UNIVERSITY OF MINNESOTA EXTENSION

Research results from Deep Winter Greenhouse horticulture trials:

A UNIVERSITY OF MINNESOTA RSDP, HORTICULTURE DEPARTMENT, AND DWG GROWER COLLABORATION

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BACKGROUND

Deep Winter Greenhouses (DWG) use passive solar technology to create an environment where cold tolerant crops like leafy greens can be grown during the winter to satisfy consumer demand for fresh local produce year-round and increase revenue for farmers. Growing in the depths of winter in Minnesota can be challenging, and plant responses change throughout the winter given the different winter sub-seasons according to day length and light availability (Table 1).

Figure 1. Deep Winter Greenhouse in Madelia, MN.

Current DWG producers have a general understanding of specific production practices that thrive in the DWG system, but some questions remain. Through a University of Minnesota and DWG producer partnership, experiments were conducted in the Minnesota cities of Bemidji, Finland, Madelia, and Lake City (between latitudes 44.15 and 47.46 °N) to address questions related to cultivar and growing media selection, seeding density, and microclimate management. These results can help inform producer decisions about growing in these unique environments and lead to increased productivity and revenue for producers.

For more information please visit:
https://extension.umn.edu/growing-systems/deep-winter-greenhouses

Table 1. Winter sub-seasons as defind in The Northlands Winter Greenhouse Manual (2009)

SUB-SEASON	TIME	SUNLIGHT
Diminishment	October to Solstice	Shorter days; Less daylight
Solstice	Mid- Dec to Mid-Jan	Stable daylength & daylight
Expansion	Late Jan to Spring Equinox	Longer days; more daylight

DWG MICROCLIMATE PARAMETERS 2019

Table 2. Monthly average microclimate parameters including ambient temperature and percent relative humidity (RH), light intensity, and below-ground rock bed temperature are shown for Deep Winter Greenhouse production across four DWGs in 2019.

MONTH	TEMP RANGE AND (AVERAGE) (ºF)	RH%	LIGHT INTENSITY (lux ft^2)	ROCK BED TEMP (ºF)
September	54-107 (64)	86	663	--
October	40-118 (64)	79	800	64
November	41-106 (56)	86	609	58
December	43-101 (54)	88	649	54
January	40-101 (53)	89	877	52
February	41-96 (53)	88	842	52
March	44-109 (62)	82	1243	59
April	46-102 (67)	67	651	65

SALAD GREEN CULTIVAR TRIALS 2018-2019

Objective: select new crop varieties and compare to standard varieties grown in DWGs

Methods

During the winters of 2018-2019, salad green cultivars were evaluated to identify those best suitable for use in Deep Winter Greenhouses (DWG) in Minnesota. Cultivars were selected based on grower preferences, previous research in DWG, and seed company descriptors of traits such as “germination at low temperatures”, “slow to bolt”, and/or “early maturing” that would be beneficial in the unique DWG growing system (Table 3). Following grower practices, greens were grown in standard gutters (4.5” x 40”) filled with a custom grower media mix (Table 2). Greens were seeded at recommended rates, mostly 144 seeds/ft^2, and harvested at maturity (~4-5”) up to three times in a given sub-season.

Figure 2. Experimental setup for cultivar & substrate trials

Results

Season	• Average total yields were almost twice as high in the Expansion season as compared to the Solstice season, and still almost 150 grams higher (per gutter on average) than the Diminishment season.
Location	• Total yields per gutter averaged 203 grams across all 4 locations. Excluding the low-yielding outlier, average total gutter yield across locations was 244 g. • Across seasons, the best performing location yielded 305 g per gutter, compared to 214, 213, and 52 g at the others.
Repetition	• Greens growing closest to the glazing wall receiving the most light yielded the highest-an average of 60 g higher than the others that experienced some shading.
Cultivar	• The lettuces grown during the expansion season yielded the highest (Table 1). • Tokyo Bekana was the only non-lettuce that yielded significantly more than the rest of the cultivars. • The spinaches, Rainbow chard, and Red Veined sorrel were among the lowest yielding. • Some cultivars show promise yielding higher than standard cultivars used; Vitamin Green, Mizspoona, Gemstone Mix, and Esmee, yielded higher than similar cultivars Mizuna, Ruby Streaks, and Arugula.

