RESEARCH PAPER SUBMITTED TO

Michael Bomford

BY

James Oswald

Title: Fresh spent mushroom compost mulch effect on bean (*Phaseolus Vulgaris*), broccoli (*Brassica oleracea* var. italica), salsola (*Salsola komarovii*), and squash (*Cucurbita pepo* subsp. *pepo*) growth, weed suppression, and broccoli yield

Co-authors: Michael Bomford

Kwantlen Polytechnic University, Faculty of Science and Horticulture, Department of Sustainable Agriculture

Advisor name: Michael Bomford

Abstract

Mushroom production is increasing globally, generating up to 5.5 x 10^7 Mg of Spent Mushroom Compost (SMC) annually. Canada is the world's eighth largest mushroom producer, with 1.2% of global mushroom production, and BC alone accounted for ~1.4 x 10^5 Mg of SMC in 2017. Salinity of fresh spent mushroom compost (FSMC) has generated concern regarding its viability for application to agricultural land. We applied 0, 5, 10 or 20 cm mulch layers of FSMC and found no significant effect on growth of broccoli, bean, salsola, and squash. FSMC mulch reduced abundance and diversity of weeds. No significant effect on broccoli yield was observed

Key words: fresh spent mushroom compost, mulch, plant growth, weed suppression, weed diversity, monocot to dicot ratio, yield.

Introduction

Spent mushroom compost (SMC) is mostly composed of "wheat straw, bedding containing hay, corn cobs, cottonseed hulls, poultry manure, brewer's grain, cottonseed meal, cocoa bean hulls, and gypsum" (Beyer 2011). Researchers suggest application of aged SMC for at least 6 months in the field instead (Sagar et al. 2007, Uzun 2004, Beyer 2011). Fresh SMC is rich in nutrients but its high salinity could potentially interfere with the plant growth (Gonani et al. 2011). Demir (2017) found out that fresh SMC reduced yield and growth of pepper and tomato, relative to aged SMC. SMC salinity interferes with seed germination but did not reduce seed emergence rates (Wang et al. 1984). Leached or aged SMC has a less amount of nutrients due to microbial activity and can be applied readily to the soil (Beyer 2011, Mullen and McMahon 2001).

Weeds can reduce crop growth and yield by competing with the crop for resources (Bitterlich 1990). Mulching can reduce weed pressure (Bitterlich 1990). Uzan (2004) found that mulching with SMC in an orchard controlled weeds, but compromised crop yield. Yordanova and Shaban (2007) found that SMC mulch reduced monocotyledons weed pressure, but did not help with dicotyledons or perennial weeds in broccoli.

This paper examines effects of fresh spent mushroom compost (FSMC) application as mulch on vegetable crop growth, weed growth, the monocot and dicot weed ratio, and broccoli yield. Several application rates were tested to identify the optimal application rate for FSMC mulch. Fresh SMC was selected rather than aged SMC to see how transplanted crops and weeds would respond to its high salt content.

Methods

Experiment site and design

This experiment was conducted at the KPU Farm on Garden City Lands, in Richmond, BC located 1 meter above sea level (49.17^2 N, -123.12^2 W). The climate is temperate west coast with an average temperature of 10°C and average annual precipitation of 1.112.6 m (Tourism Richmond 2020, City of Richmond 2018). The site has three different layers of soil with peat at the very bottom, followed by a 70 cm of mineral soil (sandy clay loam or clay) and 5 cm of organic topsoil at the surface, due to heavy amendments with compost, poultry manure, and other organic matter.

The experiment used a randomized complete block split-plot design with four replicate blocks (2 x 8 m), four main plots per block (2 x 2 m) and four sub-plots per main plot (1 x 1 m). FSMC (Highline Mushrooms, Langley City, BC), made of wheat straw, chicken manure, mined gypsum, peat moss, lime, and feather meal was applied as mulch. Main plots received 0, 5, 10 or 20 cm (0, 50, 100 or 200 l/m^2) of FSMC mulch. Sub-plots were each planted to one of four different crops: bean (*Phaseolus vulgaris*), broccoli (*Brassica oleracea* var. italica), salsola (*Salsola komarovii*), or squash (*Cucurbita pepo* subsp. *pepo*).

