Effects of Biostimulants and Plastic Mulch on Early Growth and Yield of High-density Apple Plantings with Five Cultivars

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Abstract. **In 2009, an orchard with five cultivars (Mutsu, Gala, Honeycrisp, Jonagold, and Macoun) on dwarfing rootstocks was planted at the New York State Agricultural Experiment Station, Cornell University, Geneva, NY, USA. In two experiments, we evaluated the benefits of biostimulants and plastic mulch on tree growth and yield over the first five years. Biostimulants did not have any effect on tree growth or yield with the exception of 'Honeycrisp' where cumulative growth and yield were improved. Plastic mulch increased cumulative yield but not tree growth. The positive effects of plastic mulch were greatest with 'Honeycrisp' and 'Jonagold'.**

Early apple tree growth after planting and during the first 3 years is essential in high-density apple orchards to recoup the initial investment as fast as possible (Robinson et al. 2007). The Tall Spindle system is a popular option that uses highly feathered trees planted at high densities of ∼3300 trees/ha that depends on good tree growth in the first 3 years and significant production over the first 5 years (Robinson 2008a; Robinson et al. 2006, 2011). However, some growers have the problem of poor tree growth in the first season, which limits second and third year yields.

A number of strategies have been used to improve early tree growth, including water supply (Dominguez and Robinson 2024; Pereira and Pires 2011; Robinson and Stiles 1994, 2004), fertilization (Atay 2023; Cheng and Fuchigami 2002; Stiles and Reid 1991), and crop load management (Palmer 1992; Robinson 2008b). Biostimulant products or plastic mulch have also been evaluated for positive effect on growth, yield, and fruit quality of new Tall Spindle apple plantings.

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Biostimulant materials are loosely defined as nonfertilizer products purported to have a beneficial effect on plant growth or development. They are also called by other names including biofertilizers, phytostimulators, and biostimulators. These products contain biologically active substances, that is, plant hormones, enzymes, vitamins, macro and microelements, and other compounds that may stimulate growth and increase yield of plants but are harmless to humans or the environment (Glinicki et al. 2010). They have been used primarily in vegetable and field crop production. However, they are gaining popularity among apple growers because of the potential enhancement of growth, yield, and/or fruit quality. The biostimulatory potential of many of these products has not been fully determined, due lack of scientific data proving their efficacy in plant growth. Nevertheless, biostimulant products have been used in organic apple production to supplement mineral nutrition (Delate et al. 2008). Bradshaw et al. (2013) tested the use of two different products in organic production. They concluded that the application of these products had little effect on tree growth, mineral nutrition, and yield or fruit quality compared with the nontreated control. The use of biostimulant products has given variable results in scientific studies. Depending on the experiment, improvements in tree growth, yield, return bloom, or fruit quality were observed (Bertschinger et al. 1997; Thalheimer and Paoli 2002), or no positive responses were observed (Sahain et al. 2007). Spinelli et al. (2009) tested a seaweed extract to moderate the negative effects of alternate bearing. They found that the use of this biostimulant had no effect on production in the "on" year, but in the "off" year yield was substantially greater than the control. For most previous studies using standard management practices and good growing conditions, the application of biostimulants has not improved tree growth or yield, and did not provide any commercial benefits. However, under more stressful conditions, biostimulants may improve overall apple tree performance.

Another approach to improving early tree growth and yield is the use of inorganic (plastics) and organic (compost, paper, hay, bark) mulches in high-density apple production (Neilsen et al. 2003). Mulches are being adopted by some growers, due the benefits to fruit production and soil health, especially with organic production, where the use of chemicals to control weeds is prohibited. Most of the organic mulches offer some degree of weed control, provide more efficient use of water, and enhance soil conservation. However, some organic mulch materials containing a high C/N ratio, such as sawdust, can result in N immobilization, which can lead to a reduction in tree growth. On the other hand, materials with large amount of N, such as composted animal manure, result in high rates of N mineralization (Forge et al. 2003). Plastic mulch has been used extensively in vegetable production since 1960 (Lamont 2005). It allows early harvest, higher yields and better quality, more efficient use of water and nutrients through fertigation, weed suppression, and increases in soil temperature. For these reasons, there have been attempts in using plastic mulches in apple production. Merwin et al. (1995) compared the costs and benefits of organic and inorganic mulches to conventional herbicide strip at two different locations. They found in the first cropping year that trees produced 50% more fruit with a wood-chip mulch than the other treatments. However, there were no differences in cumulative tree size or yield attributed to the ground-cover management system. They concluded that for some cultivars with high price and good fruit quality, the use of mulch can be justified. Måge (1982) found that the use of black plastic mulch resulted in the most vegetative growth, and had the highest yield compared with herbicides or a grass sod. Similar results were obtained by Neilsen et al. (1986), where yield under the black plastic was higher than full groundcover. The use of plastic mulch could potentially increase growth in northeastern US climates, where the soil in the spring is wet and cold. However, to implement this technology on a large scale would require more specialized machinery that would add cost to the already expensive high-density orchard (Merwin et al. 1995). For these reasons, plastic mulches have not been adopted on a large scale in orchards. Nevertheless, the use of some organic mulches has become common with small-scale growers, a few large-scale growers, and organic growers.

The objective of this project was to evaluate the effect of four biostimulants (combined into a single tank mix treatment) or plastic mulch on growth and yield of five common cultivars in New York State when trained to a Tall Spindle system.

Materials and methods

Two studies were carried out at the New York State Agricultural Experiment Station in Geneva, NY, USA (42N, 77W). The orchard was planted in 2009 and the experiments were carried through 2013. The soil is a Honeoye fine sandy loam (He), with good water-holding capacity, well drained, and fertile with ~3% organic matter content and a 6% slope. Five apple scion/rootstock combinations were used in these experiments: 'Mutsu' on M.9T337 rootstock, 'Brookfield Gala' on M.9Pajam2, 'Rubinstar Jonagold' on B.9, 'Honeycrisp' on M.9Nic29, and 'Macoun' on B.9. These main effect treatments are hereafter referred to as "Cultivar" effects using the monikers Mutsu, Gala, Jonagold, Honeycrisp, and Macoun with the recognition that they represent both scion and rootstock effects with respect to treatment response. The trees were planted on 18 Apr 2009, at a spacing of 1 m within the rows and 3.5 m between rows, giving 2857 trees/ha, and were trained as tall spindles. The orchard received standard disease, insect, and weed control throughout the five

Table 1. Effect of biostimulants on trunk growth [trunk cross-sectional area (TCSA)] and shoot growth of five apple cultivars over the first 5 years (2009–13) at Geneva, NY, USA.

