Cost-Effective Soy-Based Garden Pots

Progress of Work

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1. Project Summary

This work will develop a novel bioplastic formulation that will incorporate soy-based fractions that will improve the performance of the pots while being cost-competitive. The new pots will not only be fully biobased, degradable, and provide inherent fertilizer for the plant growth, but they will also prevent root circling which will promote plant health and fruit yield, e.g., in tomatoes and peppers.

2. Objectives of the research

The measurable objectives that will be accomplished by this research are:

1. Test plant health and yield with containers produced from four formulations for 2 months in NDSU greenhouses
2. Determine decomposition rates for the containers produced from the various formulations.
3. Perform economic analysis with a targeted price increase of less than 25%
4. Identify product (container) performance in terms of consumer acceptance by distributing to various commercial growers

3. Completed work

Activity A (completed): Pellets of two new formulations were compounded at NDSU:
1) Control (Polyethylene) Will be purchased from a commercial source
2) Existing formulation from SelfEco (PLA +DDGs)
3) New formulation 1 (70% PLA + 30% soy hulls and carbohydrate)
4) New formulation 2 (65% PLA + 30% soy hulls and carbohydrate + 5% SPI, soy protein isolate)

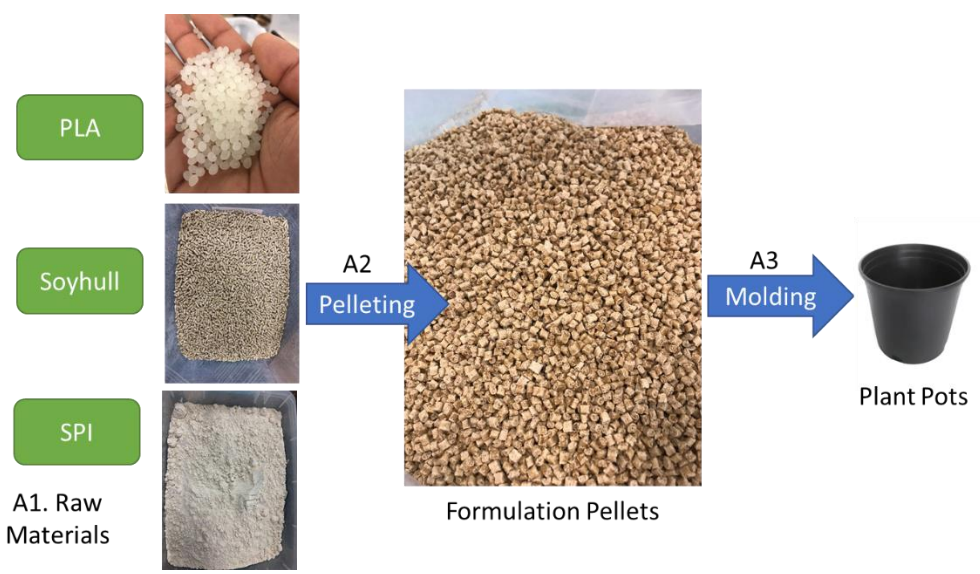


Figure 1. Process breakdown for Activity A

A1. Raw Materials: PLA were obtained from NatureWorks and soy hulls from Carrington Research Extension Center. The PI(s) had SPI in stock. Soy hulls were ground to approximately 100 um prior to compounding.

A2. Pelleting: Pelleting process was completed in collaboration with C2Renew (Fargo). The formulations were dried in the oven for 12 hours and dried at room temperature for one day after the pelleting process before the formulation was shipped to the molder, SelfEco.

Figure 2. Snapshots from the pelleting process

A3. Molding: (On-going)
After pelletizing, the materials were forwarded to SelfEco for molding into garden pots. Currently, there is a delay in molding trials because of scheduling issues. Attempts to have the mold shipped to NSDU for molding trials were considered. However, the mold has hot runners, which makes it incompatible with the NSDU injection molding machine.

Activity B (On-going): Evaluate the growth and performance of horticultural crops in bio-based plastic containers.