Crops were transplanted or direct-seeded into the plots on June 19th, 2020 (Table 1). A 10 cm diameter well was dug through the mulch layer in the center of each squash subplot to allow a single squash plant to be transplanted into the soil below the mulch. Two wells, spaced 30 cm apart, were dug through the mulch layer in the remaining subplots to allow transplanting of broccoli or salsola (one transplant per well), or direct-seeding of bean (two seeds per well).

Table 1. Crop varieties, plants, and planting methods. All seeds sourced from West Coast Seeds.

Crop	Variety	Plants/ subplot	Planting method
Bean	Speedy* (bush bean)	4	Direct-seed (2/well)
Broccoli	Calabrese*	2	36 day-old transplant
Salsola	OP Saltwort	2	36 day-old transplant
Squash	Orangeti F1* (spaghetti squash)	1	22 day-old transplant

Data Collection

Data collection started on July 3rd, 2020, and continued biweekly until August 28th 2020. Canopy cover was estimated on July 3, 17 and 31 by taking a picture with an iPad 1 m above the center of each subplot after weeding. Photos were analyzed with the Canopeo application (Patrignani and Ochsner 2015) to determine the proportion of the soil surface covered by green leaves. Weed counts were conducted on July 31st, August 14th and 28th by pulling weeds and grouping them by species.

The monocot:dicot weed ratio was calculated from the weed count data. Broccoli was harvested on August 28th and September 4th, 2020. Marketable heads were counted and weighed.

Data Analysis

Data were analyzed by analysis of variance (ANOVA) and mixed model analysis in jamovi (version 1.2). A critical value of α = 0.05 was maintained throughout. ANOVA was used to analyze monocot:dicot ratio and broccoli yield. Mixed model analysis was used for other dependent variables. Means were separated by Tukey's test if ANOVA detected significant effects, and by the Bonferroni test when significant effect were detected by mixed model analysis.

All data except broccoli yield and weed diversity underwent $\log_{10}$ transformation to satisfy assumptions of the statistical tests. Mulch depth, crop, and sample date were fixed effects and plot and replicate were random effects for mixed model analysis. Shannon diversity index values were calculated to measure weed diversity (Spellerberg and Fedor 2003). The formula for Shannon diversity index is $\mathrm{H} = \sum_{i=1}^{n} pi \ln pi$ (Spellerberg and Fedor 2003).

Results

Canopy cover differed between crops (Fig. 1) squash had the highest cover followed by salsola and broccoli. Bean had the least canopy cover. No effect of mulch depth on canopy cover was detected. Canopy cover increased over time, but there was no interaction between crop and sample date or between mulch depth and sample date

