Cool Season Crop Production Trends: a Possible Signal for Global Warming

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Abstract

There has been much discussion about the potential effects of climate warming on food production. Climate models can be used to predict the effect of global warming, but is there current evidence in yield data to suggest an effect of climate change? Cool season vegetables could be good indicators of changes, since they can be more adversely affected by temperature extremes than some warm season crops such as corn. Thus, effects from climate warming may develop first in these crops. The average yield per hectare for several cool season vegetables in Ontario, including broccoli (*Brassica oleracea* var *italica* L.), cabbage (*Brassica oleracea* var *capitata* L.), cauliflower (*Brassica oleracea* var *botrytis* L.), carrots (*Daucus carota* L.), onions (*Allium cepa* L.), and potatoes (*Solanum tuberosum* L.) was examined over the past 60 years. Overall, yields increased from the 1940's until the mid 1980's. Since then, yields per hectare have decreased and appear more variable in spite of modern cultivars and production practices. Yield of field tomatoes (*Lycopersicon esculentum* L) have increased. Coincidently, this has been the period of noticeably warmer climate. Are these changes in provincial yield data related to climate warming? Records in southern Ontario indicate a general increase in average air temperatures. Yield of cole crops, rutabaga and potatoes were found to decrease with warmer average temperature, number of days > 30 ^{o} C, and with fewer days with precipitation. Higher temperatures probably will increase heat related quality disorders and possibly reduce vitamin content. Part of the decrease in yield might be a result of other factors, such as drought, soil compaction, or changes in insect and disease pressure. However, these would be expected to also change and interact with climate warming. Implications of these observations will be discussed.

INTRODUCTION

Ontario’s average yearly temperature is 0.5 to 0.6 ^{o} C warmer now than in 1900 (Smith et al. 1998). Few studies exist on long term yields, climate or potential effects of climate warming on vegetables. Historical yield data might be used to estimate past climate effects and gain some insights on potential effects of Greenhouse warming. Nieuwhof, (1969) cited work from the early 1900's showing that cabbage(*Brassica oleracea* var *capitata* L.) yield was related to amounts of precipitation in the growing season. Field crops were studied using historical data back to 1895, and precipitation was a limiting factor (Andresen et al., 2001). El- Nino Southern oscillation (ENSO) events were shown to affect corn (*Zea mays* L.) yields primarily due to changes in precipitation (Phillips et al. 1999). Florida and Texas vegetable production was also shown to be effected by ENSO events (Park et al., 2002). Additionally, vegetables are generally regarded as shallow rooted, and more prone to heat/drought stress than deeper rooted field crops (Stone and Rowse 1982). Soil compaction is known to reduce yields (Wolfe et al. 1995) and interact with climate especially under wet conditions (Morse 1993).

There are few growth models available for studies on vegetables similar to those for cereals (Andresen et al., 2001; Phillips et al. 1999). Montieth, (1981) found that cool season cereal yields were higher in cool areas than warmer ones in the UK and we can surmise that this effect would be similar for warming climates. Higher yields from climate warming and

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higher CO_2 have been demonstrated for carrot (*Daucus carota* L), beetroot (*Beta vulgaris* L) and onions (*Allium cepa* L (Wurr et al., 1998). Other effects that have been noted are delayed curd initiation in cauliflower (*Brassica oleracea* var *botrytis* L.) (Wheeler et al., 1995; Wurr et al., 1998), and paler lettuce (*Lactuca sativa* L) (Pearson et al., 1997). These studies were in controlled environments and not subject to the potential effects of water deficits which may occur under natural, variable field conditions. Furthermore, the UK is approximately 10 ^{O} latitude further north than this location and cooler. Most cole crops have an approximate maximum temperature for growth of 25 ^{o} C, above which maturity of cauliflower and cabbage heading can be delayed (Nieuwhof 1969). Thus hotter summers may lead to reduced yields. Effects of rising temperature on visual and nutritional quality must be taken into account. High temperatures can lead to quality disorders in broccoli (*Brassica oleracea* var *italica* L.) (Grevesen 1998); cauliflower (Grevesen and Olesen 1994 b); potatoes (*Solanum tuberosum* L.) (Hiller et al. 1985) and to decreased Vitamin C content (Lee and Kader, 2000; Mozafar, 1994; Weston and Barth 1997). Thus we might expect cool season vegetable crops to show several possible effects of climate warming which may be useful indicators of climate change.

The intent of this work was to: 1. determine from historical yield data effects of climate change induced trends for a number of vegetable crops; 2. Stimulate discussion and investigation of climate effects on vegetable crops.

