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Impacts of Nitrogen Rate and Source Following Green Manure on Broccoli Yield

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Cover crops are beneficial to soil health and may be a source of nitrogen (green manure) for a main crop. The amount of nitrogen mineralized from a cover crop that is available from the main crop depends on numerous factors including how much nitrogen the cover crop contains, if and when residue is incorporated, the Carbon:Nitrogen ratio of the residue (C:N), soil temperature, and timing of N mineralization and demand.

Broccoli has a high nitrogen demand over a short amount of time, so meeting the demand exclusively with green manure may be challenging. This is especially true in soils with limited history of organic fertilizer sources or cover crops. This trial was initiated to understand nitrogen demand in a vegetable crop with high N demand (broccoli) following a spring-planted pea-oat cover crop.

A previous small trial indicated that 120 lbs N / ac as slow-release urea for broccoli following a pea-oat cover crop may be sufficient to equal yield of broccoli fertilized with 160 lbs N / ac following no cover crop. In addition, 120 lbs N / ac from Sustane organic fertilizer (composted turkey litter, feather meal, and potassium sulfate; Suståne Natural Fertilizer, Cannon Falls, MN) following pea-oat cover crop was clearly insufficient to meet broccoli demand. However, 100% availability of N was assumed from the Sustane, and the field had no history of organic fertility.

In 2021, we planted a trial to study 2 nitrogen rates and multiple N sources with a pea-oat cover crop, and pre-plant application of a microbial soil inoculant (biostimulant), and a conventional N treatment with no cover crop or inoculant.

Materials and Methods

The experiment was performed in 2020–2021 at the Southern Research and Outreach Center (Waseca, MN), with Nicollet-Webster clay loam soil (pH 6.7, 5.3% organic matter, 26 mg Bray-P / kg, 200 mg K / kg, and 1.1 mg B / kg). There was no history of organic fertilizer, manure, or cover crops in the previous 5 years. The experiment was designed as a split-plot with 5 replicates. Whole plots were broccoli variety (‘Green Magic’ or ‘Gypsy’), subplots were 8 fertilizer / cover crop treatments (Table 1). Each plot consisted of 3 rows of broccoli spaced 3 feet apart (9 ft plot width), 11 inch within-row spacing, and 15-ft plot length. The 2020 crop was spring wheat.

On 3 September 2020, fresh turkey manure was applied to appropriate plots and immediately rototilled (other plots remained un-tilled; manure details in Table 1). Then ‘Gulf’ annual ryegrass (*Lolium multiflorum* Lam.) was broadcast on manure-treated plots only (44 g per plot; Fig. 1). On 5 April 2021, all plots were cultivated and two cover crops were planted sequentially with a grain drill (Table 2). Peas were inoculated with Exceed® pea inoculant (Visjon Biologics, Henrietta, TX) per label instructions prior to planting. Cover crops were from Albert Lea Seed (Albert Lea, MN). Plots with no cover crop were maintained as such with a wheel hoe (Fig. 2).

Table 1. Fertilizer, early-season cover crop (pea + oat), and inoculant (BioTik™) treatments applied to broccoli. In addition to these treatments, 7 lbs Granubor (14.3% B; US Borax, Boron CA) was applied per acre to all plots.

	available[z] lbs / acre					fertilizer source (lbs product / acre)							
treatment	N	P_2O_5	K_2O	cover crop	[y]Bio-tik™	urea	ESN-urea[x]	Sustane® 4-6-4	Sustane® 8-2-4	blood meal[w]	turkey manure[v]	0-46-0	$KMgSO_4$
1	152	73	66	—	—	82	258					159	307
2	125	73	66	+	—	67	212					159	307
3	98	73	66	+	—	53	167					159	307
4	98	73	66	+	+	53	167					159	307
5	98	73	66	+	—			1015	638	726			
6	98	73	66	+	+			1015	638	726			
7	98	112	124	+	—					566	4775		
8	98	112	124	+	+					566	4775		

[z]Availability of N was estimated at 40% for Sustane® and 60% for blood meal. Year 1 availability of manure nutrients estimated by Stearns DHIA Laboratories (Sauk Centre, MN). All other nutrients are assumed 100% available.

