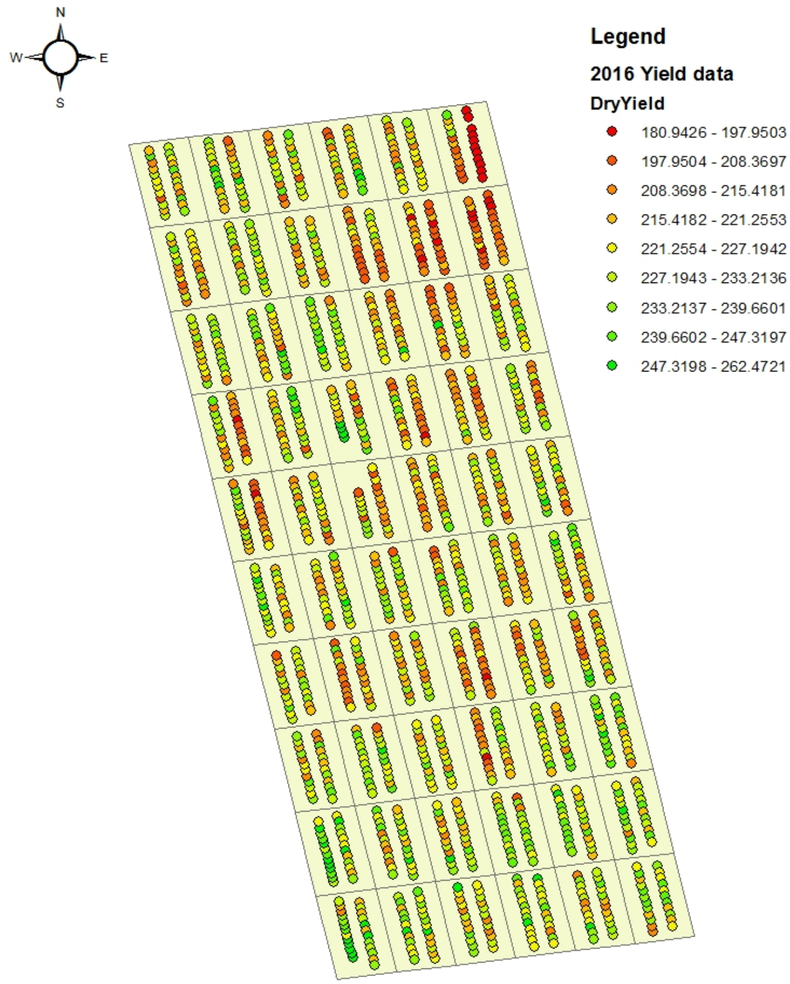

Figure 6. Example of cleaned data after buffering which was used to generate yield averages for the individual 120' sections within a field. The example shown is data collected at Rice, MN in 2016.

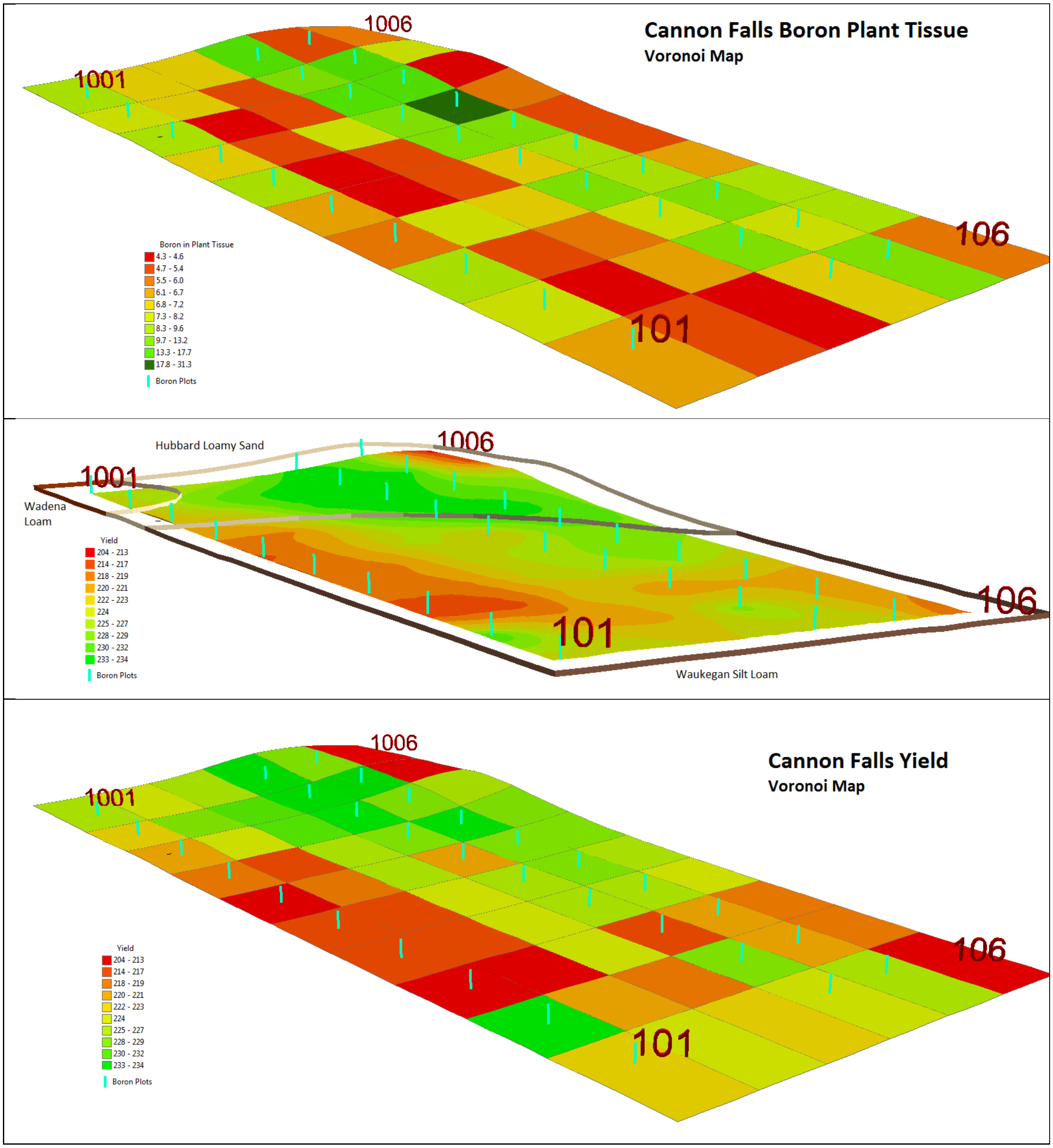

Figure 7. Surface maps generated for corn upper leaf B concentration at V10 and corn grain yield for the location at Cannon Falls, MN in 2016. Field areas marked with vertical blue bars indicate the strips where B was applied at 2 lbs per acre. Plot 101 was the NE corner of the plot.

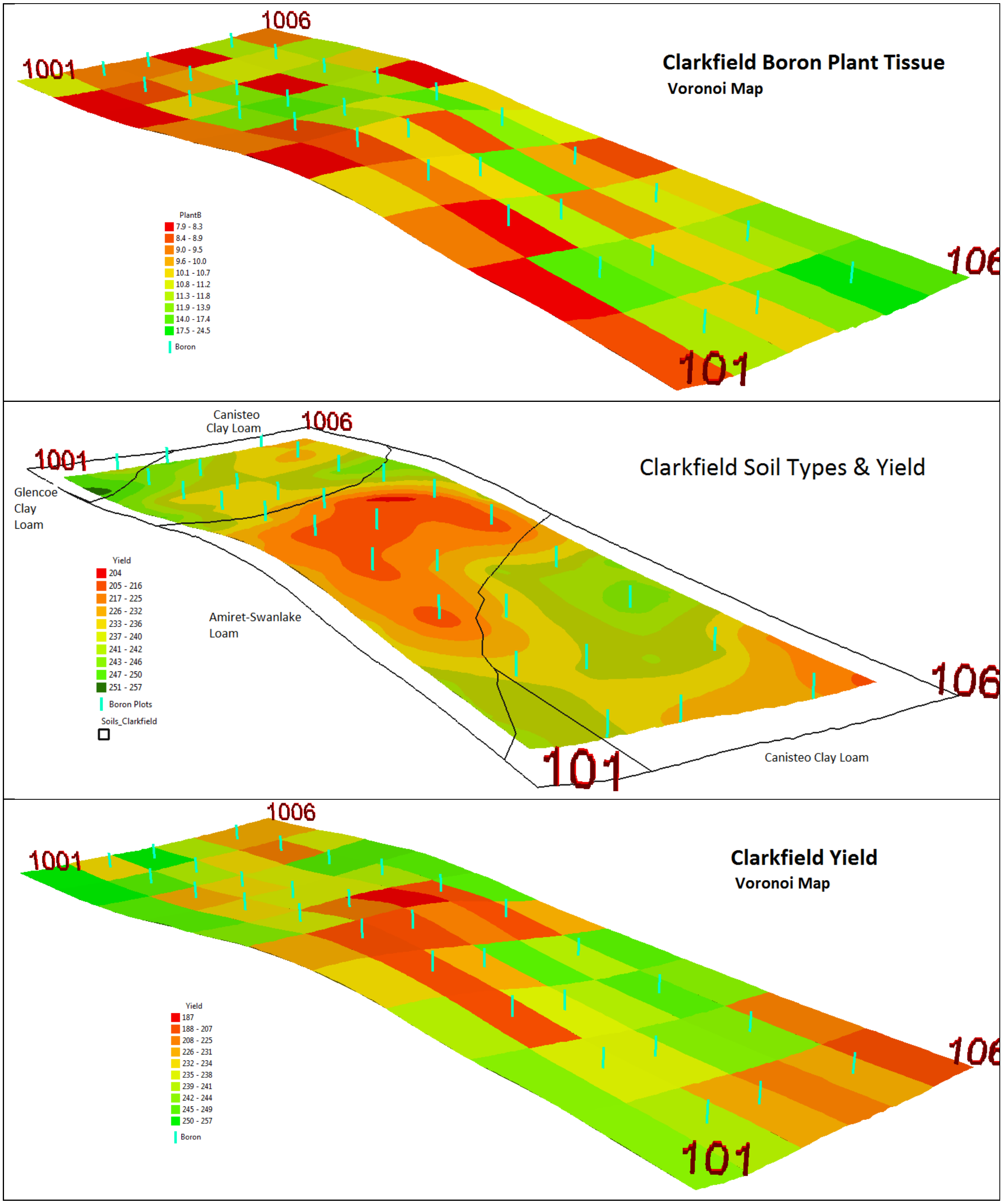

Figure 8. Surface maps generated for corn upper leaf B concentration at V10 and corn grain yield for the location at Clarkfield, MN in 2016. Field areas marked with vertical blue bars indicate the strips where B was applied at 2 lbs per acre. Plot 101 was the NE corner of the plot.