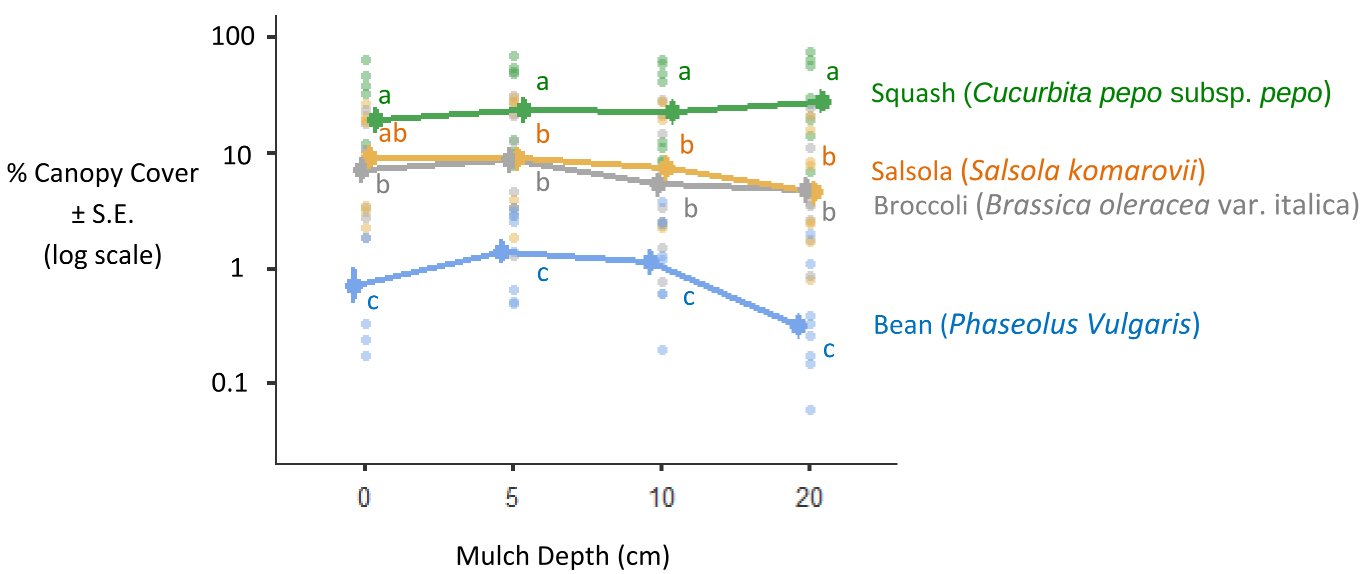

Figure 1. Canopy cover % by crops and mulch depth. Error bars denote standard error of the mean. Crops means on the same depth labeled with the same letter do not differ significantly (Bonferroni test, α = 0.05).

Figure 2 shows that weed counts were highest in the unmulched controls. No significant difference was detected between the 5 and 10 cm mulch treatments. The 20 cm mulch treatment had the least weeds overall. No significant effect of crop on weed abundance was detected. Weed abundance differed by sampling date, and an interaction between mulch depths and sampling date was found.

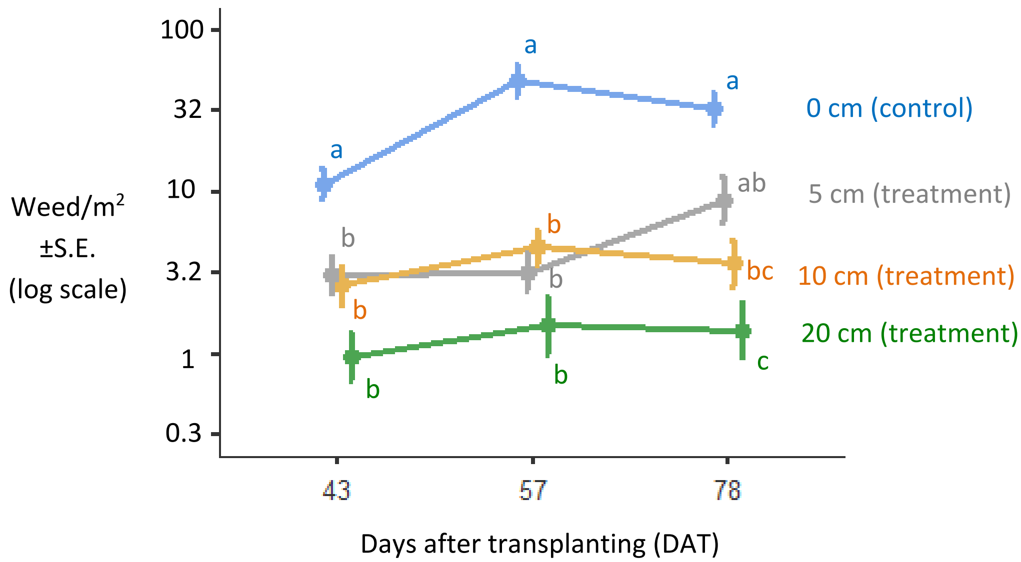

Figure 2. Weed counts by crop age and mulch depth. Error bars denote standard error of the mean. Means followed by the same letter within a sampling day do not differ significantly (Bonferroni test, α = 0.05).