[y]Plant Biotik™ is a microbial inoculant (biostimulant), applied at 0.4 lbs / acre before planting broccoli (donated by Nature's Source, Sherman, TX).

[x]ESN is slow-release urea (44%N; Nutrien Ltd., Saskatoon SK).

[w]Blood meal donated by Mason City By-Products (Mason City, IA). Analyzed at 14.0% N, <1% P_2O_5 and K_2O, and 6.1 C:N.

[v]Turkey manure donated by Tom Little, Waterville MN. At application: 30% moisture, 47.3 lbs TKN / Ton, 21 lbs available N / Ton, 24.0 C:N, 39% OM. Manure was applied in Fall 2020.

Figure 1. Annual ryegrass growing in plots fertilized with turkey manure on 3 September 2020. Photos taken 16 September, 2020 (left) or 19 October, 2020 (right). Wheat stubble, volunteer wheat, and weeds are visible in adjacent plots.

Cover crops were mowed with a flail mower on 3 June 2021 after collecting 6 aboveground biomass samples of 200 in^2 each. Samples were dried at 150ºF and found to contain 1.1±0.25 tons of dry matter and 56.6±17.7 lbs N per acre, with 2.5±0.3 %N and C:N of 15.8 ±1.8 (±SD).

Table 2. Details of cover crops grown prior to planting broccoli.

				At termination	
common name	species	planting depth (in.)	planting rate (lbs / ac)	growth stage[z]	plants / ft^2 ±SD
4010 field pea	*Pisum sativum* L.	1.5–2	100	110–113	7.1±2.1
'Morton' oats	*Avena sativa* L.	0.25–0.5	30	21–24	9.7±2.1

[z]Knott, 1987; Zadoks et al.,1974

Glyphosate herbicide was broadcast 5 June, and the field was rototilled on 7 June. The following day, plots were fertilized by hand (Table 1), then sprayed with Trust® herbicide (Trifluralin; Winfield Solutions, St. Paul MN) at 1.5 pints product / acre. The field was cultivated, shallow trenches were dug for planting broccoli, and drip irrigation was installed in the trenches. On 9 June, Plant Biotik™ was applied to trenches in designated plots (Table 1) at a rate of 0.4 lbs product / acre (1.17 g product in 220 oz water per 100 row-ft), and plots were irrigated.

Broccoli ('Green Magic' and 'Gypsy', sourced from Jordan Seeds, Woodbury, MN) was sown on 12 May in 72-cell trays with Pro-Mix FLX medium (Premier Tech Horticulture, Quakertown, PA). Seedlings were germinated and grown in a greenhouse under mist in St. Paul., MN, then moved to Waseca on 7 June after fertilizing with 200 ppm N from 19-8-12 Plantex® (Master Plant-Prod Inc., Brampton, ON). At transplant (by hand) on 10 June, 'Green Magic' had 2–3 leaves unfolded, but 'Gypsy' suffered from poor vigor (only 1–2 leaves). The largest plants were planted in the middle (harvested) row in each plot, and 'Gypsy' was planted in 4 replicates instead of 5 due to poor germination. After transplant, 0.4 lb N / ac (from 12-45-10 fertilizer;

Plant Marvel Laboratories Inc., Chicago Heights, IL) was injected through the irrigation along with 4 oz Ecotrol® Plus / 1000 ft (KeyPlex, Winter Park, FL). Fungicides and insecticides were applied as appropriate throughout the season, and plots were weeded with a wheel hoe, by hand, and with Dakota™ herbicide (clethodim; Rotam North America, Greensboro NC). Plots were drip-irrigated as needed.

Figure 2. Pea-oat cover crop planted 5 April 2021. 'Control' plots with no cover crop are visible. Photo taken 3 June, 2021.

In the middle row of each plot, 9 adjacent plants were selected for harvest. Plants were harvested every 2–3 days for 19 days, starting 50 days after transplant (30 July). Heads were harvested when they reached at least 10 cm (3.9 inches) in diameter, trimmed, and cut to 4–5 inch stalk length. Total weight and diameter of heads was recorded per plot at each harvested, and crown area per plot at each harvest was measured using the Canopeo iPod app (Fig. 3; Patrignani and Ochsner, 2015). After the final harvest, total weight and diameter harvested per 100 ft2 (ft / 100 ft^2) and total head area harvested (ft^2 / ft^2, or % area) were calculated. Heads were considered unmarketable if they had extremely non-uniform beads or were less than 10 cm in diameter as of 18 August.

