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Effect of mulching and plant density on out-of-season organic potato growth, yield and quality

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Abstract: Research was carried out on potato (*Solanum tuberosum* L., cv. Spunta) growing in the field in the Campania region (southern Italy) in 2007 and 2008, adopting organic farming practices, in order to evaluate the effects of two mulching treatments (black biodegradable film and bare soil) and six plant densities (12.5, 10.0, 8.3, 7.1, 6.2 and, as a control, 5.3 plants per m^2) on growth, yield and quality of "new potato" winter-spring and summer-autumn crops. Only in the case of the summer-autumn crop cycle, mulching resulted in a higher yield, plant dry matter and leaf area compared with the bare soil control, while in both crop cycles this latter treatment induced a delay in harvest. The winter-spring cycle gave a higher production of 40-70 mm tubers, while the summer-autumn cycle resulted in a higher vitamin C content. For the winter-spring crop cycle, the plant density of 8.3 plants·m^{-2} resulted in the highest yield for food-use tubers, whereas the highest production of seed tubers was obtained with a density of 12.5 plants·m^{-2}. The plant density of 8.3 plants·m^{-2} also resulted in the highest plant dry matter and leaf area. For the summer-autumn crop cycle, the 10 plants·m^{-2} density gave the highest production of 40-70 mm calibre tubers, as well as the highest plant dry matter and leaf area. In this cycle, the 6.3 plants·m^{-2} density resulted in the highest production of 70-80 mm calibre tubers. In terms of cost effectiveness, the choice of biodegradable mulching could save the expense of manual weed control and, in the case of the summer-autumn crop cycle, it is also associated with a higher yield. Overall, tuber yield increased with plant density but the final production was also affected by the crop cycle. This may depend on the different environmental conditions and duration which characterized each cultural cycle and, therefore, affected the vegetative development of organic new potatoes.

1. Introduction

Potato (*Solanum tuberosum* L.) is widely cultivated in Italy, with a total field area of 58,398 ha devoted to this crop in 2012, mainly in Sicily (11,236 ha), Campania (9,467 ha) and Calabria (6,115 ha) (ISTAT, 2012). In the southern Italian regions of Campania, Sicily and Apulia out-of-season crop production is traditionally practised and the early potato crop covers a total of 14,011 ha (ISTAT, 2012), that is 93.1% of the total acreage under this crop (15.051 ha) in Italy. In addition, nearly all of the Italian potato production is obtained from conventional farming practice, although in the last nine years there has been a small increase in the area devoted to organic potato production. This latter accounted for about 730 ha in 2003 and 981 ha in 2011 (1.18 and 1.58% of the total area, respectively) (CCPB, 2012).

In the Mediterranean area, out-of-season potato yield obtained from winter-spring or summer-autumn crop cycles is mainly channelled into the highly profitable export market. However, for both conventional and organic crops the availability of certified seed tubers is a limiting factor. Indeed, this crop frequently gives a modest yield because small and/or immature tubers are used (Delaplace *et al*., 2008) which are still conditioned by apical dominance owing to the brief interval between seed tuber harvest and their use for planting. In the case of the summer-autumn potato crop, a possible method to improve yield is to obtain seed tubers from an early crop (winter-spring cycle) in order to harvest the product before aphid proliferation (Monti and Struik, 1999) and to limit pathogen infections (Hospers-Brands *et al*., 2008). Under organic farming practice, Saucke and Döring (2004) found that, in addition to effective weed control, the use of biodegradable mulch films helps reduce aphid infestation on leaves and potato virus Y incidence in tubers. Moreover, within each microenvironment it is important to choose the planting time which best suits the requirements of the specific cultivar (Frusciante *et al*., 1999; Caruso *et al*., 2010) in order to obtain good results.

As a general precaution, the choice of seed tubers of the correct size should be preferred. In fact, seed potatoes should be neither too big, requiring to be cut in order to limit the possible diffusion of infections (Franc and Banttari, 1984), nor undersized to avoid slow initial growth and tuberization (Mustonen, 2004). Indeed, shoot vigour

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and development rate are inversely correlated to seed tuber size, which provides meristematic resources (MacKerron *et al*., 1988): when the latter are limited, scarce shoot emission and hence smaller within-plant resource competition occurs. This leads to the formation of fewer large tubers (Hide *et al*., 1997), which is not desirable for the production of either food-use or seed tubers.