MATERIALS AND METHODS

Marketable yield statistics from the Ontario Ministry of Agriculture and Food from 1940 to 2000 were compiled, for asparagus (*Asparagus officinalis* L.), broccoli, cabbage, cauliflower, carrots, onions, potatoes, radish (*Raphanus sativus* L.), rutabaga (*Brassica napus*) and tomatoes (*Lycopersicon esculentum* L.). Broccoli statistics were first collected in 1975. Weather data were taken from Atmospheric Environment Service records from weather stations along Lake Erie. To establish trends over time, yields were regressed with year using the PC SAS GLM procedure (SAS INST. Cary, N.C.). To remove the effects of increasing yields from agronomic practises in the 1940's to 1970, and an apparent change in climate, linear regressions on yields and climate records were calculated from 1970 onwards for average July-September, average, maximum, minimum temperature, precipitation, number of days > 30 ^{o} C, and days with precipitation plus number of winter days < -10 ^{o} C.

RESULTS AND DISCUSSION

Average Provincial marketable yields of cool season crops, broccoli, cabbage, cauliflower, carrots, onions, potatoes and rutabaga rose until about the mid 1980's, and then tended to drop with considerable variability in yield (Fig. 1, Table 1). These trends were curvilinear, with the exception of broccoli and cauliflower. Asparagus yields dropped but began to rise in the later years, probably as a result of new hybrid cultivars. The same pattern held for radish, but no statistical trends could be determined. Marketable yield of broccoli, cabbage, and cauliflower, from irrigated cultivar trials at Simcoe, in the last 10 years also show large variation (McKeown and Bakker, unpublished data). During the years 1940 - 2000, average provincial yields of tomatoes, a warm season crop increased over time (Fig. 1) and appeared less variable.

In addition to climate there are a number of other possible explanations of these yield trends. The genetically determined limits of some of these crops may have been reached. Market demand dictates the size of product, and the number of plants of any crop per unit area has a practical limit. After years of intensive vegetable production, soil depletion and compaction, pest buildup might explain part of the leveling off in yields. Climate also influences pest pressure. Mineral content of vegetables and fruit decreased over 50 years in the UK (Mayer 1997), which suggests deleterious effects of long term intensive agriculture. This should be investigated in all production areas.

Increasing maximum temperatures reduced yield for cabbage, cauliflower, rutabaga, and potato explaining 11.6, 13.9, 27.2, 14.1 percent of the variation respectively, slightly better than average temperature (Table 2). Short term heat stress (days > 30 ^{o}C) appears more important than average temperatures; as the number of days > 30 °C increased, yield decreased and there was a higher percentage of the variation explained as compared to average temperature for cabbage, cauliflower, rutabaga and potatoes (Table 2). Cole crops usually grow best where monthly average temperatures are in the 15.6 - 18.3 °C range with an average maximum of 23.9 °C (Nieuwhof, 1969), and most do not grow well at higher temperatures than 25 °C. Interestingly, the number of winter days < -10 °C were associated with higher yields of cabbage indicating that warmer winters reduced subsequent cabbage yield, perhaps due to effects on overwintering pests. Cole crops appear to have high water requirements as Nieuwhof, (1969) cites work in New York during the period of 1918 to 1940 indicating that cabbage yields were reduced by 12% in years with 80% of normal precipitation and increased 20% with 137 % of normal precipitation. Using growth models and climate records over about 100 y Andresen et al., (2001) showed low precipitation was a major limitation to yield of field corn. In our study, yield of cole crops and onions increased as the number of days with precipitation increased and the percentage variation explained was greater than that explained by total growing season precipitation, indicating that distribution of rainfall is more important than the amount (Table 2). Monteith (1981), suggested that temperature and rainfall account for 7 and 10 % of variation of cereal grain yields. Our variation explained by average temperature was similar to or higher than these figures, and including the variables days > 30 °C or days with precipitation increased the explained variation. This suggests that some cole crops and potatoes may be more affected by warmer temperatures than cereals and corn and that they could be useful indicator crops in studying climate change.