Cultivar/Stock	Biostimulants treatment	TCSA 2009 (cm^2)	TCSA 2010 (cm^2)	TCSA 2011 (cm^2)	TCSA 2012 (cm^2)	TCSA 2013 (cm^2)	Total shoot growth 2009 (cm)	Total shoot growth 2010 (cm)	Total shoot growth 2011 (cm)	Total shoot growth 2012 (cm)
Mutsu/M.9T337		4.9 a[i]	9.6 b	14.0 a	17.6 a	22.2 a	331 c	711 cd	1,243 b	2,619 b
Gala/M.9Pajam2		4.4 b	10.7 a	14.3 a	16.0 a	20.0 a	575 a	1474 a	1,991 a	3,993 a
Honeycrisp/M.9Nic29		3.7 c	7.6 c	9.8 b	11.0 b	14.4 b	262 d	1094 b	1,683 ab	1,791 bc
Jonagold/B.9		4.4 b	8.3 c	11.5 b	13.3 b	15.9 b	422 b	804 c	1,289 b	2,544 b
Macoun/B.9		3.7 c	8.0 c	10.1 b	11.5 b	14.2 b	259 d	554 d	781 c	1,445 c
Cultivar/Stock significance		**	**	**	**	**	**	**	**	**
	No biostimulants	4.2	8.5 b	11.7	13.4 b	16.6 b	377	891	1,313	2,394
	Biostimulants	4.2	9.2 a	12.2	14.4 a	18.1 a	366	972	1,496	2,586
Biostimulants treatment significance		NS	*	NS	*	*	NS	NS	NS	NS
Interaction means										
Mutsu	No biostimulants	4.9	8.8	13.4	16.1	20.1	337 cd	653	1,204	2,377
	Biostimulants	5.0	10.3	14.6	19.1	24.4	326 cd	769	1,282	2,861
Gala	No biostimulants	4.4	10.3	14.0	15.7	19.2	606 a	1,414	1,740	3,699
	Biostimulants	4.4	11.0	14.6	16.4	20.7	544 a	1,534	2,243	4,287
Honeycrisp	No biostimulants	4.0	7.8	10.6	11.7	15.7	306 d	1,089	1,538	2,074
	Biostimulants	3.5	7.4	9.0	10.2	13.0	218 e	1,099	1,829	1,509
Jonagold	No biostimulants	4.3	7.9	11.0	12.7	15.0	379 c	729	1,221	2,319
	Biostimulants	4.5	8.7	12.0	14.0	16.9	464 b	879	1,357	2,770
Macoun	No biostimulants	3.6	7.5	9.2	10.5	12.8	239 e	525	796	1,377
	Biostimulants	3.7	8.4	10.8	12.4	15.4	277 d e	579	768	1,505
Interaction significance		NS	NS	NS	NS	NS	*	NS	NS	NS

[i]Means within columns and sections with the same letter are not significantly different using Duncan's multiple range test at $P \leq 0.05$. *, **, or NS indicate treatment had a significant effect at $P \leq 0.05$ or $P \leq 0.01$ levels, or had a nonsignificant effect, respectively.

growing seasons. Crop load was managed each year as follows: In the second year, trees were hand thinned when fruitlets were 10 mm in size to a single fruit per cluster and then additional thinning was done to space the fruitlets to 10 cm between fruitlets. In the third through the fifth seasons, trees were chemically thinned when fruit size was 10 mm and then additional hand thinning was done when fruits were 25 mm, leaving a single fruitlet per cluster and 10 cm between fruits.

EXPERIMENTAL DESIGN. The two experiments were conducted using a strip-split-plot, randomized complete block with the main plot treatment being cultivar (Mutsu, Gala, Honeycrisp, Jonagold, and Macoun) and the subplot treatment being two management treatments in each study. Each study had four replications (blocks) with each management treatment randomly assigned a location within each block and within each cultivar. Each elemental plot consisted of two individual trees with guard trees between elemental plots. Cultivars were laid out as strip treatments to facilitate orchard management, especially thinning. The three management treatments were randomized within each block. The experimental orchard was organized in five rows of 97 trees each (one row per cultivar) with rows oriented north-south. Blocking of subplot treatment within each cultivar was based on initial trunk diameter measured with a digital caliper.

The first experiment compared the use of biostimulant sprays with unsprayed trees. Each spray contained a tank mix of four biostimulating products used at the label rate: Stimplex (24 oz/100 gal), Nutriphite (16 oz/100 gal), Vitazyme (16 oz/100 gal), and SystemCal (32 oz/100 gal). Trees were sprayed five times each year every 2 weeks starting on 1 Jun. At each spray timing, trees were sprayed evenly until drip using a 30-gal hydraulic sprayer.

The second experiment compared black plastic mulch on the soil with no soil mulch. Plastic mulch was installed 1 week after planting and covered the herbicide strip (1.5 m). Regular weed sprays were done in the no-mulch treatment. The mulch remained in place for the whole experiment.

MEASUREMENTS. Trunk circumference was measured at planting and in November of each year at 30 cm above the graft union and used to calculate

Table 2. Effect of biostimulants on cumulative tree growth, pruning weight, and fruiting of five apple cultivars during the first 5 years (2009–11) at Geneva, NY, USA.