The Department of Plant Sciences at NDSU will test the performance of selected horticultural crops in the four different formulations of containers specified above. Plants to be tested include: 1) fruit-bearing vegetables (tomato, eggplant, pepper) and 2) floricultural crops (petunia, geranium, marigold). Seedlings of these crops will be established in the four different container types using a commercial root substrate (Sunshine #1, Promix). Plants will be grown for 2 months in the greenhouse following the normal cultural procedures as practiced in the controlled environment agriculture (CEA) system.

B1. Trial Experiment (completed): Before the arrival of molded soy pots, trial experiments are conducted to observe the plant growth in biodegradable (paper pots) vs. non-biodegradable (plastic pots) pots as well as to compare plant health in 3-inch vs. 4-inch pots. Same plant materials and growing media were used. Seeds were grown in the 4-cell packs for four weeks before they are transferred to actual pots. Four plants were studied: French marigold, Parris island lettuce, cannonball tomato, and celebrity tomato. 4 replications were decided for each pot type per plant species. In total, 12 plants per species x 4 plant species = 48 plants.

Figure 3. Greenhouse Setup (April 3, 2021)

Summary Information from the trial experiments set up.

1. Pot sizes
   a) 3-inch paper pot x 4 pots replication
   b) 3-inch plastic pot x 4 pots replication
   c) 4-inch plastic pot x 4 pots replication

2. Plant species
   a) French marigold (x 12 pots)
   b) Cannonball tomato (x 12 pots)
   c) Celebrity tomato (x 12 pots)
   d) Parris Island lettuce (x 12 pots)

3. Growing media and fertilizers
   - Pro-Mix BX medium (with microbial fungicide)
   - Used liquid feeding with 200 ppm N using 20-20-20 commercial analysis fertilizer

4. Measurement of plant growth
   - Date planted: 02/04/2021
   - Date pictures taken: 4/9/2021, 4/15/2021
   - Date plant growth data taken: 4/9/2021, 4/15/2021

Activity C (On-going): Perform techno-economic analysis (TEA) to ensure the cost competitiveness of the proposed formulation with DDGs-based formulations. Trial experiment (B1) decomposition analysis was studied.

C1. Trial experiment (Completed): In addition to cost and nutrition to the plant, biodegradability is another aspect that attracts consumer adoption to biocomposite pots. For the trial experiment, the degradation of biodegradable (paper pots) was evaluated. The paper pots were initially weighted before the plant health assessments (B1). Many of these paper pots were degraded prematurely before plant health assessment, only the intact pots were studied.

For the degradation assessment, the paper pots were cleaned thoroughly and put in a drying facility. After 5 days at the drying facility, the weights of dry paper pots were measured and compare against the initial weight. Monitoring the weight reduction is one of the most standard methods of evaluating their biodegradability. After the weight of the dried paper pots is measured, and the percentage weight loss of pot is calculated as:

$$Weight\ loss\ (\%) = \frac{W_i - W_f}{W_i} \times 100$$

Here, W_i is the weight of the paper pots before the start of the plant health experiments, and W_f is the weight of the paper pots at the end of the plant health experiments. The figure below shows the initial weight (W_i) is marked on the pots, and the final weight (W_f) is shown on the scale, measured in grams.

Figure 3. Snapshots from the decomposition analysis

4. Preliminary results

B1. Plant Health Assessment Results: After a total of a 6-week growth period in pots, final measurements were quantified (paper and plastic pots only). The measurement variables include plant height, plant width, fresh weight, and root weight. Plant growth evaluation was carried out by destructive means, which involves removing the pots and washing away the soil. Then, the fresh mass (stem and leaves) was cut and separated from the roots, and their individual weights are recorded. Also, the height and width of the fresh mass were recorded. While this whole measurement procedure was carried out, photographs are taken at all the steps for visual analysis, with the three different pot types placed side-by-side for better growth comparison and understanding.