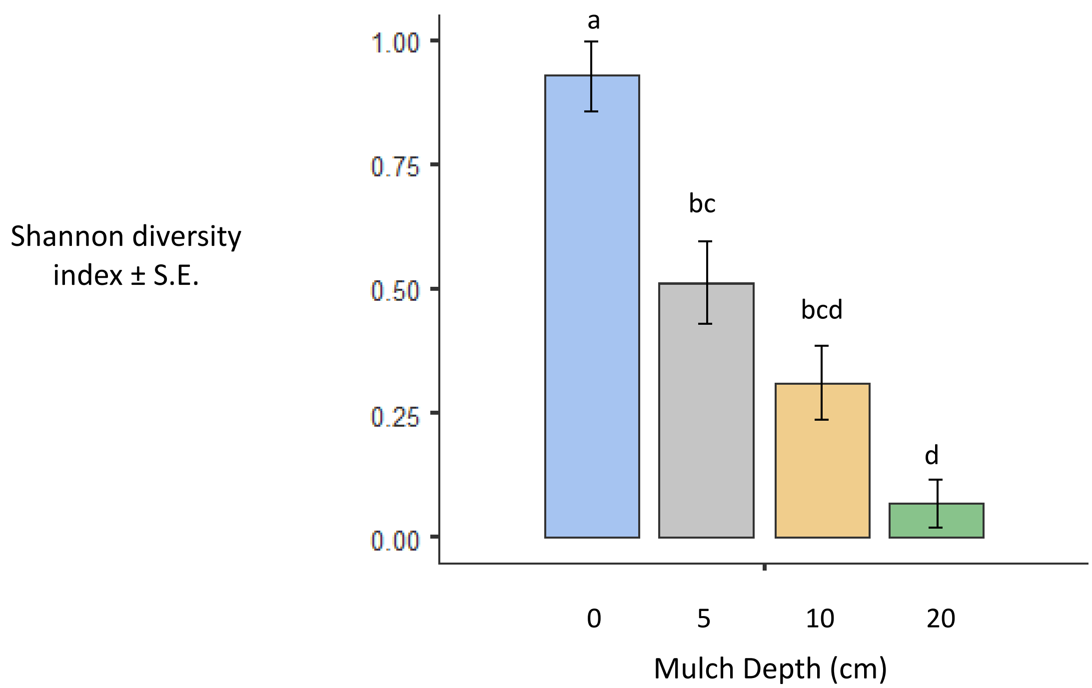

Figure 3. Average Shannon diversity index across different mulch depth. Different letters above bar indicate significant differences. Whisker on bar denotes standard error.

Weed diversity is reduced in plots with deeper mulch depth. Shown in figure 3, the highest weed diversity is found on the control plot while the lowest on the 20 cm mulch depth. Appendix 2 shows that weed diversity gets lower throughout the 43 to 78 days after transplanting (DAT) with most have the lowest diversity on 78 DAT. There are also few instances where weed diversity are getting higher throughout the 43 to 78 DAT. On average, subplots have the highest weed diversity at 43 DAT, some subplots have their highest weed diversity at 78 DAT, and very few subplots have high weed diversity at 57 DAT.

The monocot: dicot weed ratio did not differ between mulch depths (Fig. 4). Figure 4 shows that ratio between monocot and dicot is lowered with increase in mulch depth. The highest ratio was on the control and the lowest on 20 cm treatment.