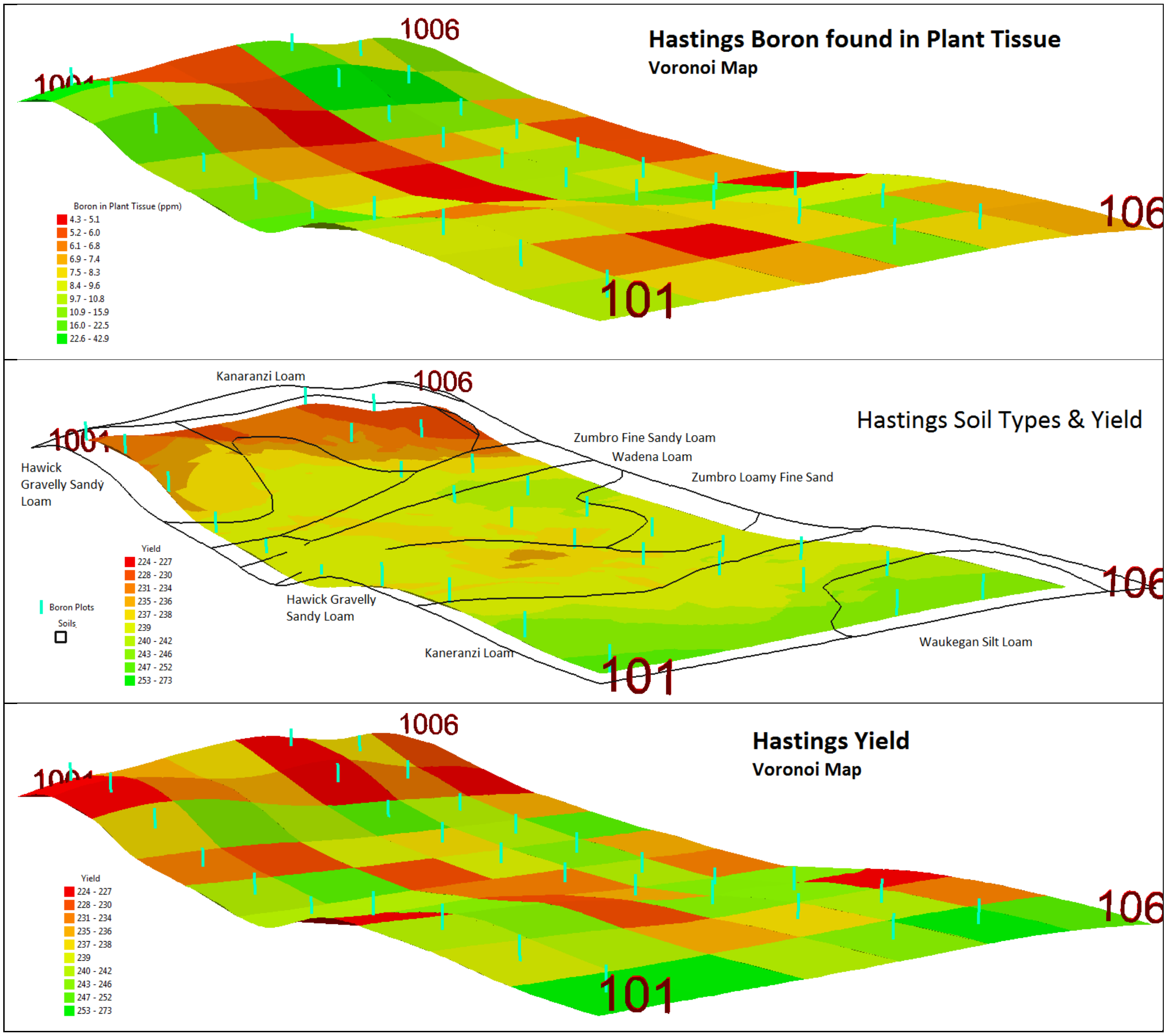

Figure 9. Surface maps generated for corn upper leaf B concentration at V10 and corn grain yield for the location at Hastings, MN in 2016. Field areas marked with vertical blue bars indicate the strips where B was applied at 2 lbs per acre. Plot 101 was the SW corner of the plot.

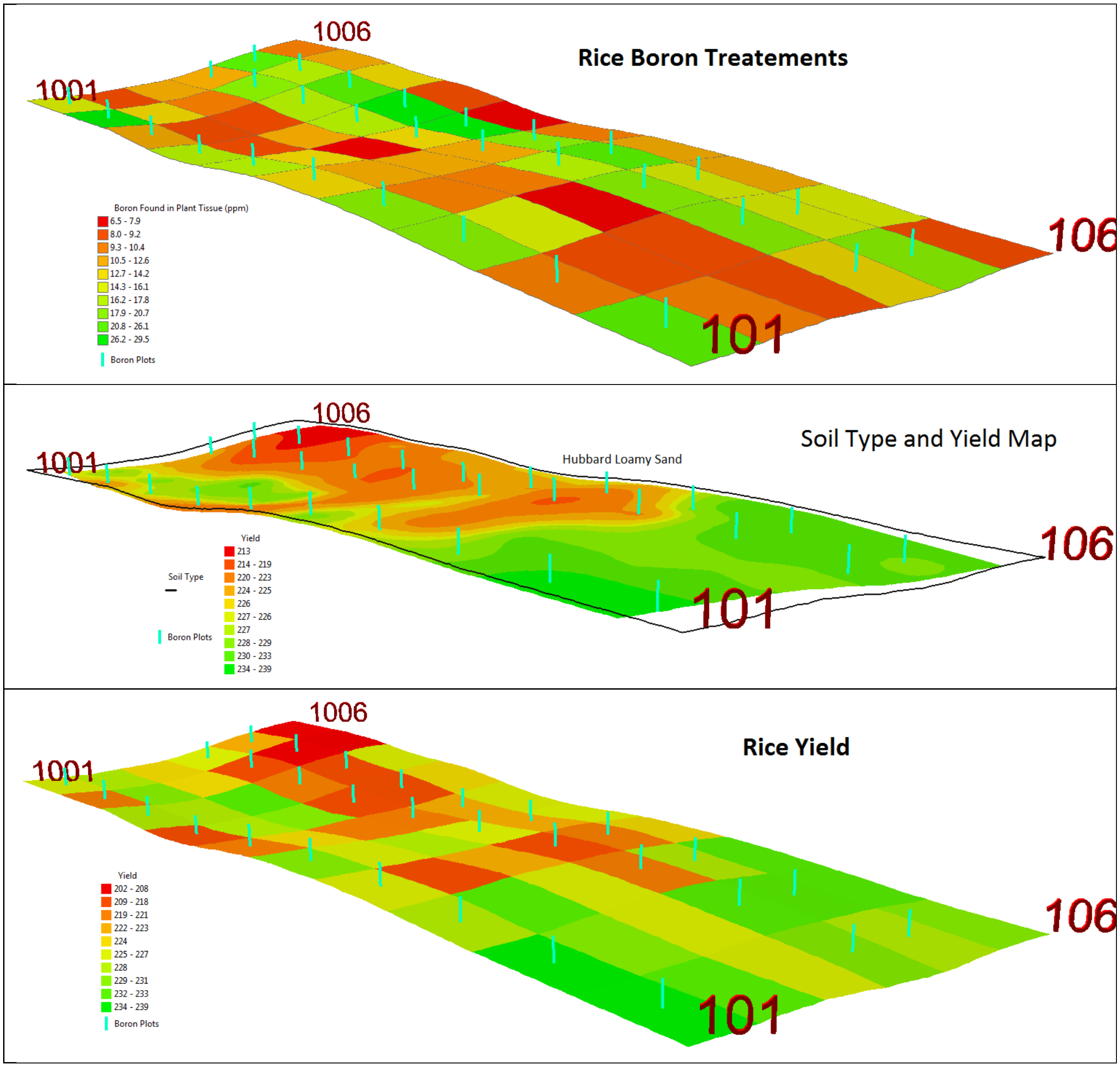

Figure 10. Surface maps generated for corn upper leaf B concentration at V10 and corn grain yield for the location at Rice, MN in 2016. Field areas marked with vertical blue bars indicate the strips where B was applied at 2 lbs per acre. Plot 101 was the SW corner of the plot.