		Cumulative growth and fruiting measurements						Avg		
Cultivar/Stock	Biostimulants treatment	Leader length (cm)	Total shoot growth (cm)	Pruning wt (g)	Yield (kg/tree)	Yield (t/ha)	Yield efficiency (kg/cm^2 TCSA)	Crop load (fruit no./cm^2 TCSA)	Fruit size (g)	Shoot length (cm)
Mutsu/M.9T337		157 b[i]	4,904 b	1,357 b	63.4 a	181.2 a	3.01 ab	3.5 c	292 a	26.3 ab
Gala/M.9Pajam2		199 a	8,033 a	2,169 a	57.6 a	164.4 a	2.98 ab	5.8 a	165 d	28.0 a
Honeycrisp/M.9Nic29		132 c	4,830 b	883 c	37.3 c	106.6 c	2.72 ab	4.2 bc	250 b	20.5 c
Jonagold/B.9		169 b	5,059 b	1,313 b	49.5 b	141.3 b	3.15 a	4.3 bc	240 c	28.5 a
Macoun/B.9		169 b	3,039 c	1,057 bc	33.4 c	95.3 c	2.48 b	4.9 b	161 d	25.0 b
Cultivar/Stock significance		**	**	**	**	**	NS	**	**	**
	No biostimulants	165	4,975	1,238	47.0	134.2	2.86	4.6	219	25.0 b
	Biostimulants	162	5,420	1,478	49.8	142.3	2.89	4.4	225	26.3 a
Biostimulants treatment significance		NS	NS	NS	*	*	NS	NS	NS	*
Interaction means										
Mutsu	No biostimulants	153	4,570	1,180	63.1 a	180.2 a	3.21 ab	3.8 ef	285	25.1
	Biostimulants	161	5,238	1,534	63.8 a	182.2 a	2.81 bcd	3.3 f	299	27.6
Gala	No biostimulants	209	7,458	1,872	59.6 ab	170.2 ab	3.26 a	6.3 a	164	27.1
	Biostimulants	189	8,608	2,467	55.5 bc	158.6 bc	2.70 cde	5.3 b	166	28.9
Honeycrisp	No biostimulants	137	5,007	993	31.0 f	88.6 f	1.97 f	3.4 f	244	21.2
	Biostimulants	127	4,654	773	43.6 e	124.6 e	3.48 a	5.0 bc	255	19.7
Jonagold	No biostimulants	168	4,648	1,238	46.9 de	134.0 de	3.20 ab	4.6 cd	236	26.9
	Biostimulants	171	5,470	1,389	52.0 cd	148.7 cd	3.11 abc	4.1 de	244	30.0
Macoun	No biostimulants	159	2,938	861	32.4 f	92.7 f	2.65 de	5.1 bc	160	24.5
	Biostimulants	160	3,128	1,228	34.2 f	97.6 f	2.33 ef	4.6 cd	163	25.4
Interaction significance		NS	NS	NS	*	*	**	**	NS	NS

[i] Means within columns and sections with the same letter are not significantly different using Duncan's multiple range test at $P \le 0.05$. *, **, or NS indicate treatment had a significant effect at $P \le 0.05$ or $P \le 0.01$ levels, or had a nonsignificant effect, respectively. TCSA = trunk cross-sectional area.

trunk cross-sectional area (TCSA). Shoot growth was recorded in November each year for the first 4 years at the end of the season but was not recorded in the final fifth season. The length of every shoot on the tree including the axis was measured. This procedure was done in 2009, 2010, and 2011. However, in 2012, the methodology was different. The leader and 30 randomly chosen shoots were measured and the total number of shoots was counted on the whole tree. The number of shoots on the tree was multiplied by the average length of the 30 randomly chosen shoots to estimate total shoot length on the tree. In the spring of each year before budbreak for the first 4 years, the weight of the prunings per tree was recorded. In the second and third seasons the number of floral buds was also counted at bloom and the number of spurs (shoots shorter than 10 cm) at the end of the season were counted.

During the first year, trees were not allowed to crop to allow maximum tree vegetative growth, but beginning in the second growing season the trees were allowed to crop and production data were collected annually. At each harvest, fruits were counted and weighed. In the third and fourth years, a sample of 10 fruits was collected from each treatment and stored in refrigerated storage for 4 to 5 months with a temperature of 2 °C and a relative humidity of 75%. After storage, the fruits of the sample were tested for soluble solids concentration (°Brix) using a portable refractometer (Atago, Bellevue, WA, USA), fruit firmness was measured from two peeled sides at the equator of each fruit using a fruit penetrometer (Pressure Tester, Model EPT-1, Lake City Technical Products Inc., Kelowna, BC, Canada). Storage disorders including bitter pit, soft scald, water core, and senescent breakdown were assessed. In the fourth year, the 10-apple sample was evaluated for fruit size and color using a commercial electronic MAF RODA Pomone fruit grader (MAF Agrobotic, Montauban, France) with a camera system for evaluating red color and load cells for evaluating fruit weight. A simulated pack-out was calculated with data from the fruit grading machine.

At the end of the 5 years, we calculated the gross cumulative crop value for each treatment by multiplying the cumulative production (t/ha) by the

Table 3. Effect of biostimulants on annual yield and fruit size of five apple cultivars in the first 4 cropping years (2010–13) at Geneva, NY, USA.