Crop mechanization (Green, 1962), aimed at reducing production costs, has led to an enlargement of between-row and in-row plant spacings. Hence, the current trend is to use spacings of 70-80 cm between the rows and 20-30 cm along the rows for conventional potato crops grown from ripe tubers in February-March. In this regard, contrasting results have been published: in some areas both lower and higher in-row spacings resulted in yield reduction (Masarirambi *et al*., 2012) while in other environments a higher plant density resulted in a higher production but reduced tuber calibre (Turajizadeh *et al*., 2011; Fontes *et al*., 2012), the latter effect being desirable for "seed" production. Moreover, increasing in-row spacing leads to greater tuber size (Tarkalson *et al*., 2011). In mild climates, winter-spring and summer-autumn crops are respectively grown from commercial "seed" potatoes or from locally (re)produced tubers. At the time of planting for out-of-season potato production, the seed tubers from these two crop cycles are still not completely mature and they are conditioned by apical dominance. In these cases, it may be interesting to increase plant density to balance the scarce shooting capacity of physiologically immature propagation material.

To our knowledge, no conclusive research has yet been published regarding the use of mulching and its interaction with plant density in organic farming practice in southern Italy. Thus, we planned our field trials with the aim of testing the effect of biodegradable mulching and of plant density on the production of "seed" and food potatoes from winter-spring crops and on the production of food potatoes only from summer-autumn crops. Trials were carried out in the Campania region (southern Italy) on organic potato crops, cv. Spunta.

2. Materials and Methods

Research was carried out in San Gennaro Vesuviano (Naples) in 2007 and 2008 on potato cv. Spunta, grown in the field under organic farming practices on a sandy-loam soil (Table 1); temperature and rainfall values are reported in Table 2 as means of the data from the first and second experimental years.

Twelve experimental treatments were compared. These were obtained from the factorial combination of two mulching treatments (black biodegradable film and bare soil) and six plant densities (12.5, 10.0, 8.3, 7.1, 6.2 and, as a control, 5.3 plants per m^2). The experimental treatments were randomized in a split-plot design with three replicates, assigning mulching treatments to the main plots and plant densities to the elementary plots; the latter had a 18.00 m^2 (6.00 x 3.00 m) surface area.

The soil was prepared by forming raised beds which were mulched with a 15-μm thick biodegradable black film made from corn starch. Potatoes were planted in double rows for all treatments except for the control crop which was grown in single rows. The six different plant densities were obtained using the following spacings: 0.40 m between the rows and 0.20, 0.25, 0.30, 0.35 or 0.40 m along the rows for 12.5, 10.0, 8.3, 7.1, 6.2 plants·m^{-2} treatments; 0.75 m between the rows and 0.25 m along the rows for the 5.3 plants·m^{-2} treatment (control).

Table 1 - Soil characteristics

On 100 g of air-dried and 2 mm sieved soil		
Coarse sand	g	35.3
Fine sand	g	45.5
Silt	g	7.8
Clay	g	11.4
Organic matter (Walkley-Black method)	g	1.18
Total nitrogen (N) - Kjeldhal method	g	0.1
Available phosphate (P_2O_5) - Olsen method	mg	1.7
Available potassium (K_2O) - ammonium acetate method	mg	54.0
Total lime (Dietrich-Früling)	g	traces
pH		7.4

Table 2 - Temperature and rainfall values (means of 2007 and 2008) during winter-spring and summer-autumn crop cycles in San Gennaro Vesuviano (Naples)

Month	Dates intervals	Temperature (°C)		Rainfall (mm)
		Minimum	Maximum	
January	21-31	9.3	14.9	13.4
February	1-10	9.5	15.2	42.2
	11-20	8.1	14.3	37.1
	21-28	10.9	17.3	17.5
March	1-10	11.3	16.0	68.1
	11-20	11.3	17.2	33.3
	21-31	8.9	16.6	65.2
April	1-10	11.8	19.8	25.7
	11-20	13.3	21.3	27.4
	21-30	13.7	22.4	21.0
May	1-10	15.2	24.1	10.6
	11-20	15.8	24.4	29.4
August	21-31	23.8	33.1	0.0
September	1-10	20.8	30.0	15.7
	11-20	18.8	27.6	35.4
	21-30	16.2	24.5	23.7
October	1-10	17.6	24.6	28.0
	11-20	16.4	24.0	6.0
	21-31	15.5	21.6	14.8
November	1-10	14.5	20.4	9.0
	11-20	10.6	15.4	24.3
	21-30	12.2	16.6	76.4
December	1-10	10.9	15.1	63.0