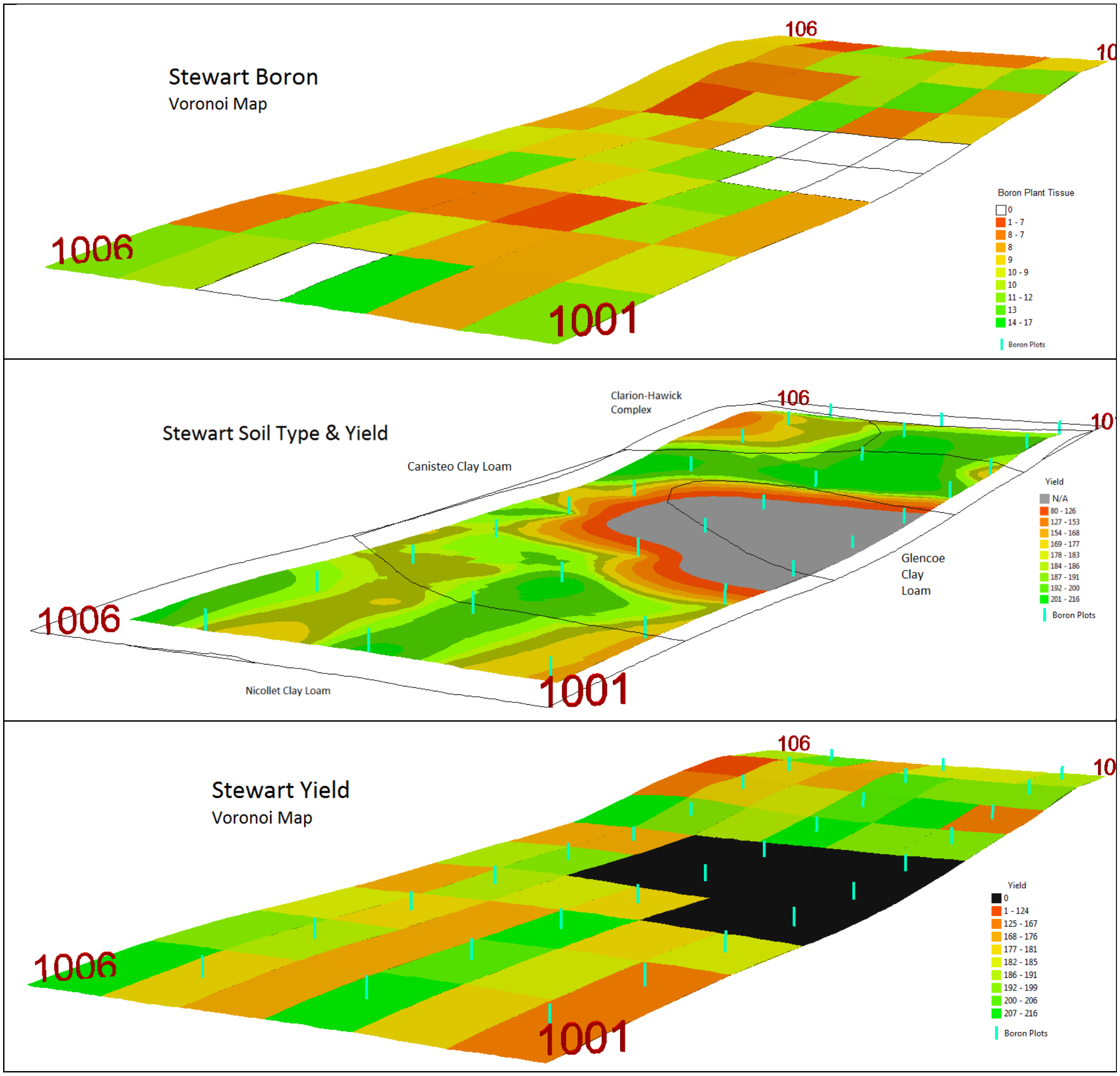

Figure 11. Surface maps generated for corn upper leaf B concentration at V10 and corn grain yield for the location at Stewart, MN in 2016. Field areas marked with vertical blue bars indicate the strips where B was applied at 2 lbs per acre. Plot 101 was the NW corner of the plot. Black or gray areas are where corn was drowned out due to excessive rainfall.

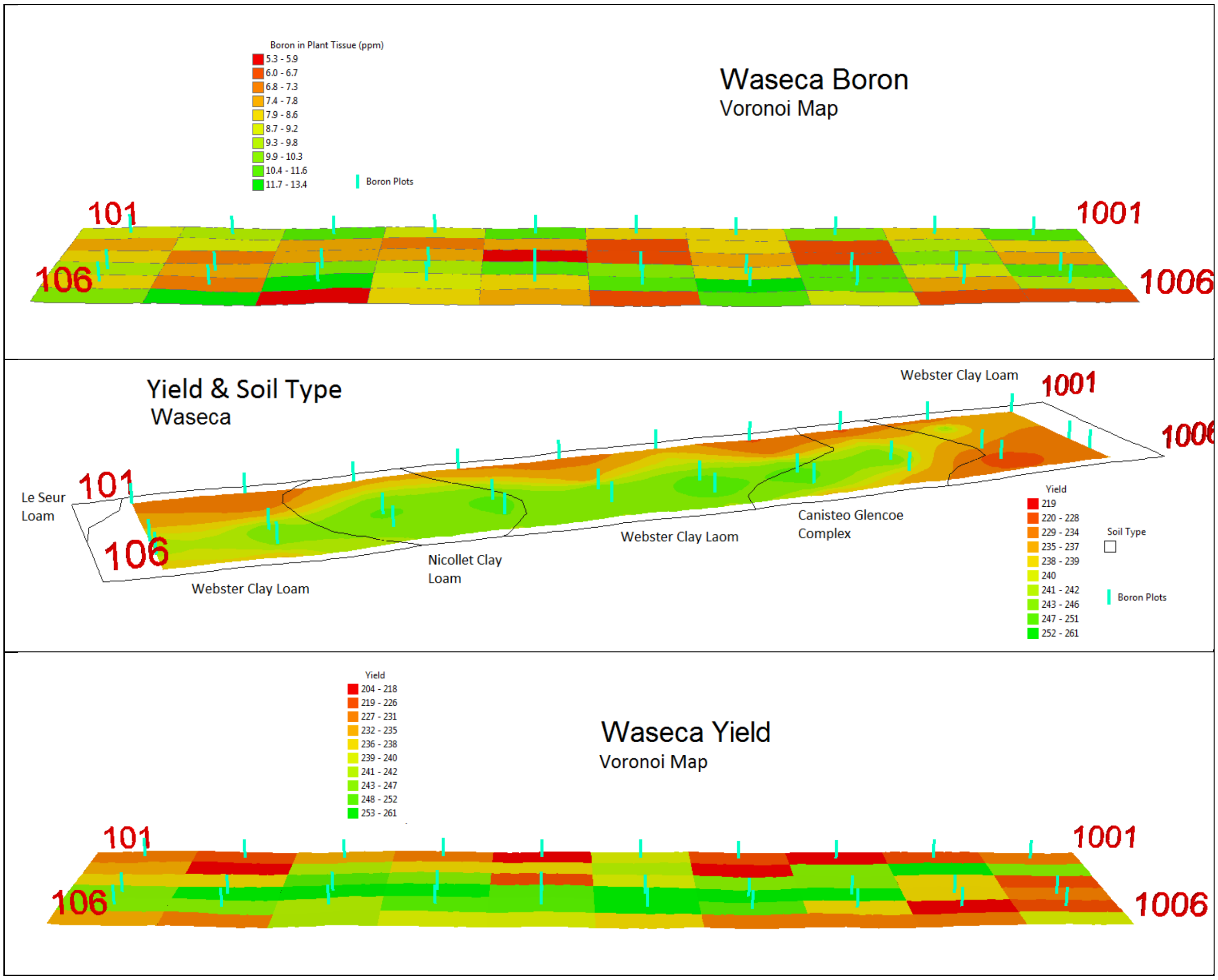

Figure 12. Surface maps generated for corn upper leaf B concentration at V10 and corn grain yield for the location at Waseca, MN in 2016. Field areas marked with vertical blue bars indicate the strips where B was applied at 2 lbs per acre. Plot 101 was the SE corner of the plot.