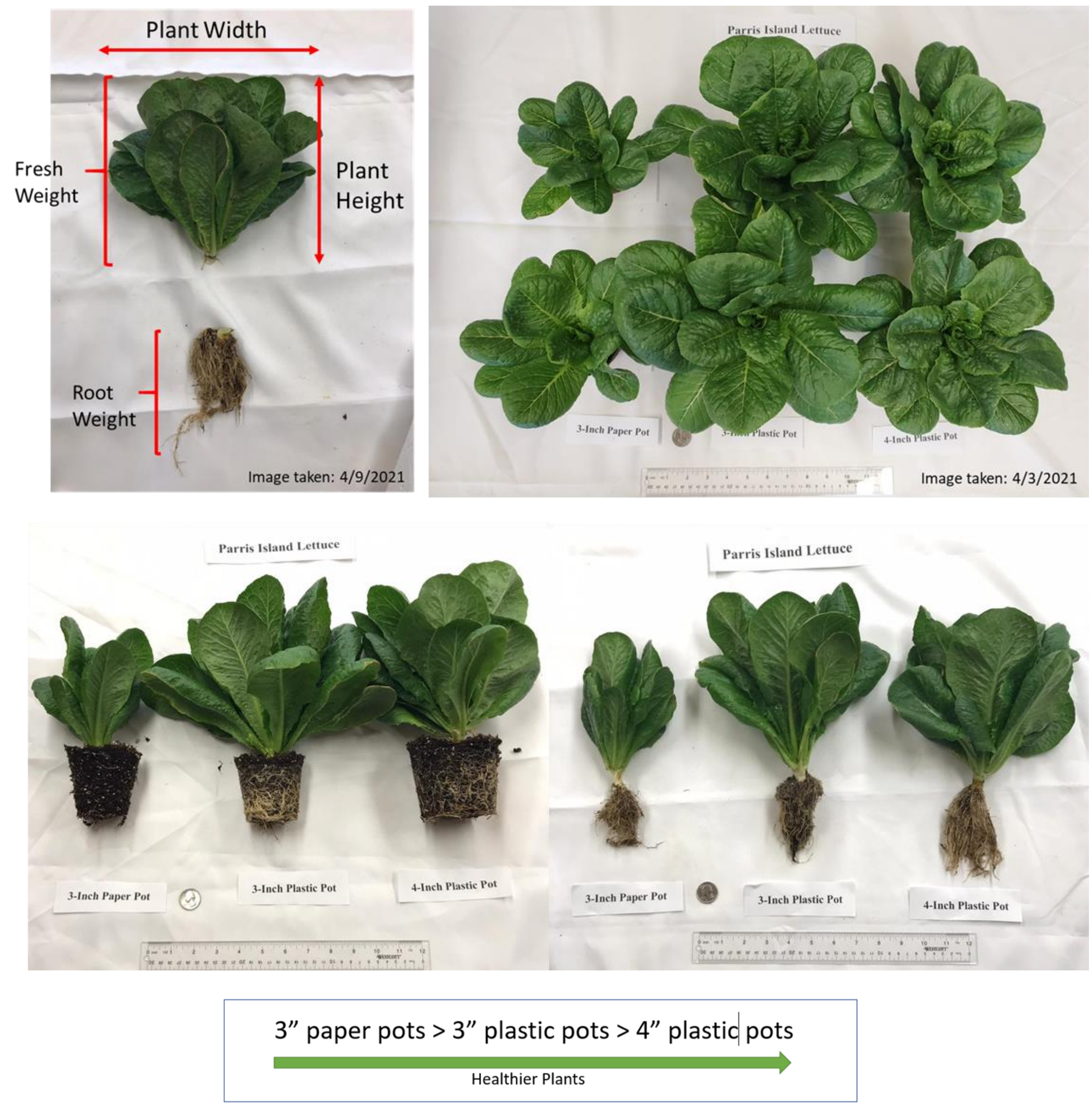
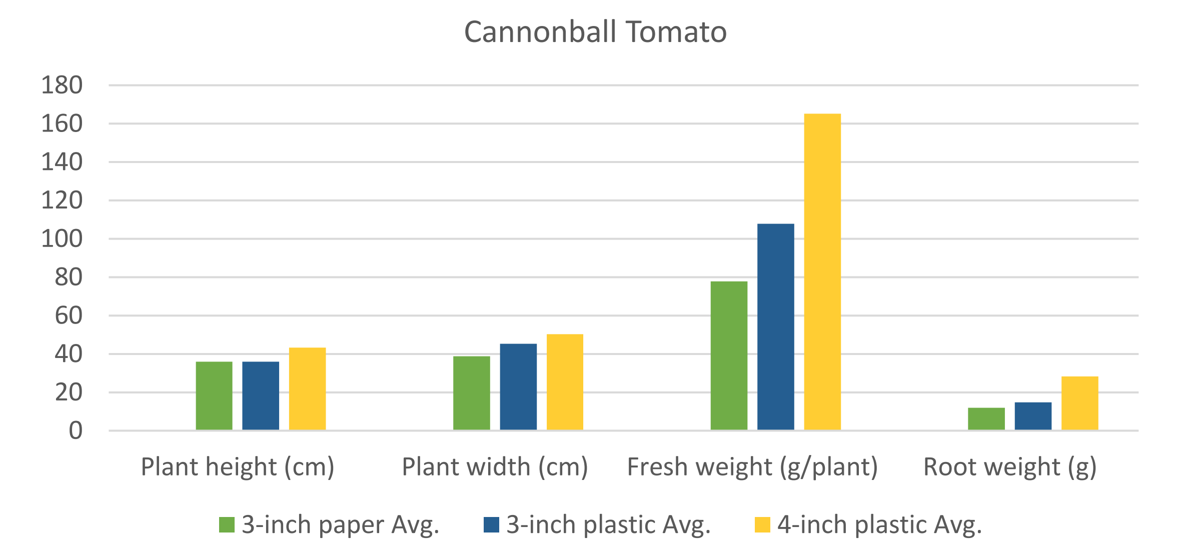