Cultivar/Stock	Biostimulants treatment	Fruit no. per tree 2010	Fruit yield 2010 (kg/tree)	Fruit size 2010 (g)	Fruit no. per tree 2011	Fruit yield 2011 (kg/tree)	Fruit size 2011 (g)	Fruit no. per tree 2012	Fruit yield 2012 (kg/tree)	Fruit size 2012 (g)	Fruit no. per tree 2013	Fruit yield 2013 (kg/tree)	Fruit size 2013 (g)
Mutsu/M.9T337		23.9 ab[i]	7.90 a	335 a	35.3 b[i]	10.2 a	305 a	40.0 d	10.2 c	266 a	135.3 a	35.13 a	262 a
Gala/M.9Pajam2		24.8 a	4.82 d	195 d	67.9 a	10.16 a	150 c	137.4 a	19.8 a	146 c	137.3 a	22.81 b	167 c
Honeycrisp/M.9Nic29		20.2 bc	5.81 c	294 b	23.3 c	6.45 bc	285 a	89.4 b	17.9 ab	209 b	42.3 c	7.19 d	209 b
Jonagold/B.9		25.8 a	6.56 b	258 c	41.3 b	8.4 ab	227 b	65.6 c	14.4 bc	221 b	86.8 b	21.49 b	255 a
Macoun/B.9		18.5 c	3.39 e	183 d	39.5 b	6.22 c	158 c	83.2 bc	12.0 c	144 c	74.1 b	11.75 c	160 c
Cultivar/Stock significance		**	**	**	**	**	**	**	**	**	**	**	**
	No biostimulants	23.6	5.85	245 b	36.2 b	7.12 b	232	90.6 a	15.4	186 b	91.9	19.07	214
	Biostimulants	21.8	5.60	263 a	46.6 a	9.47 a	219	75.9 b	14.3	209 a	98.8	20.41	208
Biostimulants treatment significance		NS	NS	**	**	**	NS	*	NS	**	NS	NS	NS
Interaction means													
Mutsu	No biostimulants	26.6	7.97	301 b	29.8	8.66	319	47.3	11.6	256 ab	133.1 a	34.89 a	264 a
	Biostimulants	21.1	7.83	368 a	40.9	11.73	291	32.8	8.8	276 a	137.5 a	35.36 a	259 a
Gala	No biostimulants	23.6	4.67	198 e	67.3	10.27	154	151.4	20.9	139 f	145.5 a	23.71 b	164 d
	Biostimulants	25.9	4.96	193 e	68.6	10.05	147	123.4	18.6	153 f	129.0 a	21.92 b	170 cd
Honeycrisp	No biostimulants	23.4	6.67	287 bc	11.9	3.47	290	102.0	18.1	180 e	12.5 c	2.78 d	227 b
	Biostimulants	17.0	4.95	302 b	34.8	9.43	280	76.9	17.6	239 bc	72.0 b	11.61 c	189 c
Jonagold	No biostimulants	25.9	6.40	252 d	36.6	7.20	231	69.6	14.6	211 d	89.1 b	21.42 b	253 a
	Biostimulants	25.8	6.73	264 cd	45.9	9.60	223	61.6	14.2	231 cd	84.5 b	21.56 b	257 a
Macoun	No biostimulants	17.7	3.21	180 e	35.4	5.83	164	81.4	11.5	141 f	77.6 b	11.95 c	154 d
	Biostimulants	19.1	3.56	186 e	43.0	6.56	153	84.8	12.5	147 f	71.0 b	11.58 c	164 d
Interaction significance		NS	NS	*	NS	NS	NS	NS	NS	*	**	*	*

[i] Means within columns and sections with the same letter are not significantly different using Duncan's multiple range test at $P \leq 0.05$. *, **, or NS indicate treatment had a significant effect at $P \leq 0.05$ or $P \leq 0.01$ levels, or had a nonsignificant effect, respectively.

typical fruit price per kilo for each cultivar ($0.65/kg for Mutsu, Gala, Jonagold, and Macoun and $1.3/kg for Honeycrisp).

In August of the first 2 years, a 50-leaf sample was collected from mid-position leaves on extension shoots of the two trees in each elemental plot. Leaves were dried, ground, and analyzed for macro and micronutrients at a commercial laboratory (A&L Great Lakes Laboratory, Fort Wayne, IN, USA) using combustion and inductive coupling plasma-spectrometry.

Statistical analysis. The data were analyzed by analysis of variance using a separate analysis for the biostimulant experiment and the plastic mulch experiment. The data were analyzed using a split plot design in which cultivar was the main plot and management treatment (untreated control, biostimulant, or mulch treatment) was the subplot factor and sub-subplots were the two individual trees in each subplot. Data for each year were analyzed separately; however, cumulative 5-year data were also analyzed. Mean separation was done by Duncan's multiple range test with $P \leq 0.05$ and the appropriate error term for cultivar or management treatment and the interaction of cultivar and management treatment.

Results

Effect of biostimulants

Vegetative growth. During the first year of growth (2009), the biostimulant treatment did not improve vegetative growth compared with the no biostimulant control treatment (Table 1). However, the interaction between cultivar and biostimulant treatment was significant where the total shoot length was increased with biostimulant treatment for 'Jonagold', but for 'Honeycrisp' the control treatment had higher total shoot length. With 'Mutsu', 'Gala', and 'Macoun', there was no significant effect.

In the second year (2010), the control treatment had greater TCSA than the biostimulant treatment (Table 1). During the third year (2011), there was no significant effect of biostimulant treatment but in the fourth year (2012), biostimulants increased TCSA significantly compared with the control treatment (Table 1). No significant interactions between cultivar and biostimulant treatment were found in 2012.

Table 4. Effect of biostimulants on leaf nutrient concentration of five apple cultivars in the first year (2009) at Geneva, NY, USA.

Cultivar/Stock	Biostimulants treatment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Zn (ppm)	Mn (ppm)	Fe (ppm)	Cu (ppm)	B (ppm)	Al (ppm)
Mutsu/M.9T337		2.80 a[i]	0.172 c	2.14 a	1.18 c	0.30 a	0.2 ab	20.8 bc	32.5 ab	63.1 a	6.52 b	28.9 c	37.4
Gala/M.9Pajam2		2.67 b	0.179 bc	2.06 a	1.21 bc	0.28 ab	0.2 b	27.2 ab	36.6 a	70.3 a	6.82 b	31.5 b	44.5
Honeycrisp/M.9Nic29		2.67 b	0.184 b	1.66 c	1.20 c	0.24 bc	0.2 ab	29.9 a	33.8 ab	65.0 a	8.76 a	34.6 a	38.8
Jonagold/B.9		2.64 b	0.193 a	1.71 bc	1.57 a	0.25 bc	0.2 b	28.2 a	29.9 b	63.2 a	5.92 c	28.3 c	39.1
Macoun/B.9		2.74 ab	0.187 ab	1.80 b	1.34 b	0.24 c	0.2 a	19.2 c	36.4 a	63.2 a	6.48 b	23.8 d	34.9
Cultivar/Stock significance		NS	**	**	NS	*	NS	*	NS	NS	**	**	NS
	No biostimulants	2.69	0.183	1.87	1.29	0.26	0.2	24.9	35.0 a	61.0 b	6.37 b	29.1	38.9
	Biostimulants	2.71	0.183	1.88	1.31	0.26	0.2	25.4	32.7 b	68.8 a	7.43 a	29.8	39.1
Biostimulants treatment significance		NS	NS	NS	NS	NS	NS	NS	*	*	**	NS	NS
Interaction means													
Mutsu	No biostimulants	2.77	0.168	2.14	1.18	0.28	0.2	19.1	32.3	60.4	5.78	28.9	44.3 a
	Biostimulants	2.83	0.176	2.14	1.19	0.31	0.2	22.6	32.7	65.9	7.26	28.9	30.5 c
Gala	No biostimulants	2.66	0.180	2.06	1.23	0.28	0.2	25.9	38.1	65.4	6.26	30.7	43.8 a
	Biostimulants	2.68	0.178	2.06	1.19	0.28	0.2	28.5	35.0	75.2	7.39	32.2	45.3 a
Honeycrisp	No biostimulants	2.64	0.185	1.65	1.15	0.24	0.2	29.0	34.8	61.9	8.39	34.2	38.0 abc
	Biostimulants	2.70	0.182	1.67	1.25	0.24	0.2	30.8	32.8	68.0	9.14	34.9	39.5 ab
Jonagold	No biostimulants	2.63	0.193	1.65	1.57	0.28	0.2	31.7	30.4	57.3	5.36	28.3	33.0 bc
	Biostimulants	2.64	0.193	1.77	1.57	0.23	0.2	24.8	29.3	69.2	6.48	28.3	45.3 a
Macoun	No biostimulants	2.75	0.188	1.83	1.33	0.24	0.2	18.0	39.6	60.1	6.02	22.7	35.0 bc
	Biostimulants	2.73	0.186	1.77	1.35	0.23	0.2	20.2	33.6	65.9	6.89	24.7	34.8 bc
Interaction significance		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*