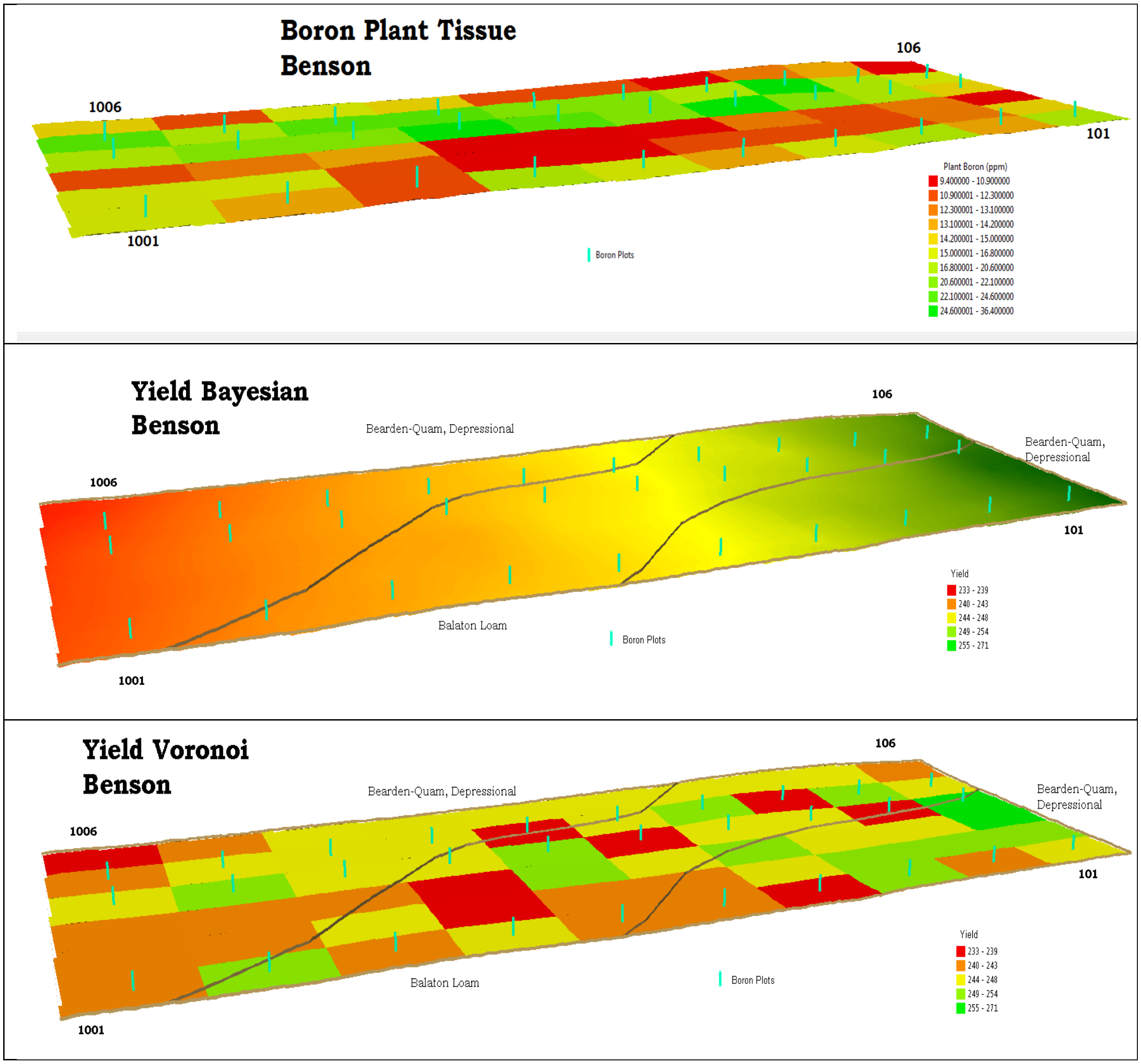

Figure 13. Surface maps generated for corn upper leaf B concentration at V10 and corn grain yield for the location at Benson, MN in 2017. Field areas marked with vertical blue bars indicate the strips where B was applied at 2 lbs per acre. Plot 101 was the SW corner of the plot.

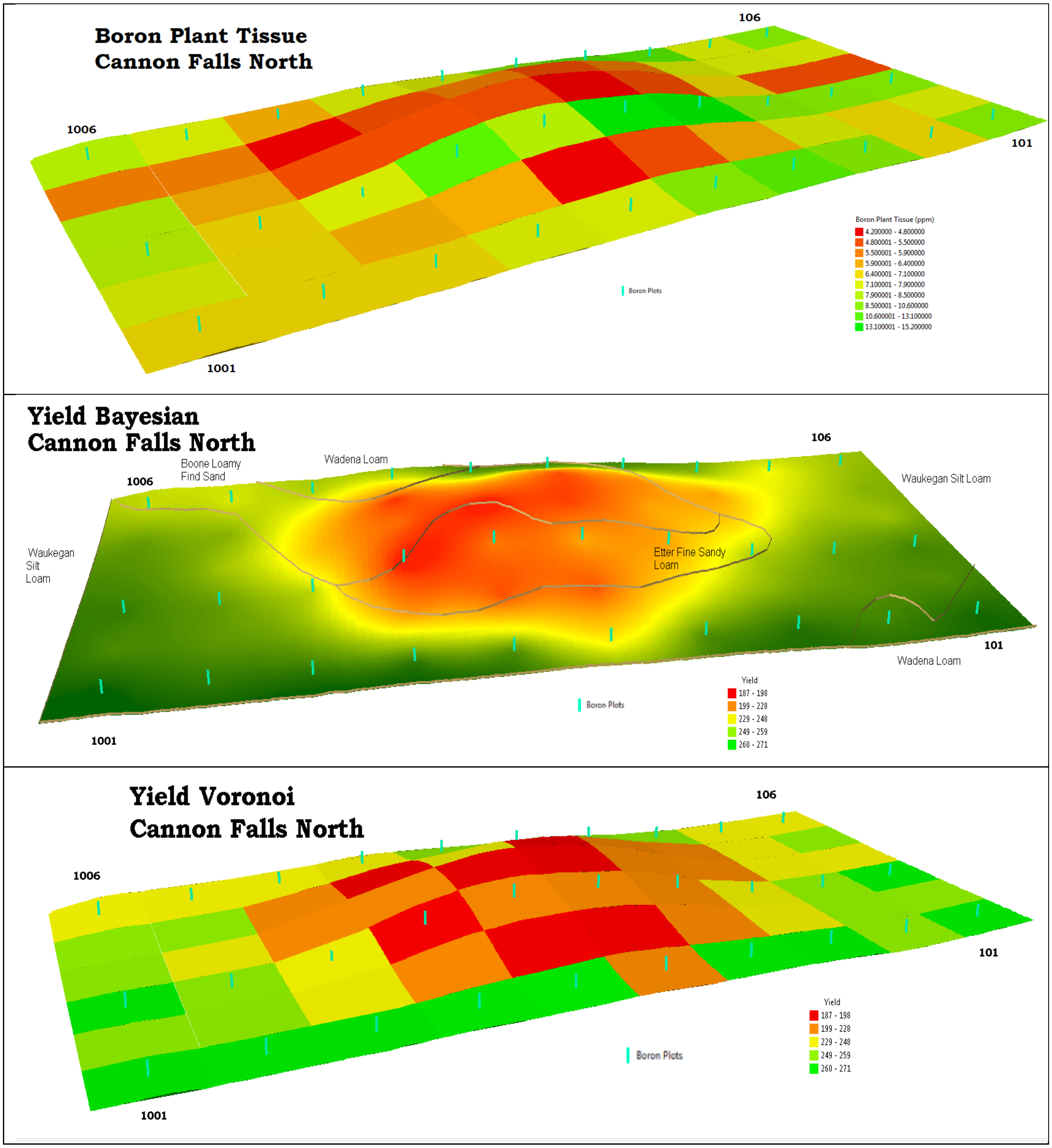

Figure 14. Surface maps generated for corn upper leaf B concentration at V10 and corn grain yield for the location at Cannon Falls (North Site), MN in 2017. Field areas marked with vertical blue bars indicate the strips where B was applied at 2 lbs per acre. Plot 101 was the SW corner of the plot.

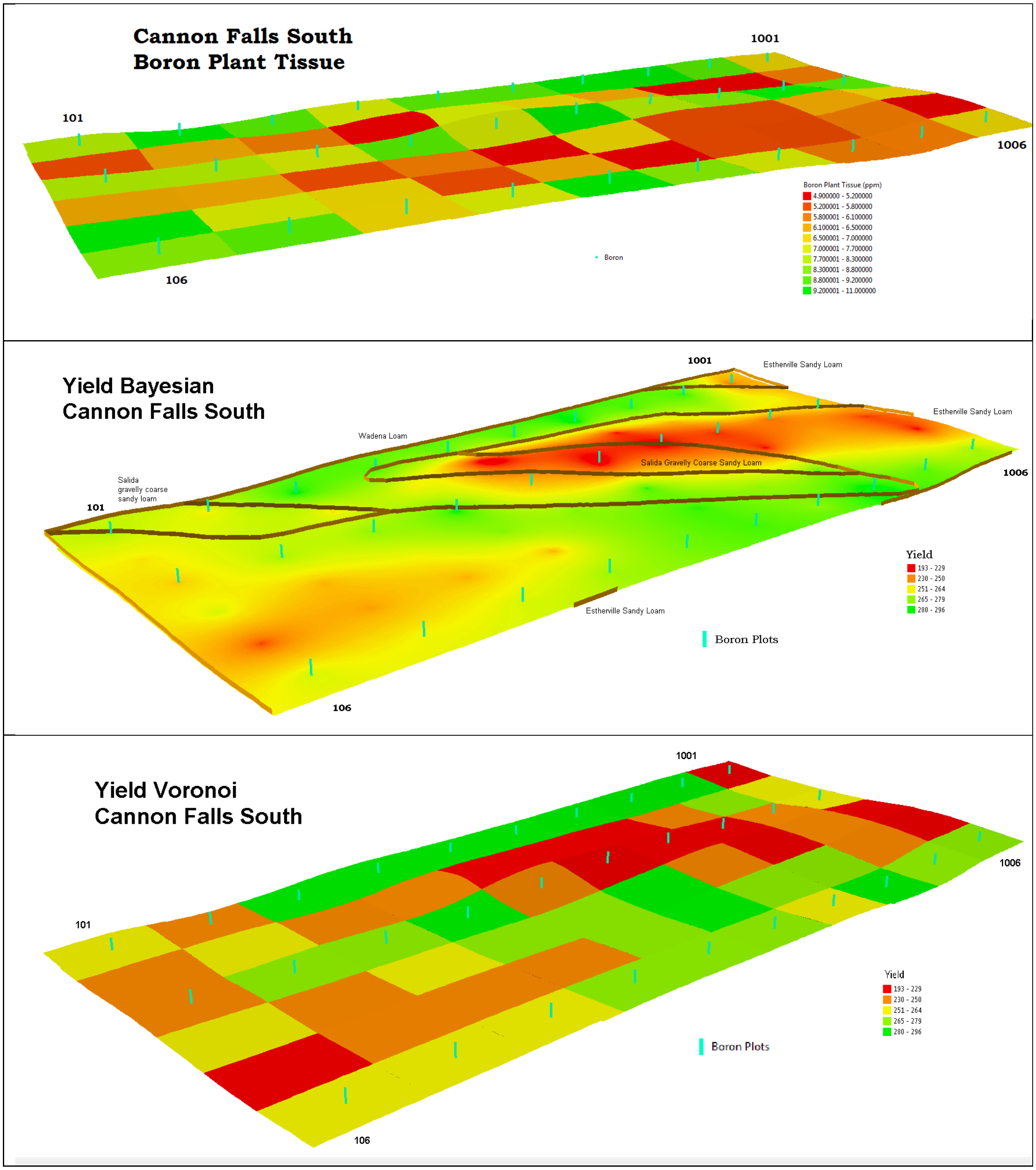

Figure 15. Surface maps generated for corn upper leaf B concentration at V10 and corn grain yield for the location at Cannon Falls (South Site), MN in 2017. Field areas marked with vertical blue bars indicate the strips where B was applied at 2 lbs per acre. Plot 101 was the NW corner of the plot.