Figure 4. Plant health measurement for the Parris island lettuce

Below are some of the detailed measurements for each species.

1. Cannonball Tomato (Date measured: 4/15/2021)

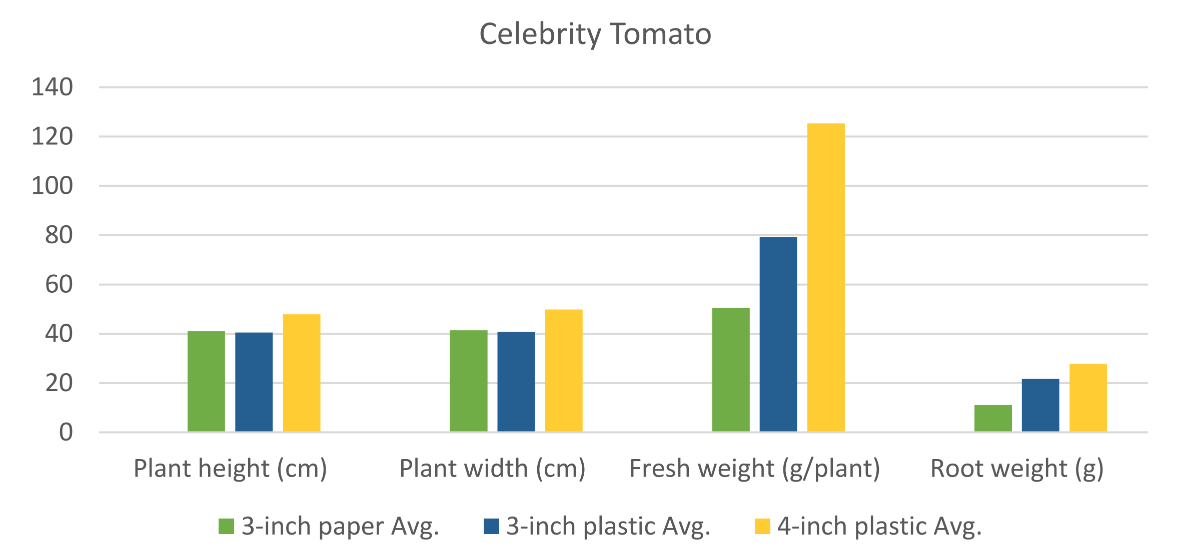
Pot size	Plant no.	Plant height (cm)	Plant width (cm)	Fresh weight (g/plant)	Root weight (g)
3-inch paper	1	42	44	86	14
	2	30	33	85	12
	3	39	39	61	8
	4	33	39	79	14
	Avg.	**36**	**38.75**	**77.75**	**12**
3-inch plastic	1	32	47	101	18
	2	41.5	52.5	101	14
	3	39	46.5	111	11
	4	31	35	118	16
	Avg.	**35.875**	**45.25**	**107.75**	**14.75**
4-inch plastic	1	42.5	52.5	126	19
	2	45.5	51.5	178	44
	3	42	42	193	33
	4	43	55.5	164	17
	Avg.	**43.25**	**50.375**	**165.25**	**28.25**