Time to reach at least 50% marketable heads in each plot and total lbs marketable per 100 ft^2 were analyzed using mixed-effects models in R. Treatment differences, means, and confidence intervals of differences were determined using post-hoc testing (emmeans). Binomial tests were performed within each treatment and variety to determine difference from 95% marketable.

Results and Discussion

Log-likelihood ratio tests comparing models where Biotik™ treatments were grouped with their corresponding non-Biotik™ plots revealed no effect of this biostimulant on time to reach 50% maturity or fresh weight yield. Therefore, Biotik™ treatments were combined with non-Biotik™ treatments for further analysis. It is possible that our Biotik™ application method was ineffective, or the frequency of application was insufficient, or the microbial constituents were ineffective in our conditions. There were also no interactions between broccoli variety and the fertilizer treatments (p>0.1).

All treatments achieved at least 95% marketable heads (Table 3). We found no effect of any fertilizer treatment on fresh weight yield (Table 3). This is to be expected, as each plot was harvested every 2–3 days, so, no heads were able to get substantially larger than others. Fresh weight was strongly correlated with crown diameter and area harvested (Fig. 4), so only fresh

Figure 3. Measuring broccoli crown area harvested using the Canopeo app on an iPod touch. The iPod was supported at a constant height for each photo, and the total area captured by each photo was 0.39 m^2.

weight was analyzed with ANOVA. If stem length or diameter were less uniform, we would expect a smaller correlation between dome area, dome diameter, and fresh weight. 'Gypsy' yielded about 18% more than 'Green Magic', with equivalent percent marketability (Table 3), though 'Gypsy' was smaller at transplant.

Because all treatments had similar % marketable and there were no treatment effects on head size, a reasonable response to study for treatment differences is time to reach maturity. 'Gypsy' harvest was about 4 days later than 'Green Magic' (Table 3). We found that plots with recommended N fertility and no cover crop (treatment 1; Rosen and Eliason, 2005) achieved at least 50% marketable heads after 53.8 days, and all other treatments were delayed compared to that (Table 3; Fig. 5). It is notable that even in broccoli receiving less than 65% of a recommended urea N rate (Treatment 1 vs. Treatment 3&4), an early-season cover crop of peas and oats was able to maintain broccoli marketability and yield. The broccoli only suffered a delay in maturity of up to 5.2 days (Table 3). A treatment with 82% of the recommended N rate (Treatment 1 vs. Treatment 2) was less-delayed (0.4 – 3.7 days).

The pea-oat cover crop average N content was 57 lbs N / ac, but this was obviously not all available to broccoli planted a week after incorporation. Due to the delay in maturity in treatment 2, we conclude that less than 27 lbs N from the cover crop was available to the broccoli (152 lbs N in treatment 1 – 125 lbs N in treatment 2 = 27 lbs N).

The organic- and manure-fertilized plots, which were estimated to have received 98 lbs available N / ac, were delayed similarly to the urea-fertilized plot that received 125 lbs N / ac (Table 3). And the delay of the organic- and manure-fertilized plots (98 lbs N / ac) was less than the delay of the urea-fertilized plot that received 98 lbs N / ac. There are two possible explanations that could both be true: 1) the timing of N availability from the organic- or manure-fertilized plots was more optimal than the timing of N availability in the urea-fertilized plots, or b) our estimates of 40% N availability in Sustane and/or 60% N availability in blood meal were too low. Estimates of N availability in this study are slightly lower than estimates of previously-measured N mineralization from similar products (Hartz and Johnstone, 2006; Gaskell and Smith, 2007). A weather station ½ mile from the field site recorded 2-inch soil temperatures from bare soil averaging 78 ºF in the first 30 days after broccoli planting. Beyond that, soil shading from broccoli was likely to substantially affect soil temperature. Higher temperatures with adequate moisture can increase biological activity (N mineralization). Additional weather information is presented in Fig. 6, which illustrates near-historic low precipitation for the duration of the trial.