[i] Means within columns and sections with the same letter are not significantly different using Duncan's multiple range test at $P \leq 0.05$. *, **, or NS indicate treatment had a significant effect at $P \leq 0.05$ or $P \leq 0.01$ levels, or had a nonsignificant effect, respectively.

In the last year (2013), biostimulants increased TCSA significantly compared with the untreated control treatment (Table 1). There was a significant interaction between cultivar and biostimulant treatment where biostimulants had the highest TCSA increase for 'Mutsu' and the lowest for 'Honeycrisp'. There was no significant difference between the treatments for 'Gala', 'Jonagold', and 'Macoun'.

During the 5 years of this experiment, biostimulants did not increase total leader length or total shoot growth but did significantly increase the average shoot length compared with the control (Table 2).

Flowering and fruiting. During the second year of growth (first cropping year 2010), the biostimulant treatment had a similar fruit number and yield as the control treatment (Table 3); however, fruit size was increased with the biostimulant treatment. There was an interaction between cultivar and biostimulant treatment with fruit size, where biostimulants increased the fruit size significantly for 'Mutsu' but for 'Gala', 'Honeycrisp', 'Jonagold', and 'Macoun', there was no effect of the biostimulants compared with the control treatment.

In the third year (2011), biostimulants treatment had higher fruit number and yield than the control treatment (Table 3). However, during the fourth year (2012), the control treatment had the higher fruit number and yield compared with the biostimulants treatment (Table 3). The biostimulant treatment increased fruit size significantly compared with the control. There was an interaction between cultivar and biostimulant treatment in which fruit size of 'Honeycrisp' was greater with biostimulants than the untreated control. However, with 'Mutsu', 'Gala', 'Jonagold', and 'Macoun', there was no difference between the treatments. In the fifth year (2013), there was significant interaction between cultivar and biostimulant treatment, in which biostimulants increased the fruit number per tree and yield for 'Honeycrisp', whereas with 'Mutsu', 'Gala', 'Jonagold', and 'Macoun' there was no effect of biostimulant treatment (Table 3).

Over the 5 years of the experiment, biostimulants increased cumulative yield per tree, and fruit size significantly compared with the

Table 5. Effect of biostimulants on nutrient concentration of five apple cultivars in the second year (2010) at Geneva, NY, USA.

Cultivar/Stock	Biostimulants treatment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Zn (ppm)	Mn (ppm)	Fe (ppm)	Cu (ppm)	B (ppm)	Al (ppm)
Mutsu/M.9T337		3.03 a[i]	0.17 b	1.52 c	2.35 b	0.43 a	0.2 ab	176 b	56.5 a	74.6 a	9.80 cd	41.2 a	8.7 b
Gala/M.9Pajam2		2.78 b	0.162 b	1.7 bc	1.72 c	0.37 b	0.2 d	146 cd	48.3 a	71.6 a	10.24 bc	39.6 a	25.8 a
Honeycrisp/M.9Nic29		2.77 b	0.167 b	1.32 d	2.4 b	0.29 c	0.2 bc	247 a	53.8 a	70.8 a	9.11 d	42.2 a	25.5 a
Jonagold/B.9		2.78 b	0.175 b	1.87 ab	1.92 c	0.44 a	0.2 cd	129 d	53.6 a	64.3 a	10.69 ab	42.9 a	21.8 a
Macoun/B.9		2.87 ab	0.199 a	1.9 a	2.85 a	0.31 c	0.3 a	156 bc	46.9 a	73.7 a	11.41 a	40 a	19.8 a
Cultivar/Stock significance		*	*	**	**	**	**	**	NS	NS	**	NS	*
	No biostimulants	2.85	0.17	1.58 b	2.24	0.38	0.2	175	54.7	71	8.25 b	41.2	21.7
	Biostimulants	2.85	0.178	1.72 a	2.26	0.35	0.2	170	48.9	71.4	12.25 a	41.1	18.9
Biostimulants treatment significance		NS	NS	**	NS	NS	NS	NS	NS	NS	**	NS	NS
Interaction means													
Mutsu	No biostimulants	2.97	0.162	1.44	2.31	0.42	0.2	185	55.9	69.8	7.95	41.7	6.7
	Biostimulants	3.08	0.177	1.61	2.39	0.44	0.2	166	57.1	79.3	11.65	40.7	10.7
Gala	No biostimulants	2.77	0.162	1.67	1.67	0.38	0.2	144	49.1	72.9	8.27	39.5	29.0
	Biostimulants	2.79	0.161	1.73	1.76	0.36	0.2	148	47.6	70.4	12.21	39.6	22.7
Honeycrisp	No biostimulants	2.89	0.163	1.25	2.47	0.30	0.2	244	54.6	70.3	6.81	42.2	29.7
	Biostimulants	2.65	0.172	1.39	2.34	0.29	0.2	250	53.0	71.2	11.40	42.3	21.3
Jonagold	No biostimulants	2.78	0.171	1.79	2.01	0.45	0.2	126	56.0	65.3	9.46	42.7	26.3
	Biostimulants	2.79	0.181	2.00	1.78	0.42	0.2	133	50.1	62.9	12.53	43.3	15.0
Macoun	No biostimulants	2.82	0.198	1.81	2.83	0.34	0.3	178	58.5	77.9	8.86	39.9	15.6
	Biostimulants	2.90	0.199	1.98	2.88	0.29	0.2	138	37.3	70.3	13.54	40.1	23.3
Interaction significance		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[i] Means within columns and sections with the same letter are not significantly different using Duncan's multiple range test at $P \le 0.05$. *, **, or NS indicate treatment had a significant effect at $P \le 0.05$ or $P \le 0.01$ levels, or had a nonsignificant effect, respectively.