Note: For cannonball tomatoes, the plants are found to be healthier in the 4 in. plastic pots for the plant height, plant width, fresh weight, and root weight assessments. This is because tomatoes inherently contain a lot of water. Since tomato plants need a higher quantity of water, thus the 4 in. pots are better for the tomato species because the 4 in. pots can contain more water than the 3 in. pots.

2. Celebrity Tomato (Date measured: 4/15/2021)

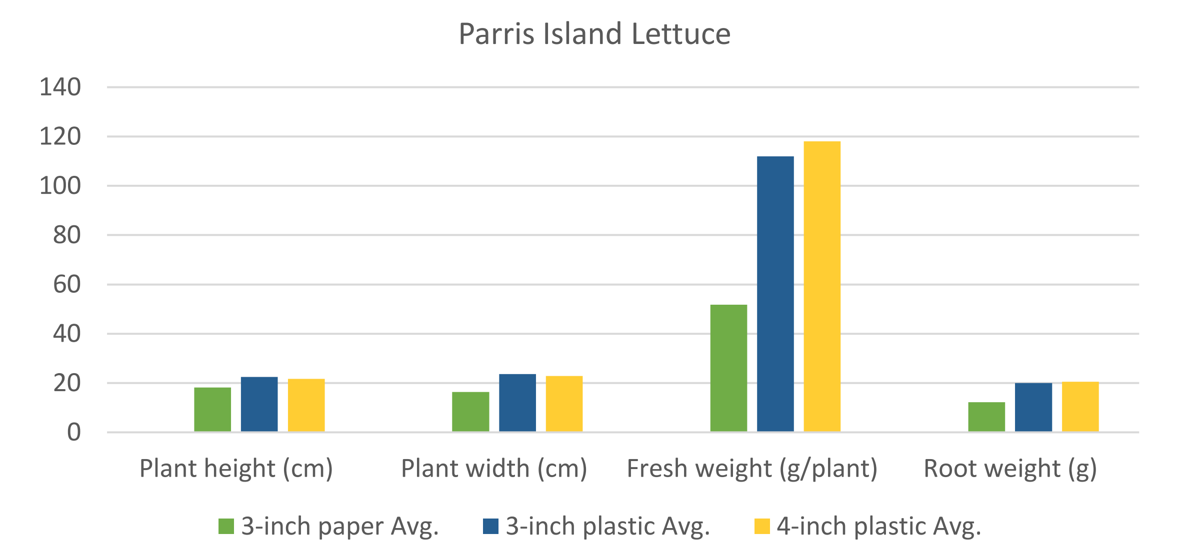
Pot size	Plant no.	Plant height (cm)	Plant width (cm)	Fresh weight (g/plant)	Root weight (g)
3-inch paper	1	42	30	38	7
	2	44	47.5	66	16
	3	31	37	36	8
	4	47	51	62	13
	Avg.	**41**	**41.375**	**50.5**	**11**
3-inch plastic	1	38	35	82	29
	2	47.5	56	75	26
	3	39.5	35	84	15
	4	37	37	76	17
	Avg.	**40.5**	**40.75**	**79.25**	**21.75**
4-inch plastic	1	49.5	52	139	21
	2	45.5	47	110	43
	3	52.5	48	125	20
	4	44	52.5	127	27
	Avg.	**47.875**	**49.875**	**125.25**	**27.75**



Note: Similar results were found for the celebrity tomatoes when compared with the cannonball tomatoes. The plants are found to be healthier in the 4 in. plastic pots in the aspect of plant height, plant width, fresh weight, and root weight. Again, this is because tomatoes inherently contain a lot of water. Since tomato plants need a higher quantity of water, thus the 4 in. pots are better for the tomato species because the 4 in. pots can contain more water than the 3 in. pots.