Table 3. Effects of fertilizer and early-season cover crop (pea + oat) treatments on time to maturity, yield, and percent marketability of two broccoli varieties.

		nitrogen treatment		time to ≥50% maturity		fresh weight yield		
	cover crop	Source	lbs / acre[w]	days	delay from baseline (days ±95% CI)	lbs / 100 ft^2	difference from baseline (% ±95% CI)	% marketable (±95% CI)[v]
treatment								
1[z]	—	urea	152	53.8	—	16.2	—	95.5, 100
2	+	urea	125	55.8*	0.4, 3.7	16.3	-8.7%, +10.9%	89.3, 99.2
3 & 4	+	urea	98	57.4*	2.2, 5.2	16.3	-7.0%, +10.1%	89.3, 97.3
5 & 6	+	organic[y]	98	56.0*	0.9, 3.7	15.7	-10.4%, +5.4%	93.7, 99.3
7 & 8	+	manure[x]	98	56.0*	0.9, 3.7	15.7	-10.5%, +5.3%	94.6, 99.6
variety								
Green Magic[z]				53.8	—	14.8	—	94.4, 98.4
Gypsy				57.8*	1.4, 6.8	17.6	+8.6%, +29.6%	94.5, 98.8

[z]Baseline within treatment or variety.
[y]Including Sustane and blood meal.
[x]Including turkey manure and blood meal.
[w]Estimated available N, see Table 1.
[v]No results were less than 95% marketable based on Holm-adjusted (n = 7) one-sided binomial tests.
*Significantly greater than baseline based on one-sided Šídák-adjusted tests ($\alpha = 0.05$).

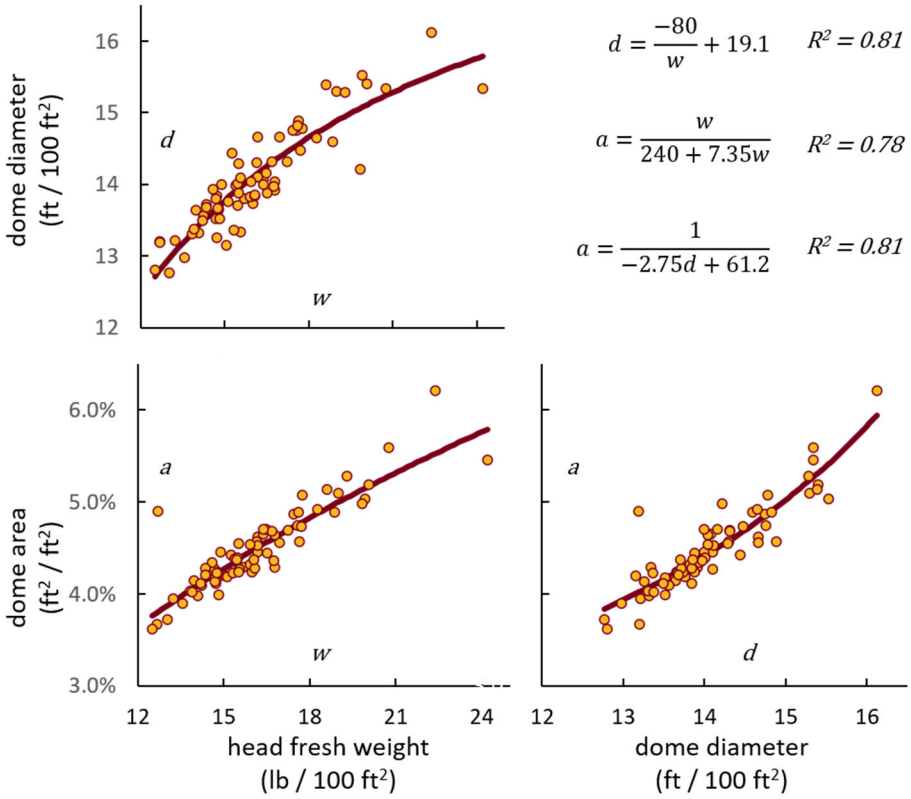

Figure 4. Correlations between marketable head fresh weight (w), marketable dome diameter (*d*), and marketable dome area (*d*) are shown. Equations describing the relationships are given, with R^2.