Suggestions for DWG producers:

- Focus on high-yielding cultivars, particularly in the Diminishment and Solstice seasons
- Space gutters to maximize light penetration and rotate gutters as needed to access sunlight
- Monitor DWG temperatures and water diligently as needed to provide optimal conditions for plant growth

Table 3. Cultivar list including seed source as well as average total fresh weight yields and relative yield potential compared across cultivars by sub-seasons for DWG research trials in 2018-2019.

COMPANY	CROP	CULTIVAR	YIELD (g)	RELATIVE SEASONAL YIELD POTENTIAL	SUB-SEASON
Johnny's[§]	Arugula	Esmee	164	mid	Diminishment [1,2]
Johnny's	Arugula	Arugula	117	low	Diminishment [2]
High Mowing	Asian Green	Mizuna	158	mid	Diminishment [2]
Johnny's	Komatsuna	Carlton	187	high	Diminishment [2]
Johnny's	Greens Mix	Ovation Greens Mix	158	mid	Diminishment [2]
Adaptive	Mustard	Mizspoona	173	high	Diminishment [1,2]
High Mowing	Asian Green	Tokyo Bekana	202	high	Solstice [2]
High Mowing	Asian Green	Vitamin Green	191	high	Solstice [1,2]
Johnny's	Broccoli, leaf	Spigariello Liscia	126	mid	Solstice [1]
High Mowing	Chard	Rainbow	111	mid	Solstice [2]
High Mowing	Endive	Frisee	182	high	Solstice [1,2]
Adaptive	Kale	Madeley	142	mid	Solstice [1]
High Mowing	Mustard	Ruby Streaks	138	mid	Solstice [2]
High Mowing	Mustard Mix	Gemstone Blend	167	mid	Solstice [1,2]
Johnny's	Sorrel	Red Veined	28	low	Solstice [1]
High Mowing	Spinach	Shelby	64	low	Solstice [1]
High Mowing	Spinach	Regiment	66	low	Solstice [1]
Johnny's	Spinach	Emperor	86	mid	Solstice [2]
Adaptive	Lettuce	Florence	329	high	Expansion [1,2]
Wild Garden	Lettuce	Really Red Deer Tongue	263	low	Expansion [2]
Johnny's	Lettuce	Salanova Blend	222	low	Expansion [1,2]
Johnny's	Lettuce Mix	Encore Lettuce Mix	278	mid	Expansion [2]
High Mowing	Lettuce Mix	Gourmet Lettuce Mix	287	mid	Expansion [2]
Adaptive	Lettuce Mix	Summer Lettuce Mix	304	high	Expansion [2]

[§]Adaptive Seeds, OR; High Mowing Organic Seeds, VT; Johnny's Selected Seeds, ME; Wild Garden Seed, OR.
[1]Cultivars evaluated in year 1 2018; [2] Cultivars evaluated in year 2 2019; [1,2] Cultivars evaluated in both years

GROWTH CHAMBER GERMINATION MAT TRIAL 2019

Some DWG growers employ germination heating mats to speed up time to germination for their crops, but is there a benefit to using them?

An experiment was setup in a growth chamber, an enclosed chamber that allows the microclimate to be programmed for experimental plant growth. For this experiment, the chamber was programed to 45-75 ºF, 60% RH, and 10.5 hr days. Six cultivars typically grown in the Diminishment season—Mizuna, Mizspoona, Arugula, Esmee, Ovation Mix, and Carlton-- were grown ½ with a germination mat and ½ without a mat, and replicated three times.

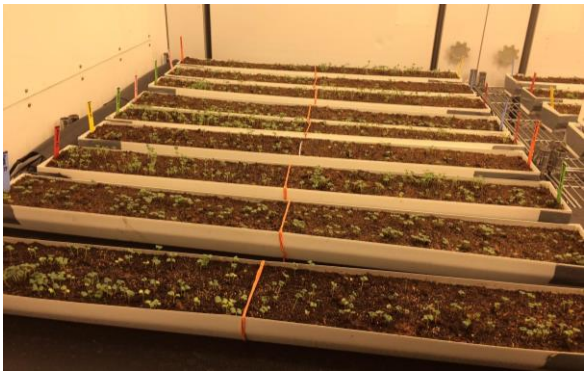

Figure 2. Freshly germinated greens inside growth chamber

Results

No statistical difference in total yield or days to maturity was observed between the two treatments, yet there were numerical differences. A 26-52 g per gutter increase in yields was recorded with a germination mat for Mizuna, Mizspoona, Esmee, and Arugula. However, Carlton & Ovation yielded 33- 63 grams per higher without a mat.