3. Parris Island Lettuce (Date measured: 4/9/2021)

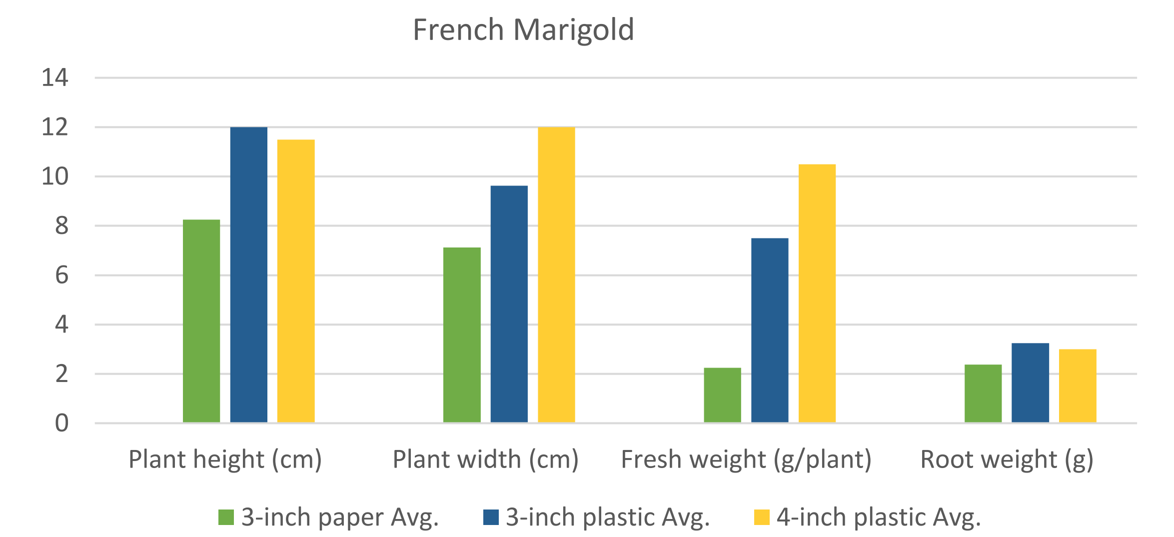
Pot size	Plant no.	Plant height (cm)	Plant width (cm)	Fresh weight (g/plant)	Root weight (g)
3-inch paper	1	17	14	36	10
	2	20.5	19	70	16
	3	15	15.4	38	9
	4	20	17	63	14
	Avg.	**18.125**	**16.35**	**51.75**	**12.25**
3-inch plastic	1	23	23.3	124	24
	2	22	22	76	18
	3	22	25.5	127	24
	4	23	23.5	121	14
	Avg.	**22.5**	**23.575**	**112**	**20**
4-inch plastic	1	20.3	24	94	19
	2	19.5	23.5	100	22
	3	24	23	152	29
	4	23	21	126	12
	Avg.	**21.7**	**22.875**	**118**	**20.5**



Note: In the case of Parris Island Lettuce, the plant health assessment is found to be slightly better for the plant height and plant width in the 3 in. pots, and the fresh weight and root weight are observed to perform better in the 4 in. pots. Based on the difference in measurements, it can be concluded that 4in. pots are better, although more experiments will be required to conclude this claim.

4. French Marigold (Date measured: 4/15/2021)

Pot size	Plant no.	Plant height (cm)	Plant width (cm)	Fresh weight (g/plant)	Root weight (g)
3-inch paper	1	11	11	5	6
	2	9	8	3	2
	3	6	5.5	0.5	0.5
	4 (dead)	7	4	0.5	1
	Avg.	**8.25**	**7.125**	**2.25**	**2.375**
3-inch plastic	1	13	12.5	13	5
	2	13	11.5	11	6
	3	10	7	3	1
	4 (dead)	12	7.5	3	1
	Avg.	**12**	**9.625**	**7.5**	**3.25**
4-inch plastic	1	10	14.5	16	3
	2	13.5	13	17	5
	3	10.5	10	4	2
	4	12	10.5	5	2
	Avg.	**11.5**	**12**	**10.5**	**3**



Note: For Frech marigold's case, the plant health assessment is found to be slightly better for the plant width and fresh weight in the 3 in. pots, and the plants height and root weight are observed to perform better in the 4in. pots. Two plants in the 3in pots (one in 3in. paper pots and one in 3in. plastic pots) are dead prior to the plant health assessment. Based on this scenario, it is concluded that bigger pots size are more suitable for the Frech marigold case.