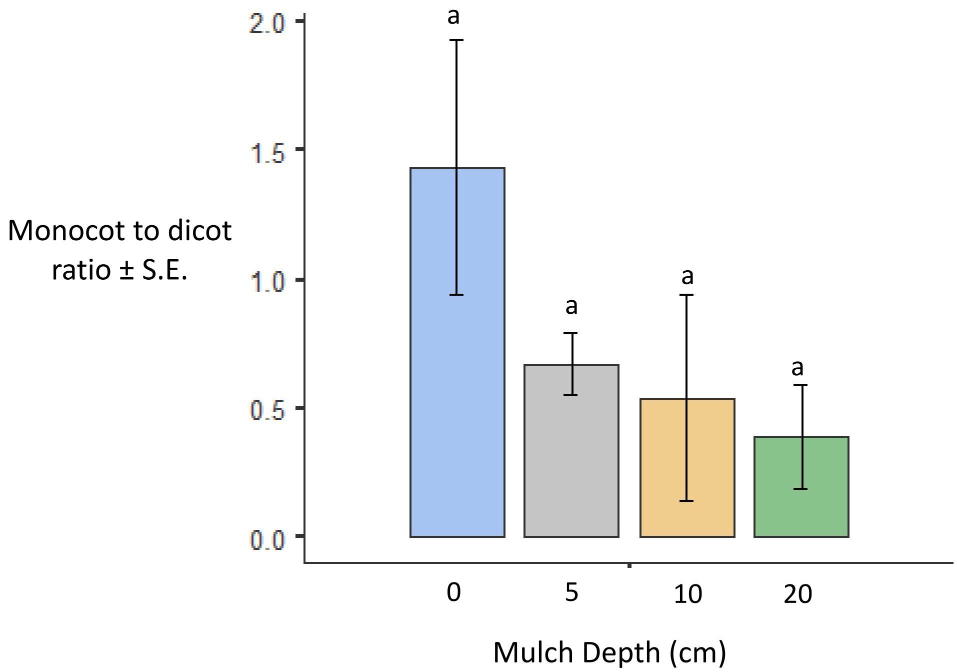

Figure 4. Ratio between monocot/dicot weed. Bars labeled with same letter do not differ significantly. Whisker on bar indicate standard error (ANOVA test, $\alpha = 0.05$)..

No significant effect of mulch depth on broccoli yield was detected (Figure 5). Average broccoli yield in the 5 cm mulch treatment was more than double that of the unmulched control, but this effect was not statistically significant due to variability within treatments.

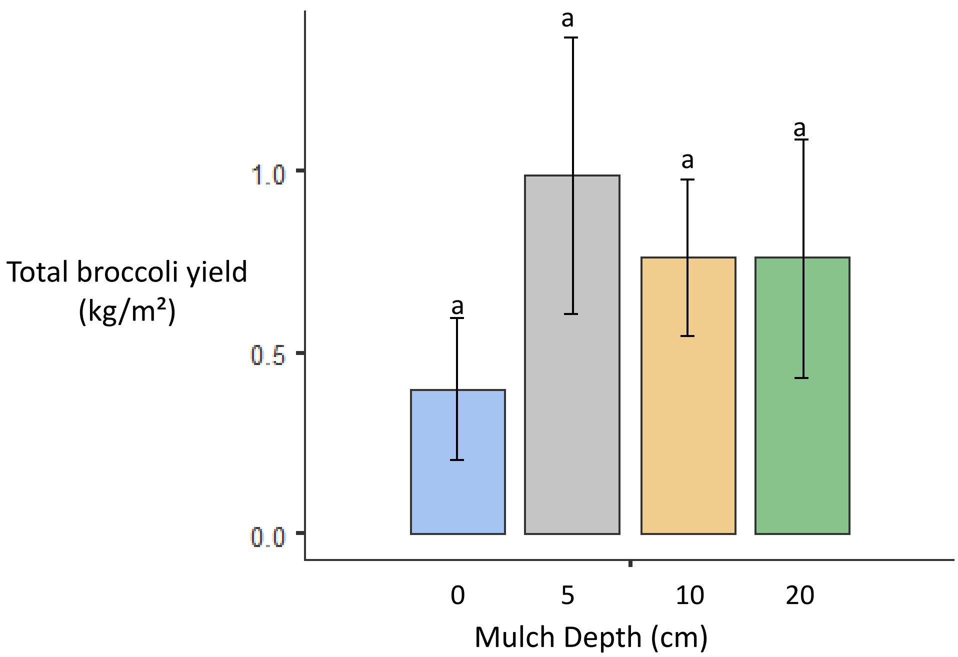

Figure 5. Broccoli yield (kg/m²).Error bars denote standard error of the mean.Bars labeled with same letter do not differ significantly. Whisker on bar plot indicates standard error (ANOVA test, $\alpha = 0.05$).