Table 6. Effect of biostimulants on fruit quality and storage disorders of five apple cultivars in the third year (2011) at Geneva, NY, USA.

Cultivar/Stock	Biostimulants treatment	Fruit firmness (N)	Soluble solids (%)	Dry matter (%)	Storage disorders incidence (%) Flesh browning	Bitter pit	Brown core
Mutsu/M.9T337		59.6 c[i]	14.6 a	15.3 a	0.0	0.0 b	0.0
Gala/M.9Pajam2		68.1 a	14.3 a	13.5 a	0.0	0.0 b	0.0
Honeycrisp/M.9Nic29		62.3 b	13.6 b	13.9 a	0.0	17.3 a	0.0
Jonagold/B.9		45.8 d	13.5 b	14.3 a	0.0	0.0 b	0.0
Macoun/B.9		46.3 d	12.6 c	13.0 a	1.3	0.0 b	5.6
Cultivar/Stock significance		**	**	NS	NS	**	NS
	No biostimulants	56.9	13.9	14.6	0.0	2.6	1.2
	Biostimulants	56.0	13.6	13.5	0.5	3.7	1.0
Biostimulants treatment significance		NS	NS	NS	NS	NS	NS
Interaction means							
Mutsu	No biostimulants	60.5	15.0	15.7	0.0	0.0 b	0.0
	Biostimulants	58.7	14.2	14.9	0.0	0.0 b	0.0
Gala	No biostimulants	68.1	14.5	15.4	0.0	0.0 b	0.0
	Biostimulants	68.1	14.2	11.6	0.0	0.0 b	0.0
Honeycrisp	No biostimulants	64.1	13.6	14.2	0.0	15.7 a	0.0
	Biostimulants	61.4	13.7	13.7	0.0	18.4 a	0.0
Jonagold	No biostimulants	46.3	13.4	14.0	0.0	0.0 b	0.0
	Biostimulants	45.8	13.7	14.7	0.0	0.0 b	0.0
Macoun	No biostimulants	46.7	12.8	13.5	0.0	0.0 b	6.3
	Biostimulants	45.4	12.4	12.6	2.5	0.0 b	5.0
Interaction significance		NS	NS	NS	NS	*	NS

[i] Means within columns and sections with the same letter are not significantly different using Duncan's multiple range test at $P \leq 0.05$. *, **, or NS indicate treatment had a significant effect at $P \leq 0.05$ or $P \leq 0.01$ levels, or had a nonsignificant effect, respectively.

untreated control treatment (Table 2). However, there was a significant interaction between cultivar and biostimulant treatment with yield per tree. Biostimulants increased yield significantly for 'Honeycrisp'; however, for 'Mutsu', 'Gala', 'Jonagold', and 'Macoun', no effect of biostimulants was found. Cumulative yield efficiency and average crop load with 'Honeycrisp' were significantly higher with the biostimulants treatment than the control, whereas with 'Gala' the untreated control had higher cumulative yield efficiency and crop load. With the other cultivars (Mutsu, Jonagold, and Macoun), there were no differences between the treatments.

Nutrient concentration in the leaves. In the first year of growth (2009), trees receiving the biostimulant treatment had a higher concentration of Fe and Cu in the leaves but a lower concentration of Mn (Table 4). There was a significant interaction of cultivar and biostimulant treatment with Al concentration, whereas with 'Mutsu', the biostimulant treatment had lower concentration of Al than the control treatment. However, for 'Jonagold' the biostimulant treatment had the higher Al concentration. No differences in Al concentration were found for 'Gala', 'Honeycrisp', and 'Macoun'.

During the second year (2010), biostimulants gave a higher concentration for K and Cu in the leaves compared with the control treatment (Table 5). No significant interaction between cultivar and biostimulant treatment was found for nutrient concentration in 2010.

Fruit quality, storage disorders, and fruit pack-out. During the third and fourth years (2011, 2012), biostimulants treatment had no effect on fruit quality or storage disorder incidence (Tables 6 and 7). However, in 2011, there was a significant interaction of cultivar and biostimulant treatment caused by the high incidence of bitter pit with 'Honeycrisp' whereas the other cultivars had none.

Effect of plastic mulch

During the 5-year duration of this experiment, the cumulative growth variables did not show differences due to the plastic mulch treatment compared with the no plastic control treatment. However, the plastic mulch increased cumulative yield per tree significantly compared with the no plastic control treatment (Table 8). Other yield variables did not show any differences between the treatments.

Discussion

Vegetative growth. The use of various biostimulant products has been adopted recently in many crops with reported beneficial effects in growth (Rathore et al. 2009; Russo and Berlyn 1991; Vernieri et al. 2005). In our trial, the use of biostimulants as foliar sprays did not improve tree growth consistently over the 5-year duration of observations. Malaguti et al. (2002) tested the use of seaweed extracts (brown algae, *Fucus* spp.) with results similar to ours.

In our trial, we used a combination of a seaweed extract (Stimplex), vitamins and enzymes (Vitazyme), phosphite and organic acids (Nutriphite Magnum), and foliar Ca fertilizer (System-Ca). The combined use of these biostimulant products has not been reported in the literature. We used the products in combination due the individual positive effects on growth that had been reported by other authors in different crops. We hypothesized that their combined use would result in better growth than

Table 7. Effect of biostimulants on fruit quality, and storage disorders of five apple cultivars in the fourth year (2012) at Geneva, NY, USA.