Conclusions on B1 activity: Based on the plant dimensions, the three in. paper pots showed the least plant growth, especially in the case of Parris Island lettuce and French marigold. Plants are found to be healthier in the 4 in. plastic pots.

The average fresh weight and the average fresh root weight is the maximum in 4 in. plastic pots, followed by 3 in. plastic pots, and the least in 3 in. paper pots. 3 in. paper pots showed the least plant growth, especially in the case of Parris Island Lettuce and French Marigold. In general, by visual analysis alone, plants looked under-developed in 3 in. paper pots compared to the plants in the other two pot types.

All the plants studied did not perform well in paper pots because the paper pots absorb too much water, and many started to disintegrate early (even before the plant health assessment). In addition, the paper pots experience high water loss through their porous sidewalls and subsequently suffer from a high evaporation rate. The water needs of plants in paper pots are not fulfilled sufficiently, leading to poor plant growth.

C1. Degradation Assessment Results: Only eight paper pots were measured and included in the assessment. Most of the paper pots had disintegrated. The pots were weighed before and after the plant health assessment. The details are summarized as follows. The initial and final weights of the paper pots (in grams) are reported in the following table, along with the weight loss percentage of the respective paper pots.

Table 1. Paper Pots Measurement before and after plant health experiment

Paper Pots ID	Initial Weight (g)	Final Weight (g)	Weight loss (%)
1	8.875	8.6132	2.950%
2	8.914	8.8980	0.179%
3	8.815	8.7878	0.309%
4	8.450	8.4316	0.218%
5	8.749	8.7174	0.361%
6	8.890	8.8830	0.079%
7	9.005	8.7517	2.813%
8	8.346	8.3383	0.092%
Avg.	**8.756**	**8.6776**	**0.875%**

Conclusions on C1 activity: The average weight loss of the paper pots during the 6-week use period is about 0.875%. Most of the weight loss data is uniform except for two cases, which might contribute to the position of the paper pots during irrigation in the greenhouse. The paper pots placed at the extremities are less protected from the elements (water and heat) than the pots placed in the middle between other plant pots, and as a result, these pots placed at the extremities might decompose a little more rapidly than the other pots. If all the damaged pots are included in the assessment, the decomposition rate would be a lot higher.

Final conclusions: Based on the trial experiments conducted, it is concluded that the biodegradable pots should be able to retain water to ensure good plant health and prevent premature decomposition process. Thus, soy-based garden pots would be a strong candidate to achieve these criteria and will be studied next.

5. Work to be completed

Works to be completed is to compare the plant health of the soy pots with the plastic pots and existing biodegradable pots from SelfEco. As seen below, to date, a portion of the task has been completed.

Table 2. Gantt chart for the proposed project

Tasks	**Year 1**				**Year 2**				**KPIs***	**Measurable Milestones/ Outcomes**
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4		
A) Develop and characterize four pellets formulations at NDSU	X	X							PS, TC	- 4 pellets formulations - Pots are molded by SelfEco and Ainong
B) Test performances of fruit-bearing plants and flower crops grown in pots from Part A		X	X						PS, TC, KG	- Plants are grown in 2 months in NDSU greenhouse - Posts decomposed after 4 months
C) Conduct techno-economic and sensitivity analysis to ensure cost competitiveness			X						KG, TC	- 25% increase in short-term cost savings - 65% increase in the long-run
D) Perform customer acceptance study as a part of technology transfer to industry partners									PS, KG	- Pots sent to various commercial growers for evaluation - Products' strengths and weaknesses are identified
E) Finalize specifications and market placement of the proposed products									PS, KG	- Final formulations for commercial-scale are determined - Pots are distributed to local garden vendors

* Notes: X = completed, Product specification (PS)- in terms of pellets formulations, targeted thermomechanical properties, degradation rate, etc., knowledge generated (KG) – in terms of plant health, fruit yield, etc., and targeted costs (TC).