Discussion

This experiment provides evidence that fresh spent mushroom manure (FSMC) does not affect crop growth significantly. Different crops have a different reaction to the increased thickness of the spent mushroom compost (SMC) mulch. Bean (*P. Vulgaris*), broccoli, (*B. oleracea* var. italica), and salsola (*S. komarovii*) exhibits a lower growth following the increase in mulch thickness. On the contrary, squash (*C. pepo* subsp. *pepo*) appears to exhibits a higher growth in higher mulch thickness. The differences in canopy cover between each crop might be due to their ability to tolerate excess salt and their growth pattern. Beans that have a lower salt tolerance was shown struggling when grown on the 20 cm mulch in the early planting date (Çiftçi et al. 2011). Aside from the inability to tolerate high salt concentration, each plant also has a different growth pattern. For instance, squash has the highest cover because it is a vine, grow big leaves, and grow sideways instead of reaching for the sunlight. Other plants grow stalk instead of a vine, have smaller leaves, and growing up first instead of sideways.

On the other hand, the application of fresh spent mushroom manure (FSMC) significantly reduces the amount of weed that grows on each treatment. This follows earlier research that mentions SMC can suppress weed growth (Yordanova and

Shaban 2007). Furthermore, an increase in mulch thickness has a positive correlation with weed suppression. The inability for weed to grow might be caused by inadequate resources needed for the seedling to grow at deeper mulch depth (Saha et al. 2019). Furthermore, because this experiment does not directly plant broccoli, salsola, and squash seeds into the soil, it is unclear whether the suppressive characteristics of SMC might also be relevant to mentioned crops.

Weed diversity are affected by the different fresh spent mushroom compost (FSMC) mulch thickness. The highest diversity could be found on the control plot, which does not have any mulch. Further, the lowest diversity was found on the 20 cm mulch. The reason might be due to the weed suppression ability that SMC mulch possesses (Uzun 2004). This might also be caused by inadequate resources needed for the seedling to grow at deeper mulch and also due to the nutrient toxicity (Saha et al. 2019).

The ratio between monocot and dicot weed that grows in each subplot does not show that monocot struggle more than dicot statistically. As shown in figure 4 a high variability can be found on each group resulting in insignificant treatment effects. Based on collected data, grass can actually be found throughout the weed counting period on the 20 cm mulch. However, the amount of grass growing on the 20 cm plot is less than 5 per plots. For reference, all of the weeds that grow on the field were dicot, except for grass and unknown (Appendix 1). The result contradicts a previous study which states that monocot weeds growth were more hindered than dicot weeds (Yordanova and Shaban 2007). The results might be influenced by the population of nearby weeds that grow beside the plot (edge effect) and last season potato planting. Another reason is due to the unspecific and unknown data that cannot be counted towards the data. Further, the possibility of miscounting the weed could also alter the ratio.

Although broccoli yield is not statistically significant between each treatment, a slight increase can be seen across all treatments compared to control with the highest was on 5 cm treatment. This might be due to the slow release of nutrients from the mulch into the soil compared to control that does not gain any additional nutrients aside from the soil (Uzun 2004).

Conclusion

Although fresh spent mushroom compost (FSMC) provides good weed suppression, it did not promote crop growth or improve broccoli yield. Furthermore, weed abundance and diversity were reduced by increasing mulch thickness, which could help farmers control weeds. Future studies could try to answer the differences between fresh or aged SMC applications as either compost or mulch compared to regionally available compost application in growth and yield of broccoli. Future work could compare the benefit of using fresh or aged SMC with benefits from other composts.

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Appendix

Appendix 1. List of weed that grow on the field with their amount after 43, 57, and 78 days after transplanting (DAT)

Weed Category	43 DAT	57 DAT	78 DAT	Total weed per category
Brassica	30	35	152	217
Grass	94	142	297	533
Potato	35	2	7	44
Clover	41	98	59	198
Pineapple Weed	1	0	2	3
Groundsel	45	3	75	123
Polygomum	3	0	0	3
Compositae	7	0	0	7
Morning Glory	1	0	0	1
Buttercup	1	0	0	1
Vetch	6	2	11	19
Unknown	14	894	15	923
Lady's thumb	1	0	0	1
Sorrel	3	0	0	3
Aster	1	0	0	1
Chickweed	5	0	0	5
Buckwheat	0	1	0	1
Unknown 1	0	0	66	66
Unknown 2	0	0	1	1
Unknown 3*	0	0	19	19
Unknown 4*	0	0	5	5
Unknown 5	0	0	235	235
Unknown 4	0	0	1	1
Unknown 3	0	0	3	3
Unknown 6	0	0	23	23
Turnips	0	0	2	2
Hairy Cat's ear	0	0	1	1
Total per days after transplant	288	1177	974	

Appendix 2. Shannon index table for 43, 57, and 78 days after transplanting (DAT). "0" means the subplot is dominated by only a single species while "Undefined' means there are no weeds growing on that subplot.