Cultivar/Stock	Biostimulants treatment	Fruit firmness (N)	Fruit soluble solids (%)	Fruit dry matter (%)	Fruit storage disorders incidence (%)					
					Superficial scald	Bitter pit	Lenticel breakdown	Senescent breakdown	Flesh browning	Watercore
Mutsu/M.9T337		62.7 a[i]	17.9 a	20.7 a	0.0 b	0.0	0.0 b	10.6 a	0.0 b	0.8
Gala/M.9Pajam2		63.2 a	16.1 b	19.3 b	0.0 b	0.7	0.4 b	0.0 b	2.6 a	0.0
Honeycrisp/M.9Nic29		53.4 b	13.8 d	17.2 c	4.4 a	1.7	5.7 a	0.0 b	0.0 b	0.0
Jonagold/B.9		47.2 d	15.9 b	19.1 b	2.5 ab	0.0	0.5 b	9.4 a	0.0 b	0.0
Macoun/B.9		49.4 c	14.7 c	17.8 c	0.0 b	0.0	0.0 b	3.3 b	1.1 b	0.4
Cultivar/Stock significance		**	**	**	NS	NS	*	**	**	NS
	No biostimulants	55.6	15.7	18.7	1.5	0.5	1.0	4.6	0.5	0.1
	Biostimulants	54.7	15.7	18.9	1.3	0.5	1.6	4.8	0.9	0.3
Biostimulants treatment significance		NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction means										
Mutsu	No biostimulants	62.3	17.8	20.3	0.0	0.0	0.0	12.3	0.0	0.0
	Biostimulants	63.2	17.9	21.1	0.0	0.0	0.0	8.9	0.0	1.7
Gala	No biostimulants	63.2	16.0	18.8	0.0	1.4	0.7	0.0	2.6	0.0
	Biostimulants	63.2	16.2	19.9	0.0	0.0	0.0	0.0	2.7	0.0
Honeycrisp	No biostimulants	53.4	13.6	17.4	7.1	1.0	3.1	0.0	0.0	0.0
	Biostimulants	53.4	13.9	17.0	1.7	2.3	8.2	0.0	0.0	0.0
Jonagold	No biostimulants	47.6	16.0	19.1	0.0	0.0	1.1	7.6	0.0	0.0
	Biostimulants	46.7	15.9	19.1	5.0	0.0	0.0	11.3	0.0	0.0
Macoun	No biostimulants	51.2	15.0	17.9	0.0	0.0	0.0	2.8	0.0	0.8
	Biostimulants	48.0	14.6	17.6	0.0	0.0	0.0	3.7	2.0	0.0
Interaction significance		NS	NS	NS	NS	NS	NS	NS	NS	NS

[i] Means within columns and sections with the same letter are not significantly different using Duncan's multiple range test at $P \leq 0.05$. *, **, or NS indicate treatment had a significant effect at $P \leq 0.05$ or $P \leq 0.01$ levels, or had a nonsignificant effect, respectively.

when used individually. It is important to point out that our trees with or without biostimulants received the same amount of nitrogen through fertigation. Cheng et al. (1999) tested the application of foliar urea to increase nitrogen reserves and improve growth. They found that if the nitrogen level in the trees was initially high, urea application did not have a significant effect in N reserves and growth. This also could explain why the use of biostimulants did not have a positive effect on growth in our study, because our trees were receiving a constant amount of N throughout spring and early summer and probably reached their maximum potential growth given the weather and climate conditions we had.

The use of plastic mulch has been well documented for vegetables and field crops. Many authors have found that the use of plastic mulch increased plant biomass in wheat (Li et al. 1999), in cotton (Dong et al. 2009), and in tomato and cucumber (Wolfe, et al. 1989). In apple, Måge (1982) found that young apple trees with the soil covered with black plastic had significantly higher vegetative growth. In our data, the plastic mulch did not improve the overall tree growth, with results similar to the findings of Neilsen et al. (1986). However, their study found higher N concentrations in leaves with plastic mulch, which is the opposite of our findings, where we did not find any differences in leaf N concentrations. In our trial, the use of plastic mulch improved tree growth only in 'Gala', where shoot length and pruning weights were significantly higher than the nonplastic control treatment.

Flowering and fruiting. In our trial, the effect of biostimulants on cumulative yield was variable among cultivars. With 'Honeycrisp' the use of these products improved yield significantly compared with the control, whereas with 'Mutsu', 'Jonagold', and 'Macoun', there was a numeric improvement in yield but it was not statistically different from the control. However, with 'Gala', the untreated control treatment had numerically greater but not significantly different yield than the biostimulants treatment. Thalheimer and Paoli (2002) tested three different biostimulant products on 'Braeburn', 'Golden' and 'Fuji',

Table 8. Effect of plastic mulch on cumulative tree growth and fruiting of five apple cultivars during 5 years at Geneva, NY, USA.