TREATMENT	TOTAL YIELD (g per gutter)	DAYS TO MATURITY
Mat	333 g	34
No Mat	328 g	37

GROWTH CHAMBER TEMPERATURE THRESHOLD TRIALS 2018-2019

Light availability and temperature fluctuates widely in the DWG during the winter and within a single day. We wanted to see what effect temperatures alone had on the yield performance of the greens. Two experiments were conducted to evaluate temperature extremes from cold (35°F night/50°F day) to hot (70°F night/ 85°F day) treatments, while maintaining optimal light levels of 400 umol/m^2/sec and relative humidity levels of 65-70% over 10.5 hour days. Year 1 cultivars (Table 3) were evaluated over 3 reps.

Results

Overall, yields were lower in the Cold treatment and higher in the Hot treatment as compared to average DWG yields. The spinaches were most affected by these treatments, yielding twice as high in both treatments compared to DWG yields, potentially indicating their preference for a more narrow temp range (~15°). Days to maturity were drastically increased in the Cold treatment.

TREATMENT	TOTAL YIELD (g per gutter)	DAYS TO MATURITY
Cold	190 g	81
Hot	220 g	31

Suggestions from both growth chamber experiments

- Germination mat may not be necessary, and may lead to a decrease in yield for some cultivars
- Maintain temperatures between 50°F and 85°F for best results, minimizing swings and extremes

DWG SOILLESS MEDIA SUBSTRATE TRIALS 2018-2019

Objective: identify optimal substrate for winter production based on salad green performance and considering sustainability of source

In 2018, the growth of 'Arugula' grown in three different substrates: 1) Grower Mix (Table 4), 2) Dick's Super Soil (Ottertail, MN), and 3) JavaCycle (4-4-4) mixed with Purple Cow Potting Mix was compared. Trials took place on-farm at three DWGs and repeated in the Solstice and Expansion seasons.

2018 Results

Yields were highest in the Grower Mix and Super Soil treatments, while little to no growth was observed in the Java Cycle treatments due to ammonia and salt toxicity. The conclusion was made, however, that the Super Soil was not sustainable for use due to the fact that it is merely harvested topsoil. A different direction was taken in 2019.

Table 4. Grower Mix recipe as detailed in The Northlands Winter Greenhouse Manual (2009)

INGREDIENTS	AMOUNT *
Peat	3 gallons
Lime	1/2 cup
Compost	3 gallons
Vermiculite	2 gallons
Greensand	1 cup
Rock Phosphate	1 cup
Blood Meal	1/2 cup

** Recipe fills ~ 3.5 - 4 gutters*

SUBSTRATE	TOTAL YIELD (g)
Grower Mix	122 a
Super Soil	121 a
JavaCycle	16 b

In 2019, three different crops were grown according to sub-season; ‘Astro’ arugula in the Diminishment season, ‘Red Giant’ mustard green during the Solstice season, and ‘Five-Star Lettuce Mix’ during Expansion. Crop yield was evaluated in four different substrate mixes: 1) standard Grower Mix containing Mississippi Topsoils compost, 2) Grower Mix without the bloodmeal, 3) Grower Mix with Purple Cow compost instead of Mississippi Topsoils, and 4) Mississippi Topsoils’ Potting Soil. This trial took place at four DWGs throughout the winter of 2018-2019 across four reps. These alterations of the Grower Mix recipe were made based on grower concerns for potential excess nitrate in the mix. It is discussed later that nitrate ingestion from leafy vegetables is not considered harmful.

2019 Yield Results

Across seasons, all cultivars grew best in the standard Grower Mix with Mississippi Topsoils compost, though the Grower Mix with the PC was close behind. An almost 100 g yield loss was observed when removing the bloodmeal from the substrate mix, indicating the plants are responding to this addition. Yields were low in the Potting Soil and showed signs of nutrient deficiency, also evident in Table 5.