Treatment	Rep	Plot	Subplot	43 DAT Shannon Index	57 DAT Shannon Index	78 DAT Shannon Index
5	1	1	Bean	0	Undefined	0.94
5	1	1	Broccoli	0.6	0	1.03
5	1	1	Salsola	0.76	0.62	1.6
5	1	1	Squash	0.69	0.41	0.11
0	1	2	Bean	1.52	1.08	0.73
0	1	2	Broccoli	1.56	0.77	0.71
0	1	2	Salsola	1.66	0.91	1.44
0	1	2	Squash	1.7	0.64	1.19
10	1	3	Bean	0	1.31	0.69
10	1	3	Broccoli	0	Undefined	0
10	1	3	Salsola	0	0	0
10	1	3	Squash	0	0	Undefined
20	1	4	Bean	0	0	0.69
20	1	4	Broccoli	0	Undefined	0
20	1	4	Salsola	0	0	Undefined
20	1	4	Squash	0	Undefined	0
20	2	5	Bean	Undefined	Undefined	0
20	2	5	Broccoli	Undefined	Undefined	0.64
20	2	5	Salsola	0	0	Undefined
20	2	5	Squash	0	Undefined	Undefined
10	2	6	Bean	0.56	Undefined	0.64
10	2	6	Broccoli	1.33	0	Undefined
10	2	6	Salsola	Undefined	0.68	Undefined
10	2	6	Squash	0	0	Undefined
0	2	7	Bean	1.33	0.33	1.47
0	2	7	Broccoli	0.9	0.1	1.3
0	2	7	Salsola	0.86	0.47	0.59
0	2	7	Squash	1.15	0.5	1.21
5	2	8	Bean	0	0	0.45
5	2	8	Broccoli	0.56	1.01	Undefined
5	2	8	Salsola	Undefined	Undefined	Undefined
5	2	8	Squash	Undefined	0.38	0.69

0	3	9	Bean	1.26	0.23	0.73
0	3	9	Broccoli	1.13	0.06	1.29
0	3	9	Salsola	1.36	1.31	0
0	3	9	Squash	1.48	0	0.78
10	3	10	Bean	0	0	0.61
10	3	10	Broccoli	Undefined	0	0
10	3	10	Salsola	0.69	0	Undefined
10	3	10	Squash	0	0.53	0.64
5	3	11	Bean	Undefined	0.41	0.64
5	3	11	Broccoli	0	0	1.04
5	3	11	Salsola	0	0.56	Undefined
5	3	11	Squash	Undefined	Undefined	Undefined
20	3	12	Bean	Undefined	Undefined	Undefined
20	3	12	Broccoli	Undefined	0	Undefined
20	3	12	Salsola	Undefined	Undefined	Undefined
20	3	12	Squash	Undefined	Undefined	Undefined
20	4	13	Bean	0	Undefined	Undefined
20	4	13	Broccoli	Undefined	0	Undefined
20	4	13	Salsola	Undefined	0	Undefined
20	4	13	Squash	Undefined	Undefined	0
5	4	14	Bean	1.55	Undefined	0.69
5	4	14	Broccoli	Undefined	Undefined	Undefined
5	4	14	Salsola	0	0	Undefined
5	4	14	Squash	0.64	Undefined	Undefined
0	4	15	Bean	1.33	0.33	0.94
0	4	15	Broccoli	1.54	0.46	1.43
0	4	15	Salsola	1.14	0.42	0.4
0	4	15	Squash	1.21	0.32	1.29
10	4	16	Bean	Undefined	0	Undefined
10	4	16	Broccoli	0.5	0.69	1.09
10	4	16	Salsola	Undefined	0	Undefined
10	4	16	Squash	Undefined	Undefined	Undefined