Cultivar/Stock	Plastic mulch treatment	Cumulative growth and fruiting measurements: Leader growth (cm)	Total shoot growth (cm)	Pruning wt (g)	Yield (kg/tree)	Yield (t/ha)	Yield efficiency (kg/cm^2 TCSA)	Avg: Crop load (fruit no./cm^2 TCSA)	Fruit size (g)	Shoot length (cm)
Mutsu/M.9T337		157.3 b[i]	5,193 b	1,435 b	62.2 a	177.8 a	2.79 b	3.3 c	290.0 a	24.7 b
Gala/M.9Pajam2		195.8 a	8,676 a	2,337 a	58.2 a	166.3 a	2.84 b	5.5 a	162.8 d	27.4 a
Honeycrisp/M.9Nic29		136.6 c	5,338 b	1,069 c	39.7 c	113.4 c	2.54 b	3.9 c	247.3 b	20.8 c
Jonagold/B.9		165.8 b	4,999 b	1,352 b	52.5 b	150.0 b	3.38 a	4.6 b	237.7 c	26.4 a
Macoun/B.9		154.9 bc	2,915 c	787 d	33.4 d	95.5 d	2.60 b	5.1 ab	157.8 d	23.5 b
Cultivar/Stock significance		**	**	**	**	**	**	**	**	**
	No plastic	158.4	5,149	1,236	47.6 b	135.9 b	2.8	4.5	220.0	24.1
	Plastic	166.2	5,834	1,590	51.7 a	147.7 a	2.87	4.5	221.4	25.1
Biostimulants treatment significance		NS	NS	NS	*	*	NS	NS	NS	NS
Interaction means										
Mutsu	No plastic	149.5	4,960	1,212	61.9	176.8	2.99	3.5	286.5	24.8
	Plastic	165.2	5,427	1,658	62.6	178.9	2.60	3.2	293.4	24.6
Gala	No plastic	199.2	7,875	1,981	58.2	166.2	2.99	5.8	164.0	26.8
	Plastic	192.4	9,478	2,694	58.3	166.5	2.69	5.3	161.6	28.0
Honeycrisp	No plastic	131.7	5,107	948.8	34.3	98.0	2.20	3.6	243.7	20.3
	Plastic	141.5	5,570	1,189	45.1	128.8	2.87	4.2	251.0	21.2
Jonagold	No plastic	158.6	4,612	1,192	48.7	139.1	3.27	4.5	240.6	25.3
	Plastic	172.9	5,386	1,513	56.4	161.0	3.48	4.7	234.8	27.5
Macoun	No plastic	152.6	3,016	811	33.7	96.3	2.53	4.9	160.3	23.2
	Plastic	157.3	2,804	761	33.2	94.7	2.67	5.3	155.1	23.8
Interaction significance		NS	NS	NS	NS	NS	NS	NS	NS	NS

[i] Means within columns and sections with the same letter are not significantly different using Duncan's multiple range test $P \leq 0.05$. *, **, or NS indicate treatment had a significant effect at $P \leq 0.05$ or $P \leq 0.01$ levels, or had a nonsignificant effect, respectively.

and found no differences in yield or return bloom. However, Spinelli et al. (2009) found that the use of an algae-based product decreased the oscillation in yield between the "on" and the "off" year and increased yield in the "off" year.

It is important to note that our work and the previously cited work were done in climates with very favorable growing conditions. In addition, our trees were irrigated and fertigated and received good cultural and disease management practices. It is possible that the use of biostimulant products in a more stressful environment could potentially have a positive effect in yield. Sahain et al. (2007) tested the use of two biostimulant products with different concentrations in a more adverse environment (hot and dry climate, calcareous soil, and the use of flood irrigation) and found that biostimulants improved growth and yield of 'Anna' apple compared with the untreated control treatment.

Although fruit growers in New York State commonly use several biostimulant products, there is little scientific evidence regarding whether they are beneficial in increasing apple tree growth and yield in humid climates. The vast majority of the work with these products has been done in annual crops (Abetz and Young 1983; Rathore et al. 2009; Russo and Berlyn 1991). For tree fruits, there are few scientific trials that have tested the use of biostimulants.

In general, fruit quality or packout was not improved by the use of biostimulant products in our trial. This is similar to the results of Thalheimer and Paoli (2002), who found no significant improvement in the internal or external fruit quality (size, color, fruit firmness, soluble solids, and acidity). In addition, bitter pit was high for 'Honeycrisp' in 2011 and the use of biostimulants did not reduce the incidence of this disorder.

The use of black plastic mulching typically increases soil temperature as well as maintaining a constant moisture condition on the root zone. We hypothesized that this microclimate modification could potentially increase vegetative growth and yield in apple in New York State. We found that the use of black plastic mulch did not improve the cumulative yield for 'Mutsu', 'Gala', and 'Macoun'; however, for 'Honeycrisp' and 'Jonagold', the black plastic mulch improved yield significantly. These results are in agreement with the results from Måge (1982), where trees under plastic mulch yielded twice as much as trees growing in an herbicide strip. Neilsen et al. (1986) compared the use of black plastic mulch with full groundcover and found higher yields under the plastic. In a separate trial, Neilsen et al. (2003) compared the use of black plastic mulch with other organic mulches. They found shredded paper with or without biosolids and the black plastic mulch increased the yield of 'Spartan' apple significantly more than the control (herbicide strip). In humid climates, the use of organic and plastic mulches was tested by Merwin et al. (1995). They concluded that organic mulches provided long-term improvements in soil fertility and water conservation. However, these benefits sometimes do not compensate for the additional costs of the mulches. Fruit quality, pack-out, and storage disorders were unaffected by the use of black plastic mulch.

Many other crops have shown improved yield with the use of plastic, especially with vegetable production. The use of black plastic mulch increased yield and reduced weed infestation with tomato (Shrivastava et al. 1994). Moreno and Moreno (2008) tested the use of different biodegradable mulches showing very similar results with tomato. Also, the use of plastic has been tested in field crops, in corn. Liu et al. (2009) tested the use of mulching at different timings and found that mulching applied before sowing gave earlier germination and better plant establishment and better yield.

Conclusions

The success of a high-density apple orchard depends on choosing the right planting system and getting the trees into production as fast as possible so that the high investment can be recovered as soon as possible. First, the tree must grow and develop a framework suitable for early production. However, many orchards experience difficulties that inhibit good tree growth in the early life of the planting, therefore affecting early cropping. This study was intended to overcome some of these problems with the objective to improve growth and maximize yield of high-quality fruit.

Our results showed that the use of common biostimulant products was not beneficial and do not support our hypothesis that these products could increase tree growth and yield. This is especially true when orchards already are in an adequate nutritional status, which was the case for our orchard. However, cumulative yield of 'Honeycrisp' was improved by 36 t/ha compared with the control. It seems that the use of biostimulants may help this cultivar in the off year, resulting in better yields.

The use of synthetic black plastic in orchards could be beneficial but has some drawbacks. First, most growers lack the specialized equipment needed to lay out the plastic in large scale, and also the cost and durability of the mulch is a deterrent; however, the use of black plastic mulch could reduce the cost of herbicides and the labor cost to control weeds because it provides multiyear weed control. However, if yields are improved, like in our case, especially for a high-priced cultivar such as 'Honeycrisp', this could be a feasible alternative to the conventional systems.

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