Plantings took place on the following dates: 24 January for the winter-spring crop using certified "seed" tubers (50±2 g) and 20 August for the summer-autumn crop using "seed" tubers obtained from the previous crop cycle (30-40 mm). Tubers were kept at 7°C until use and showed no pre-sprouting at planting time. Potato crops were preceded by common bean and fava bean on the same plots.

The organic farming system was managed in compliance with EC Regulation 834/2007 and the farming practices were: fertilization before planting with 100 kg·ha^{-1} of N, 85 of P_2O_5 and 210 of K_2O with Biolsa 6-5-13; drip fertigation with 50 kg·ha^{-1} of nitrogen as 8.5 N hydrolyzed animal epithelium; weed control by hand; plant protection treatments with copper, azadirachtin and rotenone.

New potato tubers were harvested when the aerial part of the plant showed the initial symptoms of senescence (leaf yellowing) and wilting.

Tubers from the winter-spring crop were harvested on 18 May 2007 and 21 May 2008. The summer-autumn crops were harvested on 4 December 2007 and 2 December 2008. Undamaged tubers of regular shape were classified as "marketable" and graded as follows: the 30-40 mm and 40-70 mm grades (which are usually addressed to the large scale retail channel and packaged in boxes or bags, respectively) and the 70-80 mm grade (which is usually channelled to the local market).

At the time of harvest, the following determinations were made in each plot: number of failures; number of shoots per plant; number and weight of tubers; tuber mean weight on a 50-unit sample; tuber grading and classification into the three calibre classes. Tubers falling into the 30-40 mm class were classified as "seed" tubers in the case of the winter-spring crop or as food tubers in the case of the summer-autumn crop.

The weight of tubers unsuitable for the market was also recorded in order to monitor total biomass production for each treatment. Plant biomass was calculated as the sum of the aboveground plant biomass at the end of the experiment plus the total tuber production. Dry residue was assessed after dehydration of the fresh samples in an oven at 70°C under a vacuum until they reached constant weight. Leaf area was measured at the end of the cycle, using a bench top LI-COR leaf area meter.

In order to evaluate the quality of tubers produced both from the winter-spring and from the summer-autumn crop, samples of 20 tubers per plot were randomly collected at harvest time and transferred to the laboratory, where the following determinations were made:

- dry residue, in an oven at 70°C under vacuum until steady weight;
- vitamin C content, using a Waters 600E HPLC system equipped with a Waters 486 UV detector set to 410 nm λ and a Biorad column mod. HPX87H at 35°C.

Data were processed by analysis of variance and mean separations were performed through the Duncan multiple range test, with reference to 0.05 and 0.01 probability levels, using SPSS software version 15.

3. Results and Discussion

From statistical processing of the data, no differences were detected between 2007 and 2008, therefore only the mean values of the two research years are shown.

In the case of winter-spring crops, mulching did not significantly affect yield but the crop cycle of the mulched crops was four days and a half shorter compared with the bare soil treatments (Table 3). Similar results were published by Boyd *et al*. (2001) and Döring *et al*. (2005) who reported that mulching did not produce any increase in yield and tuber size but it only caused an increase in soil temperature (Xing *et al*., 2012). Conversely, Maletta *et al*. (2006) reported that mulching resulted in increased yield and tuber size in organic potato.