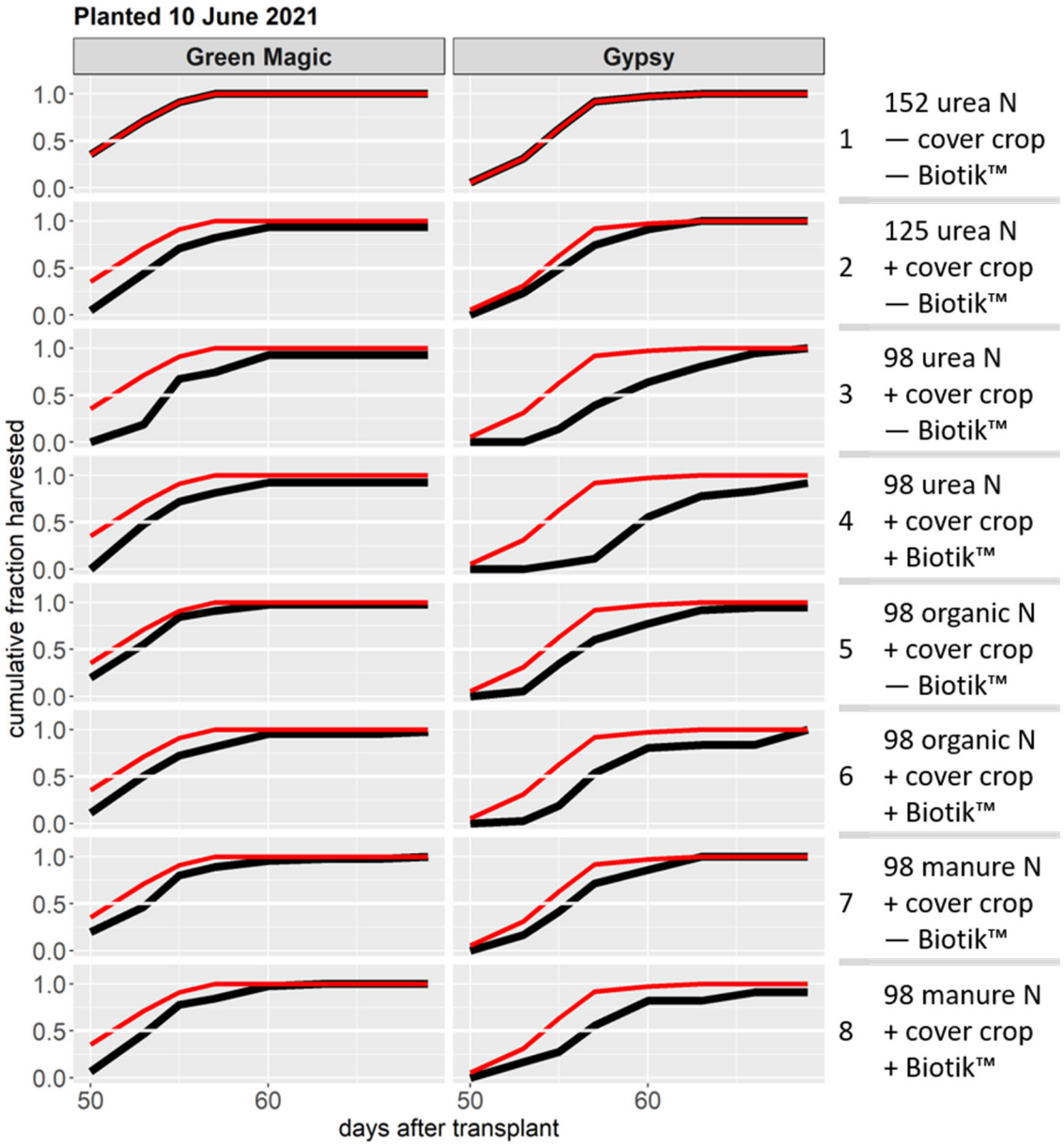

Figure 5. Cumulative harvest of 'Green Magic' and 'Gypsy' broccoli within each nitrogen (estimated 98 – 152 lbs available N / ac), cover crop, fertilizer, and Biotik™ treatment. The red line indicates harvest of the control treatment (1), black lines are treatments 2–8.