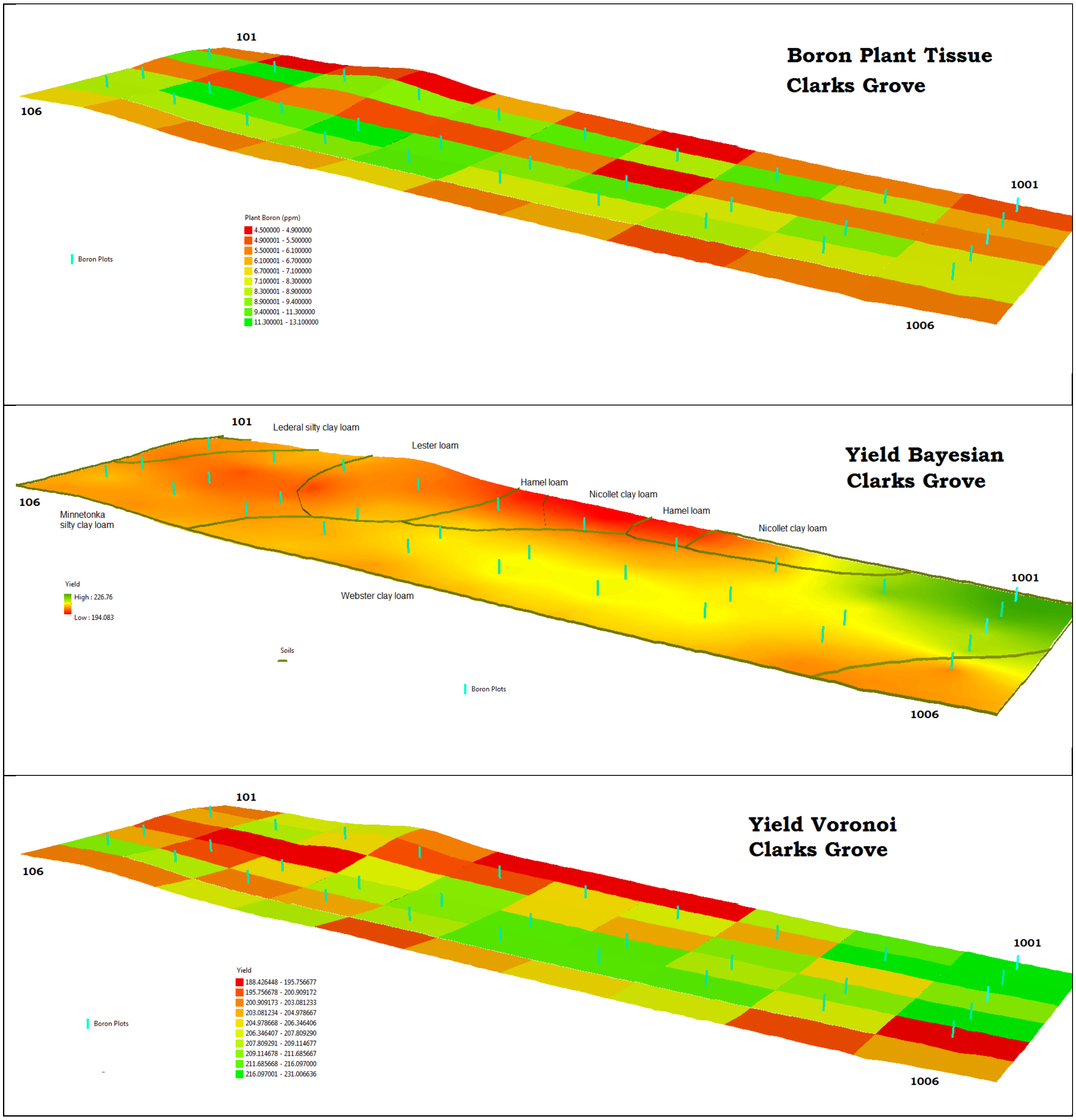

Figure 16. Surface maps generated for corn upper leaf B concentration at V10 and corn grain yield for the location at Clarks Grove, MN in 2017. Field areas marked with vertical blue bars indicate the strips where B was applied at 2 lbs per acre. Plot 101 was the NW corner of the plot.

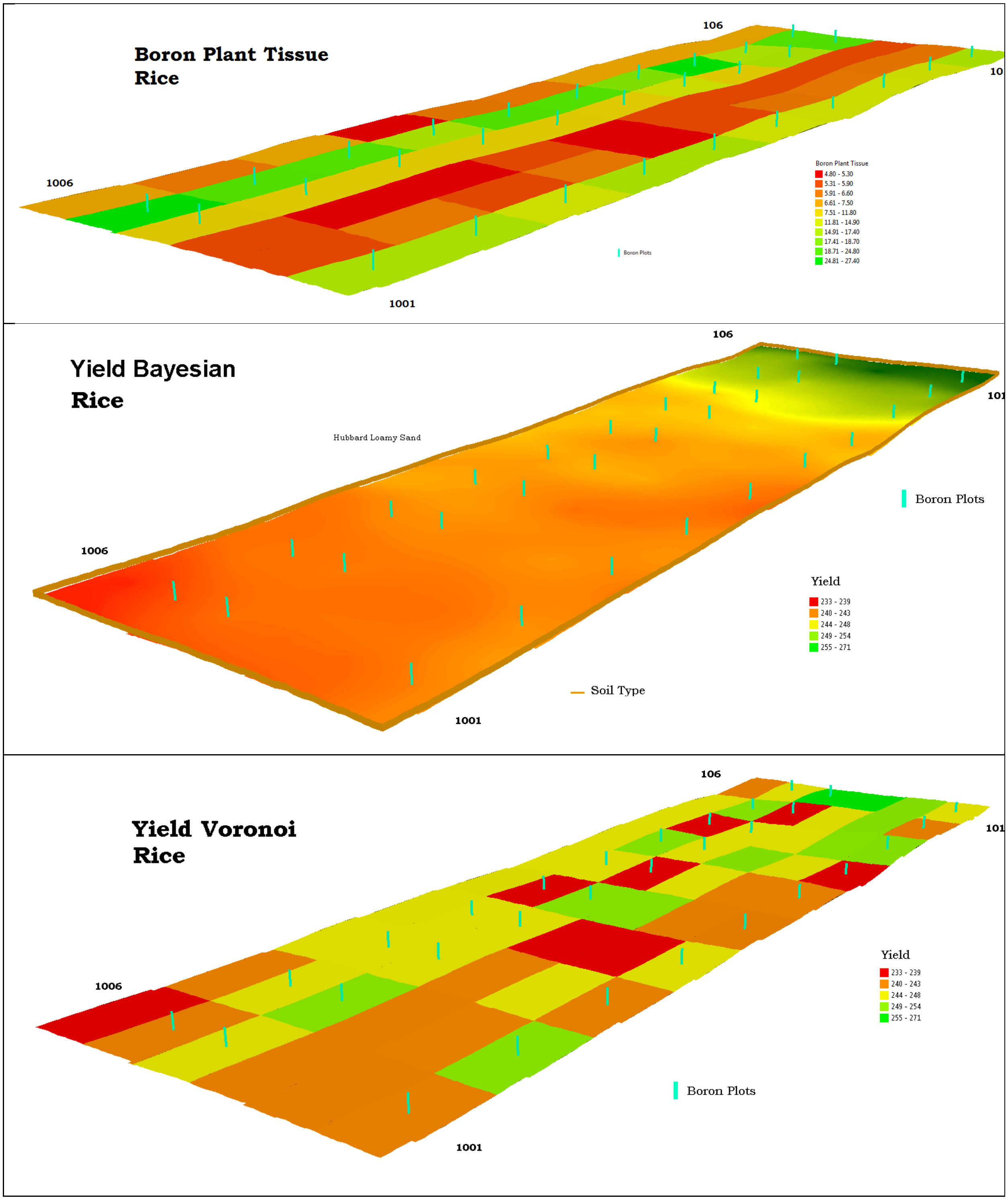

Figure 17. Surface maps generated for corn upper leaf B concentration at V10 and corn grain yield for the location at Rice, MN in 2017. Field areas marked with vertical blue bars indicate the strips where B was applied at 2 lbs per acre. Plot 101 was the SW corner of the plot.