Plant density significantly affected yield (Table 3): maximum production was obtained with a plant density

Table 3 - Yield results and growth indices of winter-spring potato crop

Treatment	Failures %	Actual density no.·m^{-2}	Shoots no.·pt^{-1}	Tubers no.·m^{-2}	Tuber mean weight g	Yield t·ha^{-1}	Crop duration days	Plant growth indices (maximum values) Dry matter g·m^{-2}	LAI m^2·m^{-2}
Mulching									
Biodegradable film	4.7	7.9	1.08	25.1	110.6	26.8	114.5	696.3	2.1
Bare soil	4.6	7.9	1.09	25.1	107.0	26.0	119.0	663.9	2.0
	NS		NS	NS	NS	NS	*	NS	NS
Plant density									
5.3 pt·m-2	4.0	5.1	1.10	16.9 f	123.3 a	20.8 d	117.2	546.4 d	1.6 d
6.3	5.3	5.9	1.15	19.8 e	121.5 ab	24.1 c	117.0	622.3 c	1.9 c
7.1	4.6	6.8	1.15	22.5 d	117.5 bc	26.4 b	116.8	681.0 b	2.1 b
8.3	3.7	8.0	1.12	26.1 c	112.0 c	29.2 a	116.7	748.5 a	2.3 a
10.0	5.0	9.5	1.03	29.9 b	97.4 d	29.1 a	116.5	744.0 a	2.3 a
12.5	5.4	11.8	1.00	35.5 a	81.3 e	28.8 a	116.3	738.3 a	2.2 ab
	NS		NS				NS		

* = significant at p≤0.05; NS = not significant; whitin each column, means followed by different letters are significantly different according Duncan test at p≤0.05.

of 8.3 plants·m^{-2}, though it was not significantly different from 12.5 and 10.0 plants·m^{-2}. The control plant density of 5.3 plants·m^{-2} gave the lowest yield. Similar results were reported by Fontes and coworkers (2012), who found that reducing the in-row spacing from 50 to 29 cm led to a higher tuber number and greater yield. However, Masarirambi *et al*. (2012) reported a yield decrease when plant density increased from 3.7 to 7.4 plants·m^{-2}. Due to the early plantings, the "seed" tubers used to start the winter-spring crops had still not reached their full physiological maturity. Consequently, they produced plants with only one shoot and a small number of tubers which did not vary between the treatments. Therefore, the productive results were affected both by the number of tubers per square meter and by the tuber mean weight: the highest number of tubers was recorded at the highest plant density while the highest tuber mean weight was obtained with 5.3 plants·m^{-2}. No difference in precocity among the treatments was recorded. Total yield increased with increasing plant density up to 8.3 plants·m^{-2}, because the apical dominance effect induced tubers to produce only one shoot, thereby reducing dramatically the competition between plants and within each plant.

Growth parameters varied similarly to yield in response to mulching and plant density (Table 3). Dry matter and leaf area were not significantly affected by mulching, while plant density increases up to 8.3 plants·m^{-2} resulted in the highest values of both dry matter and leaf area, reflecting the mulching effect on total yield.

The relative proportion of tubers classified into the different calibre classes (Table 4) was not significantly different between the mulched or bare soil treatments, but significant effects were recorded in response to the different plant densities. The highest densities of 12.5 and 10.0 plants·m^{-2} resulted in the highest incidence of 30-40 mm grade tubers, which are suitable for uncut "seed" use and may therefore be considered the best choice as seed potatoes for the following summer-autumn crop. The plant densities of 6.3 and 7.1 plants·m^{-2} produced the highest proportion of 40-70 mm grade tubers, which are suitable for the food market, whereas plant density did not significantly affect the incidence of 70-80 mm calibre tubers. These results are in accordance with previously published studies reporting an increase in the small- and medium-tuber size class when the in-row plant spacing was reduced from 50 to 29 cm (Fontes *et al*., 2012) and plant density from 8.0 to 5.3 plants·m^{-2} (Turajizadeh *et al*., 2011).

As a quality indicator of potato tubers, the dry residue was not significantly affected by mulching or by plant density (Table 4). Vitamin C content was higher in tubers obtained from mulched plots, whereas it did not vary in response to the different plant densities. Similar results were published by Gram (1951) who found that tubers from straw-mulched crops had significantly higher ascorbic acid content. Moreover, in more recent years Dvorak *et al*. (2012) reported no significant effects of mulching on potato tuber ascorbic acid content under different soil or climatic conditions. These contrasting results suggest that the actual ascorbate content of potato tubers may result from an interaction of multiple factors. However, the tuber vitamin C values detected in our research fall in the range reported by Brown (2005).