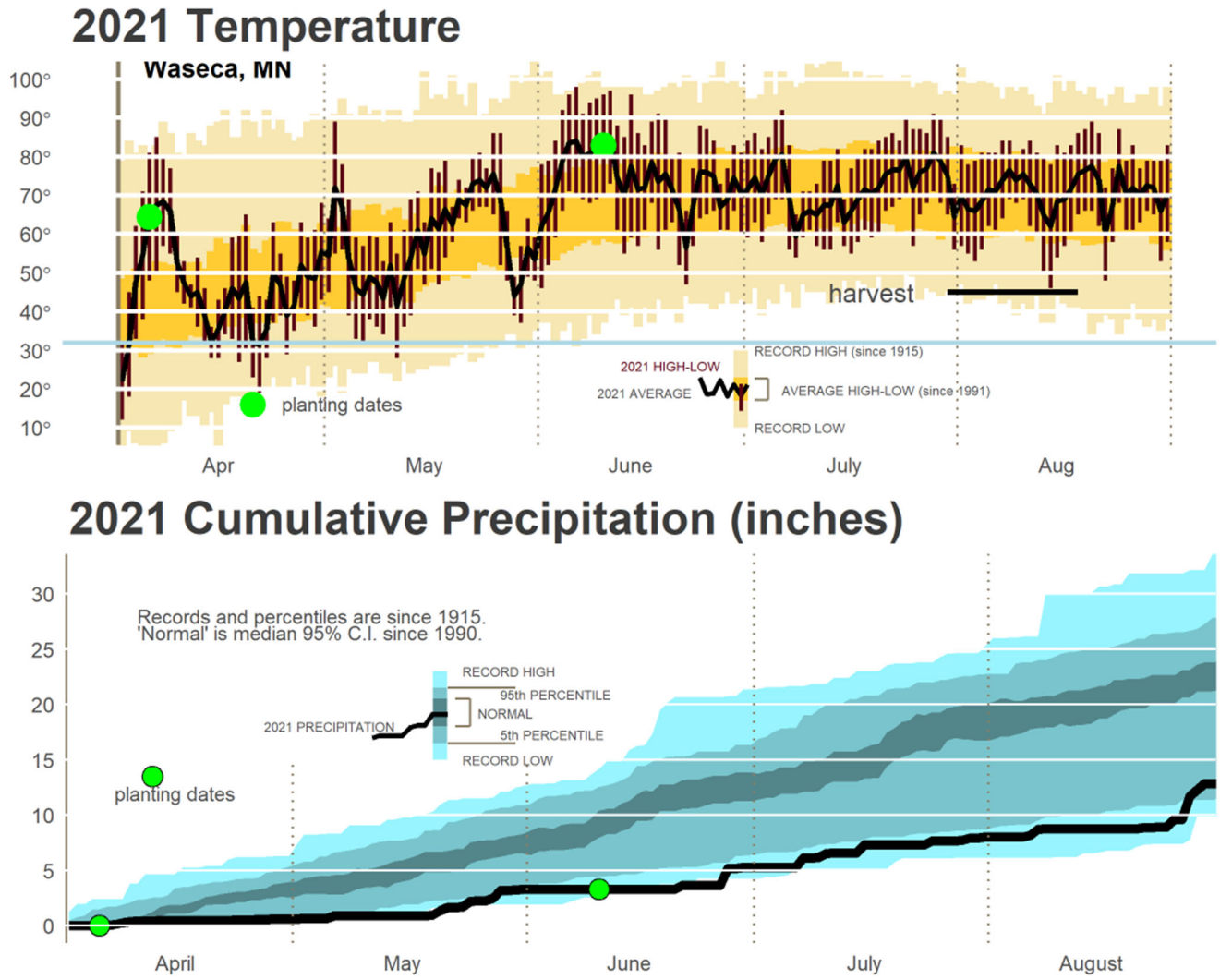

Figure 6. Temperature and precipitation historically and during the 2021 growing season in Waseca, MN. Planting dates of cover crop (5 April) and broccoli (10 June) are indicated with green circles, and harvest period is shown in the temperature chart as a horizontal line.

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