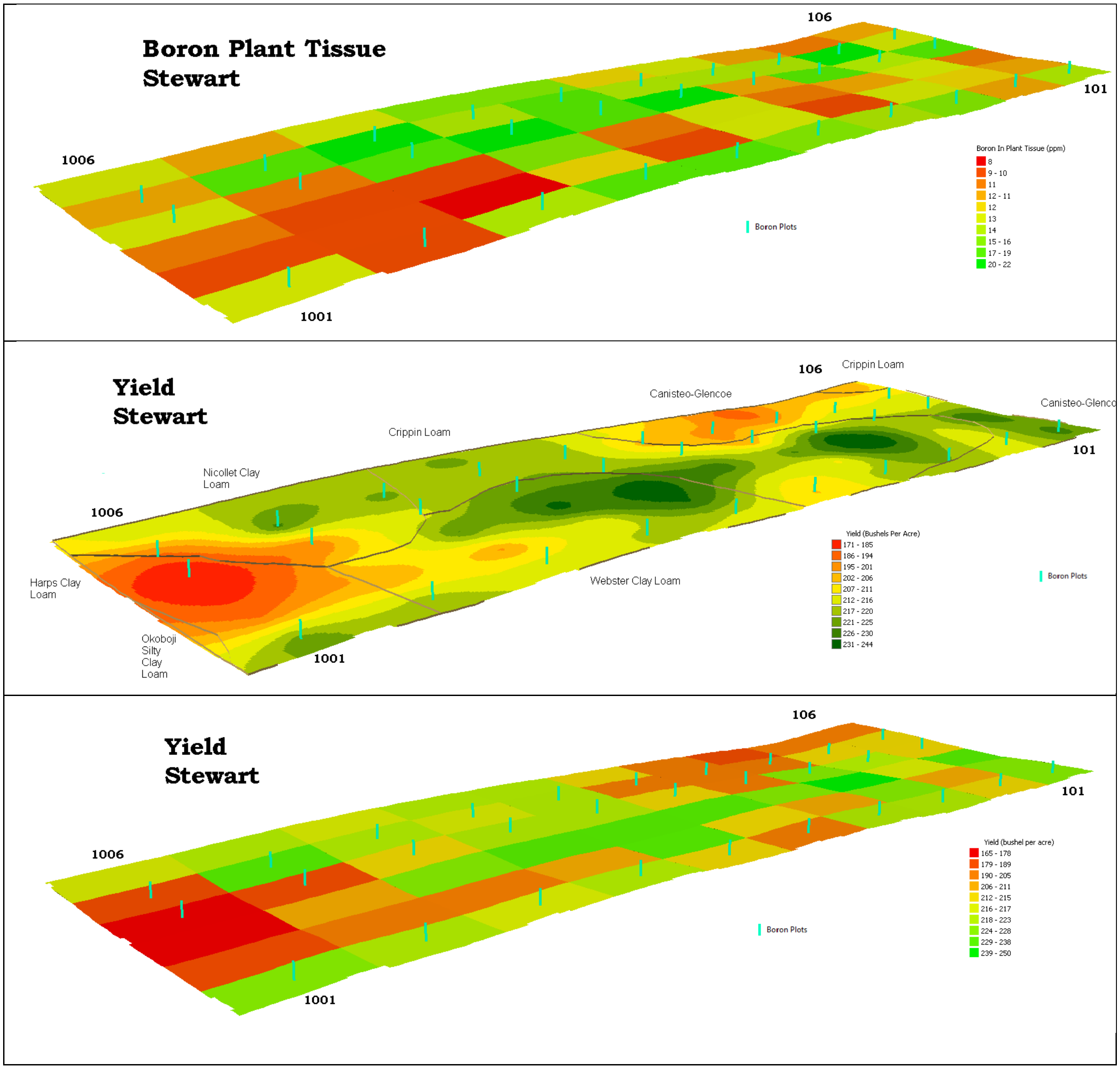

Figure 18. Surface maps generated for corn upper leaf B concentration at V10 and corn grain yield for the location at Stewart, MN in 2017. Field areas marked with vertical blue bars indicate the strips where B was applied at 2 lbs per acre. Plot 101 was the SE corner of the plot.

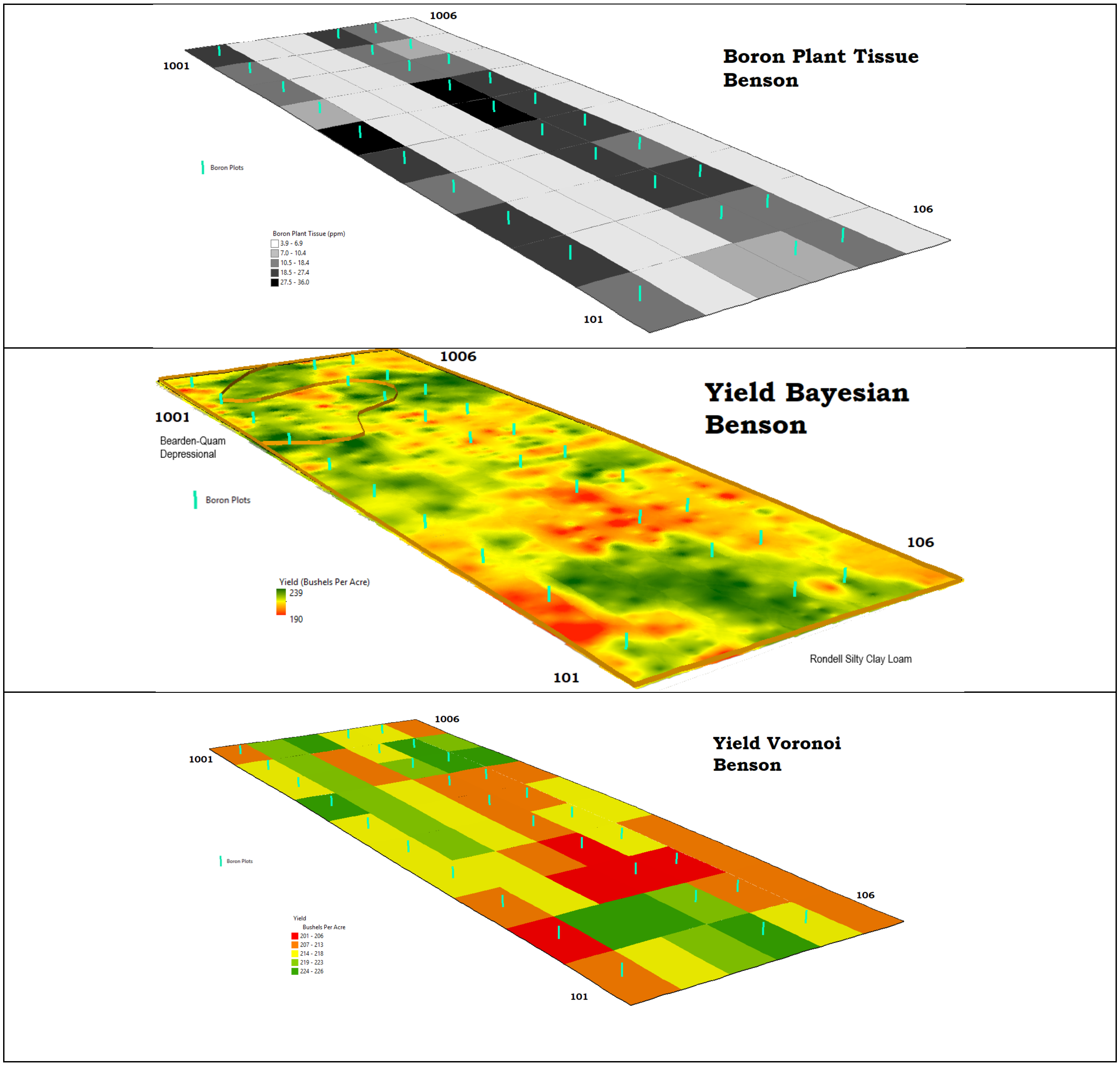

Figure 19. Surface maps generated for corn upper leaf B concentration at V10 and corn grain yield for the location at Benson, MN in 2018. Field areas marked with vertical blue bars indicate the strips where B was applied at 2 lbs per acre. Plot 101 was the NW corner of the plot.