SUBSTRATE	TOTAL YIELD (g)
Grower Mix	200 a
Grower Mix with Purple Cow	159 ab
Grower Mix No BM	108 bc
MSTS Potting Soil	81 c

2019 Nutrient Analysis Results

Table 5. Dry soil and plant nutrient components as well as fresh weight levels of nitrate from crops (arugula, mustard, lettuce) grown in respective seasons in DWGs during 2018-19.

TREATMENT	*Soil Nutrients*			*Plant Nutrients*			*Fresh Weight*		
	N ppm	**P** ppm	**K** ppm	**N** %	**P** %	**K** %	**NITRATE** ppm	**NITRATE** mg kg^{-1}	**Serving limit***
DIMINISHMENT	**123**	**308**	**567**	**4.87**	**1.02**	**6.18**	**8850**	**752**	**3**
CAROLMIX	301	293	477	6.49	0.90	6.70	15735	1337	2
PURPLECOW	131	176	638	5.90	0.82	6.80	12862	1093	2
NOBM	52	270	459	4.09	1.03	5.90	5274	448	6
MSTS	7	491	692	2.78	1.35	5.23	689	59	44
SOLSTICE	**117**	**309**	**542**	**5.36**	**0.83**	**7.18**	**15306**	**1301**	**2**
CAROLMIX	227	307	339	6.97	0.70	8.08	28060	2385	1
PURPLECOW	126	178	609	6.29	0.69	7.51	19993	1699	2
NOBM	33	300	480	4.26	0.95	6.69	6780	576	4
MSTS	80	498	715	3.99	0.99	6.48	6684	568	5
EXPANSION	**134**	**401**	**662**	**3.92**	**0.86**	**6.89**	**4277**	**364**	**7**
CAROLMIX	141	428	653	4.51	0.88	6.88	6696	569	5
PURPLECOW	137	187	592	4.77	0.92	8.05	4563	388	7
NOBM	35	286	531	2.91	0.84	6.07	1142	97	27
MSTS	224	704	871	3.37	0.79	6.43	4757	404	6
Adequate levels	20	60	150	3.95	0.38	4.72	2000	--	--

*Servings based on 100 g of fresh weight for a 70 kg person at a limit of 259 mg NO_3 per day.

Suggestions

- The Grower Mix is recommended, though all nutrient components could be lowered to a degree.
- While dietary nitrate from some sources is considered carcinogenic, nitrate ingestion from leafy vegetables is not considered harmful, and is in fact linked to cardiovascular benefits. Still, controversial limits are set for production and ingestion. If people are concerned, they could limit their servings of these leafy greens, particularly during Solstice when nitrate levels are highest due to low light conditions.

SEEDING DENSITY TRIALS 2018-2019

Objective: determine optimal seeding densities for greens grown in DWGs

Many DWG producers seed their gutters at a much higher rate than is recommended. To test whether or not this strategy is beneficial, three different seeding rates for three different salad green cultivars were evaluated in greenhouse at the University of Minnesota in 2018 and 2019. Cultivars selected were 'Arugula', 'DMR Lettuce Mix', and 'Tokyo Bekana'. Greens were seeded into DWG gutters and replicated four times.

Seeding Rates:

- Grower Rate (4x recommended label rate) – *green label in photos below*
- Middle Rate (2x recommended rate, ½ Grower Rate) – *yellow label*
- Recommended Label Rate – *red label*

Results

CULTIVAR	GROWER	MID	REC	*Average*
Arugula	273	251	238	*254*
DMR Lettuce Mix	621	567	474	*554*
Tokyo Bekana	469	450	419	*446*
Average	*454*	*423*	*377*	*418*

Suggestions

- Arugula → Recommended Rate
- Lettuce → Mid-High Rate
- Tokyo Bekana → Mid- High Rate
- Mid-Rate generally sufficient

Overall, yields were the lowest in the recommended seeding rate treatment. On a per gutter basis, 1/6th of a pound may not seem like a meaningful increase in yields, but across an entire greenhouse production these values add up. Still, there wasn't a significant difference between the grower and middle rates, so growers could cut back their seeding rates by half and still maintain similar yields.

No negative effects such as increased disease pressure or moisture buildup were observed with the high seeding rate. However, these plants were grown in a well ventilated, low humidity greenhouse as opposed to the closed, humid DWG environments where we have witnessed these issues. Gutters with the higher seeding rates dried out faster, so DWG producers should keep this in mind for their watering schedules.