After discarding about 10% of virus-infected tubers, the 30-40 mm tubers produced by the winter-spring crops were used as seed potatoes for the following summer-autumn crops. These seed tubers were to be planted about three months after harvest, before they could reach their full physiological maturity, similarly to the commercially available seed potatoes used for the winter-spring crops. As discussed

Table 4 - Grading and quality indicators of "seed" and food-use potato tubers produced from winter-spring crop

Treatment	Seed-use grade 30-40 mm				Food-use grades 40-70 mm	Food-use grades 70-80 mm	Tuber quality indicators	
	Yield t·ha^{-1}	% of total yield	Tuber mean weight g	Potential Use ^{z} ha	% of total yield	% of total yield	Dry residue %	Vitamin C mg·100 g^{-1} f.w.
Mulching								
Biodegradable film	8.9	33.2	49.1	3.4	58.7	8.0	18.5	23.0
Bare soil	8.8	34.0	50.6	3.3	58.0	7.9	18.8	22.2
	NS	NS	NS	NS	NS	NS	NS	*
Plant density								
5.3 pt·m^{-2}	6.7 e	32.2 bc	50.4 ab	2.5 e	59.8 ab	8.0	18.5	22.7
6.3	7.6 d	31.4 c	51.8 a	2.7 de	60.5 a	8.1	18.6	22.5
7.1	8.7 c	32.8 b	51.1 ab	3.2 cd	59.1 ab	8.1	18.7	22.9
8.3	9.8 b	33.4 b	50.3 ab	3.6 bc	58.6 b	8.0	18.9	22.3
10.0	10.3 ab	35.5 a	48.9 bc	4.0 ab	56.6 c	7.9	18.6	22.7
12.5	10.5 a	36.4 a	47.0 c	4.2 a	55.7 c	7.9	18.8	22.5
						NS	NS	NS

^{z} Using the traditional 75 x 25 cm spacings (5.3 plants·ha^{-1}) in the following summer-autumn crop; * = significant at p≤0.05; NS = not significant; whitin each column, means followed by different letters are significantly different according Duncan test at p≤0.05.

above, their immature state caused each "seed" to originate only one shoot and, consequently, the number of tubers per plant did not differ among the treatments. Therefore, yield in the different plots was only affected by the number of tubers per unit surface area and by the tuber mean weight (Table 5).

In the summer-autumn cycle, mulching increased crop precocity and affected tuber production favourably, as compared with bare soil treatments (Table 5). This result may be explained by the lower failures and higher tuber mean weight recorded in mulched plots, though these variables were not significantly affected by mulching. It was suggested that mulching resulted in higher potato yield due to the reduction of soil nutrient loss caused by runoff (Rees *et al*., 2002) and to the prevention of excessive soil heating (Dvorak *et al*., 2012).

Plant density significantly affected tuber production (Table 5) and the highest yields were recorded with 10.0 and 12.5 plants·m^{-2}, whereas the control plots (5.3 plants·m^{-2}) gave the lowest production. At the same time, tuber mean weight was affected by competition among plants and it increased at lower plant densities. No significant effect of plant density on precocity was recorded. Total production increased with plant density up to 10.0 plants·m^{-2}, i.e. even over the 8.3 density threshold recorded for the winter-spring crop. In fact, the latter showed greater plant expansion (Tables 3 and 5) due to the longer crop cycle, causing presumably greater plant competition for available resources. Moreover, both growth indexes (plant dry matter and leaf area) attained higher values with mulching compared with bare soil, whereas they were not significantly affected by plant density (Table 5).

Tubers harvested in the autumn were graded only with regard for the food market (Table 6). Mulched plots pro-