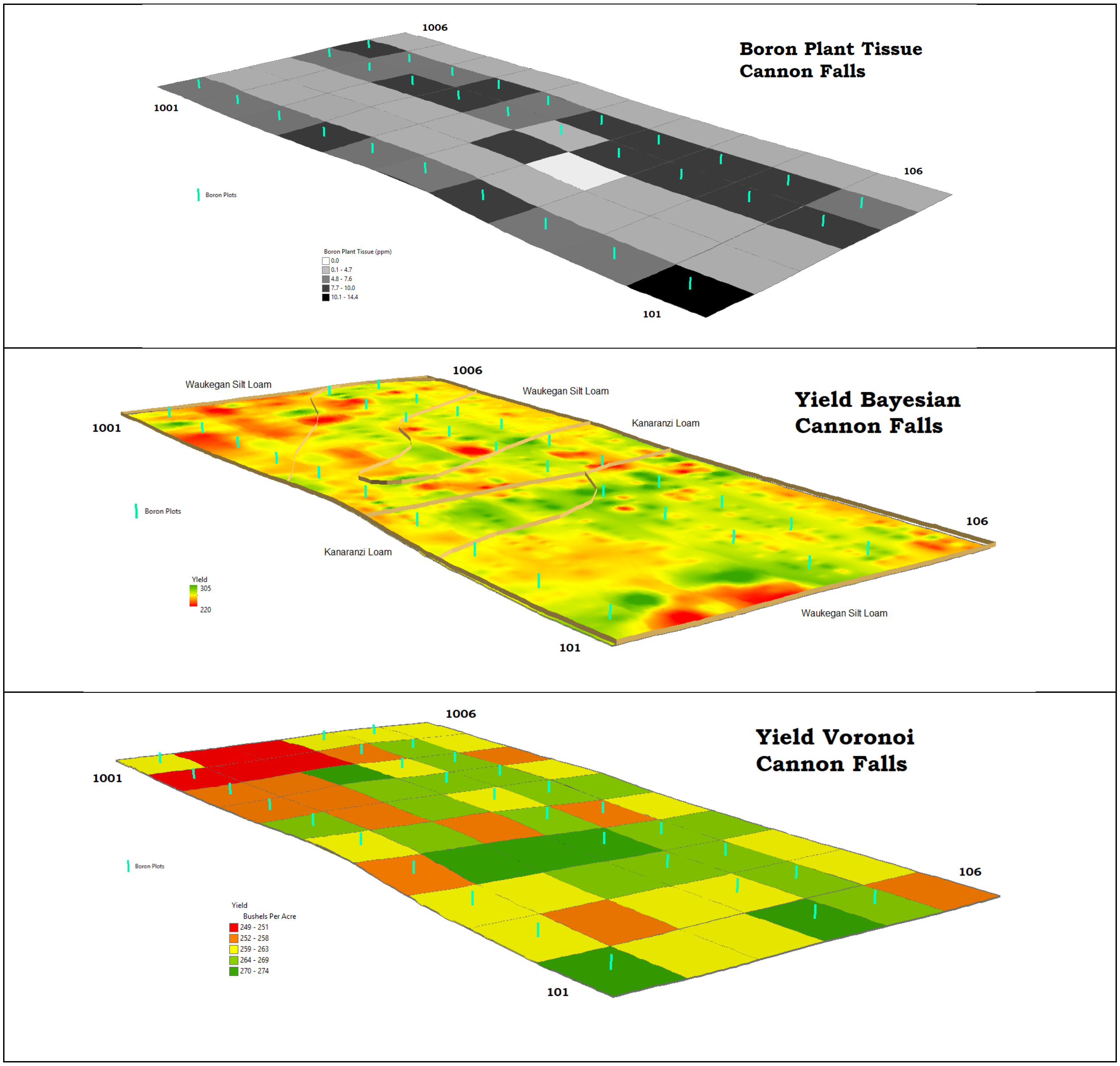

Figure 20. Surface maps generated for corn upper leaf B concentration at V10 and corn grain yield for the location at Cannon Falls, MN in 2018. Field areas marked with vertical blue bars indicate the strips where B was applied at 2 lbs per acre. Plot 101 was the NE corner of the plot.

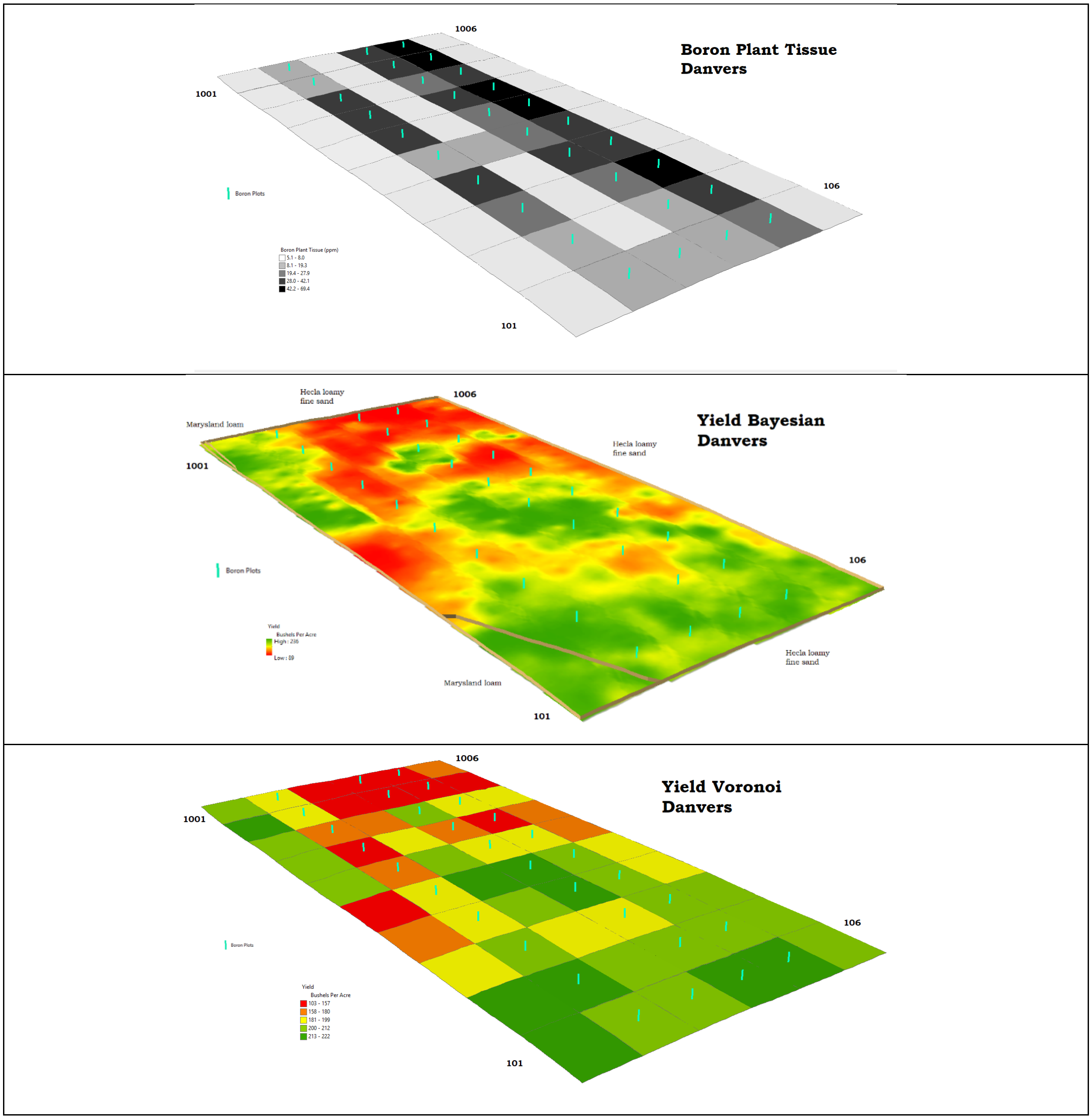

Figure 21. Surface maps generated for corn upper leaf B concentration at V10 and corn grain yield for the location at Danvers, MN in 2018. Field areas marked with vertical blue bars indicate the strips where B was applied at 2 lbs per acre. Plot 101 was the SW corner of the plot.

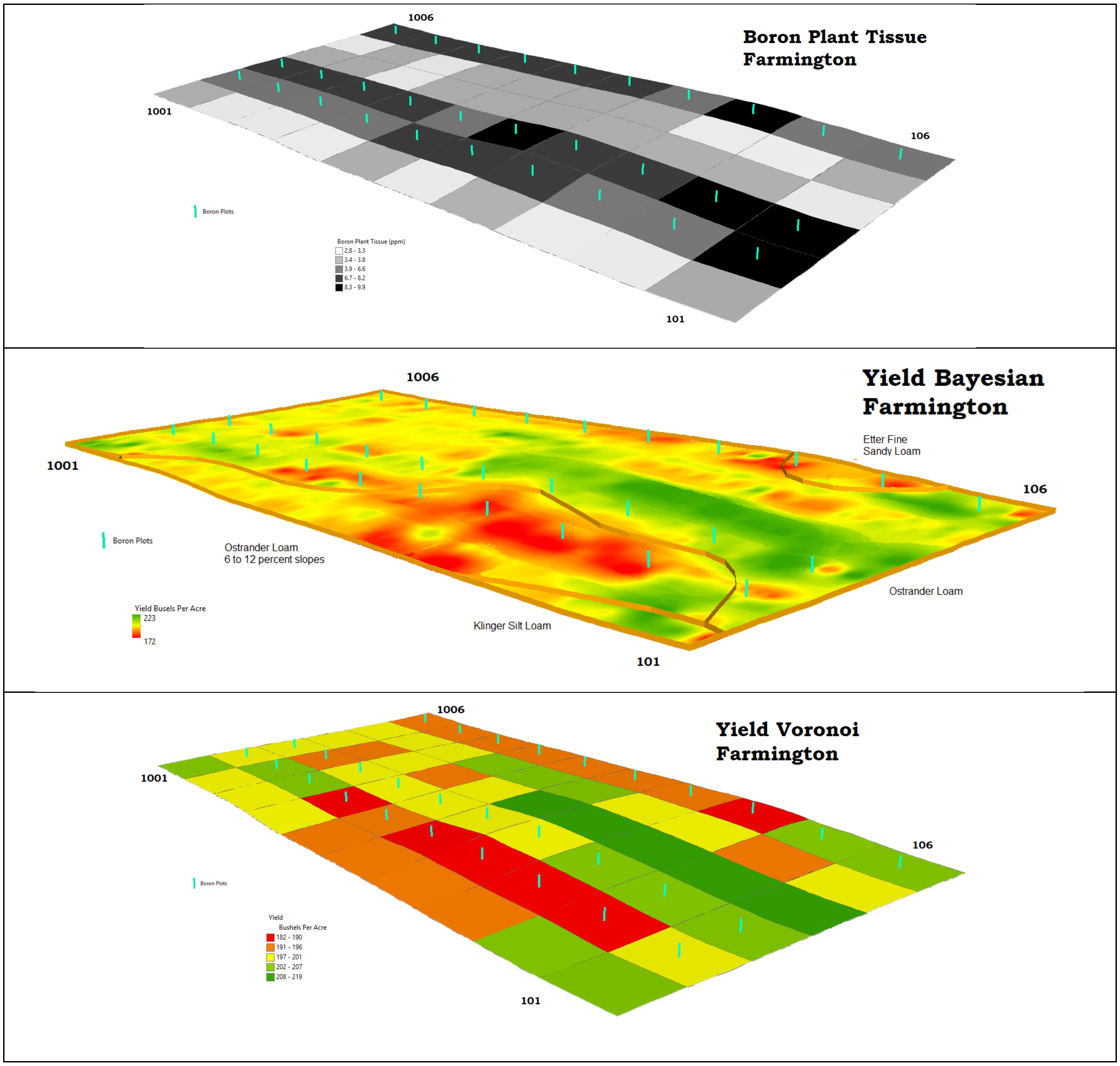

Figure 22. Surface maps generated for corn upper leaf B concentration at V10 and corn grain yield for the location at Farmington, MN in 2018. Field areas marked with vertical blue bars indicate the strips where B was applied at 2 lbs per acre. Plot 101 was the NW corner of the plot.

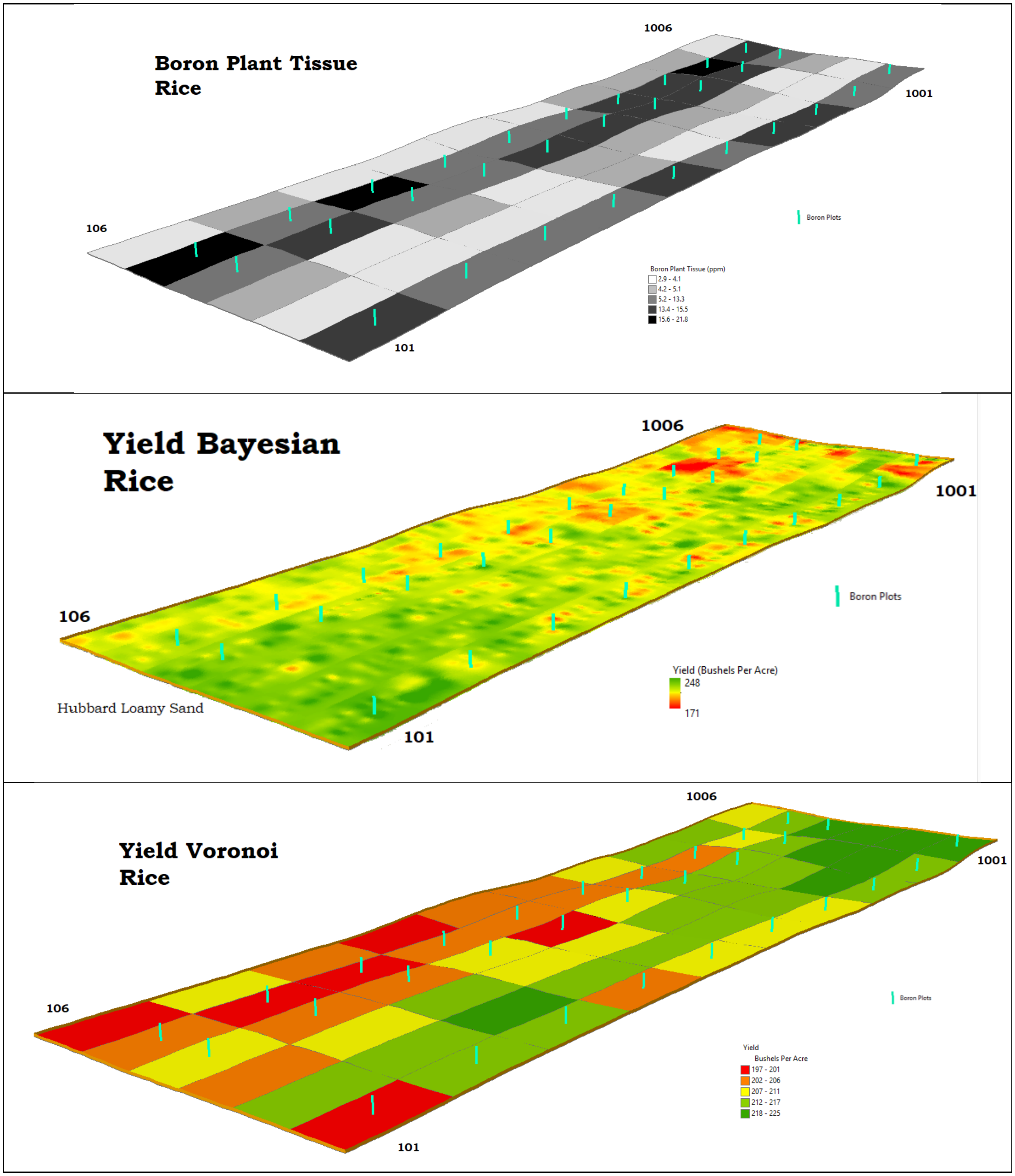

Figure 23. Surface maps generated for corn upper leaf B concentration at V10 and corn grain yield for the location at Rice, MN in 2018. Field areas marked with vertical blue bars indicate the strips where B was applied at 2 lbs per acre. Plot 101 was the NE corner of the plot.

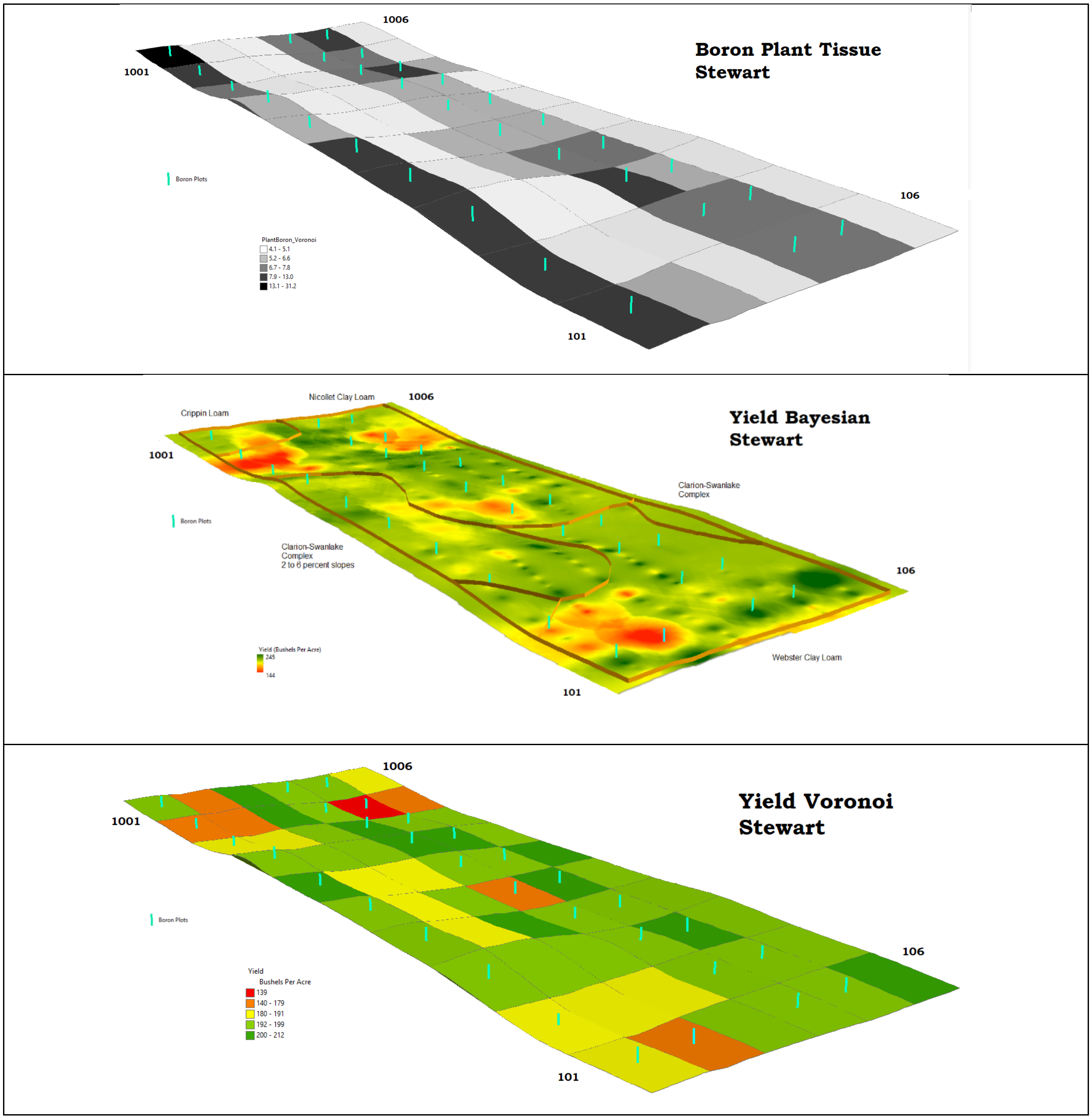

Figure 24. Surface maps generated for corn upper leaf B concentration at V10 and corn grain yield for the location at Stewart, MN in 2018. Field areas marked with vertical blue bars indicate the strips where B was applied at 2 lbs per acre. Plot 101 was the NE corner of the plot.