Table 5 - Yield results and growth indices of summer-autumn potato crop

Treatment	Failures %	Actual density no.·m^{-2}	Shoots no.·pt^{-1}	Tubers no.·m^{-2}	Tuber mean weight g	Yield t·ha^{-1}	Crop duration days	Plant growth indices (maximum values) Dry matter g·m^{-2}	LAI m^2·m^{-2}
Mulching									
Biodegradable film	14.5	6.9	1.0	20.9	114.1	24.7	105.0	582.1	1.8
Bare soil	15.7	7.0	1.0	20.4	112.0	20.7	109.3	496.5	1.5
	NS		NS	NS	NS	*	*	*	*
Plant density									
5.3 pt·m-^{2}	15.1	4.5	1.0	13.6 f	125.7 a	17.1 e	107.7	372.3 d	1.2 d
6.3	14.9	5.4	1.0	16.2 e	124.5 a	20.2 d	108.4	475.6 c	1.4 c
7.1	15.0	6.0	1.0	18.2 d	118.5 b	21.6 d	108.0	510.2 c	1.5 c
8.3	15.2	7.0	1.0	20.9 c	115.5 b	24.1 c	107.1	570.7 b	1.7 b
10.0	15.3	8.5	1.0	24.7 b	110.0 c	27.1 b	106.4	642.9 a	1.9 a
12.5	15.2	10.6	1.0	30.9 a	84.5 d	26.1 a	105.8	663.8 a	2.0 a
	NS		NS				NS		

* = significant at p≤0.05; NS = not significant; whitin each column, means followed by different letters are significantly different according Duncan test at p≤0.05.

Table 6 - Grading and quality indicators of food-use potato tubers produced from summer-autumn crop

Treatment	Food use tuber grades 30-40 mm % of total yield	40-70 mm % of total yield	70-80 mm % of total yield	Tuber quality indicators Dry residue %	Vitamin C mg·100 g^{-1} f.w.
Mulching					
Biodegradable film	26.4	62.4	11.2	17.8	21.7
Bare soil	28.4	59.2	12.4	18.0	21.4
	*	*	*	NS	NS
Plant density					
5.3 pt·m-^{2}	26.2 d	60.8 bc	13.0 d	17.9	21.5
6.3	26.0 d	58.5 d	15.5 a	18.0	21.6
7.1	27.0 c	59.9 c	13.1 b	17.7	21.4
8.3	27.9 b	61.0 b	11.1 c	17.8	21.7
10.0	28.6 a	62.1 a	9.3 d	18.0	21.5
12.5	28.9 a	62.5 a	8.6 e	17.8	21.6
				NS	NS

* = significant at p≤0.05; NS = not significant; whitin each column, means followed by different letters are significantly different according Duncan test at p≤0.05.

duced a higher percentage of medium-sized tubers (40-70 mm) whereas the crops grown on bare soil produced a higher percentage of small and large tubers (30-40 mm and 70-80 mm, respectively).

The highest plant densities of 12.5 and 10 plants·m^{-2} led to the highest proportion of 30-40 mm calibre tubers, as well as of the 40-70 mm calibre. Moreover, the percentage of the largest tubers increased at lower plant densities, whereas this parameter was not significantly affected in the case of the winter-spring crop cycle.

The quality indicators of potato tubers (dry residue and vitamin C) were not significantly affected by the experimental factors during the summer-spring crop cycle (Table 6).

Tuber dry residue and vitamin C contents of tubers harvested in the autumn were as much as 4 and 5% lower compared with tubers harvested in the spring. These results were in accordance with previous research (Ierna, 2010) reporting higher values of yield and tuber dry residue, but lower tuber mean weight in spring tubers compared to autumn ones.

Finally, the winter-spring crop cycle resulted in lower tuber mean weight and higher yield, compared with the summer-autumn crop cycle.

4. Conclusions

In the case of the winter-spring cycles, the use of biodegradable mulching induced an anticipation of the harvest but it was not found to have significant effects on tuber production.

The use of biodegradable mulching for the summer-autumn crop cycle gave better production results and an anticipation of the harvest; moreover, it also had positive effects on the prevention of water logging caused by abundant rainfall in November.

Since chemical weed control is not permitted in organic farming, in both crop cycles mulching allowed easier and cheaper weed control than that carried out by hand for bare soil cultivation.

Unlike conventional "mature potato" crops which are usually grown with a plant density of 5-6 seed tubers per m^2, in the case of "new potato" crops a higher yield was obtained by increasing plant density both in the winter-spring and summer-autumn cycles. In this respect, the summer-autumn cycle allowed the highest plant density (up to 10.0 plants·m^{-2}) compared with the winter-spring cycle (up to 8.3 plants·m^{-2}) because of the lower plant vegetative growth. In the case of the winter-spring cycle, a plant density of 12.5 plants·m^{-2} density produced the highest amount of "seed" potatoes (30-40 mm) to be used for the next summer-autumn crop cycle.

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