Because visual quality is so important in vegetables, effects of higher temperature on quality must be considered in addition to effects on yield. High temperatures delay heading of cabbage (Nieuwhof, 1969); cauliflower (Wheeler et al., 1995; Wurr and Fellows, 1998); induce floral disorders in broccoli (Grevesen, 1998); cauliflower (Grevesen and Olesen, 1994 b). There are also different temperature requirements for stages of growth for cauliflower and broccoli (Grevesen and Olesen, 1994 a, b; Grevesen, 1998; Grevesen and Olesen, 1999). Tuber malformation disorders in potatoes can be induced by as little as 7 days of high temperature stress (Hiller et al., 1985). Heat necrosis of potatoes is another tuber disorder related to high temperatures. Therefore, as the frequency of days > 30 °C increases, we can expect more yield decline and loss due to reduced visual quality.

Cultivar development or management studies are based on yield, disease resistance, visual quality, but quality pertaining to human nutrition is not usually taken into account. We believe this is of concern in relation to climate change as high temperatures result in lower vitamin C content (Lee and Kader, 2000; Mozafar, 1994; Weston and Barth 1997). Temperatures less than 20 °C favour vitamin C accumulation, and temperatures between 10 - 15 °C favour the accumulation of B vitamins in green vegetables (Weston and Barth 1997). Warm season tomatoes had higher B vitamins at 27-30°C which indicates potential differences in vitamin responses and concentrations between cool and warm season vegetables. Thus, with the cool season crops at least, not only do higher temperatures have the potential to reduce growth, increase visual quality disorders but in addition have the potential to reduce vitamin C content. This aspect of potential detrimental effects of climate warming on food quality is important. This suggests that further study on the relative importance of genetics, climate and production practices on this essential human nutrient is warranted.

Compacted soils reduced cabbage yield by 29% for transplanted crops, (Wolfe et al. 1995), and effects of compaction were worse in wet years for some crops (Morse 1993). Vegetable crop yield has been shown to be particularly sensitive to water supply due to shallow roots limiting uptake (Stone and Rowse 1982). Thus management practices can accentuate effects of climate, and might have more impact if the climate becomes more variable.

A period of stable climate from 1954 to 1973 preceded by periods of greater yield variability was found for field crops in adjacent US states (Andresen et al., 2001). This appears similar to records of vegetable yields in Ontario and is of concern. This effect of climate on yield variability warrants further study in Ontario. Interannual climate variability is one of the greatest risks farmers face either from direct effects or effects on pests, fertilizer efficacy, or price (Phillips et al., 1999). ENSO events have been shown to affect corn yields in the USA (Phillips et al. 1999) or vegetables (Park et al., 2002). Park et al. (2002) also showed that El-Nino events had a negative effect on supply, with 15, 21, 5 % yield reduction over the mean of Texas grown muskmelon (*Cucumis melo* L), Florida fall squash (*Praecitrullus fistulosus* Pang.) and lettuce (*Lactuca sativa* L) respectively and an positive effect 7%, and 10, 25 % yield increase on summer onions (*Allium cepa* L) winter and summer crops of Florida tomato (*Lycopersicon esculentum* L) respectively. La Nina events reduced yield of various Texas grown melons by 13-29% depending on the type. How much direct effect ENSO events have locally remains to be determined, but supply and prices in Florida, and Texas have an impact on N. American markets. Knowing the effects of ENSO events on yield and pests may lead to better pest management, fertility practices by modifying practices to take into account ENSO events.

What May Be Expected from Warming Climates

One climate change projection suggests about 48 hot days (>30 °C) in the London, Ontario, Canada area as opposed to the 1951-1980 climate normals of about 9 (Wheaton, 1999). Our observations that the number of days with maximum temperature >30 °C reduced yields, suggest that warmer temperatures and more frequent hot days will, in addition to reducing yields, increase heat related disorders and quite likely reduce vitamin content. We can also anticipate more need for water conservation and improved irrigation scheduling especially since the frequency of precipitation appears key for some vegetables. More variable yield would be consistent with the effects of more variable climate on yield found by Andresen et al., (2001). The period of stable climate observed by Andresen et al., (2001) also coincides with most of our gains in agricultural knowledge and productivity. If greater climate variability becomes the norm, considerable effort will be required to overcome detrimental effects on yield. Cultivars and management will have to be developed that are less dependent on stable conditions. Depending on when, intensity, cultivar and duration a heat/drought stress in the development of a crop occurs the damage may range from delayed harvest to considerable loss due to quality disorders. A warming climate may well lead to longer growing seasons but potentially much lower yields of some crops due to lost biomass and/or quality disorders. Irregardless of the cause, means to adapt production techniques must be found to enable crop production to be maintained.

CONCLUSIONS

Our results clearly show temperature related deceases in yield for cole crops, rutabagas and potatoes. Using days > 30 °C shows effects of short term heat stress that cannot be detected well in growing season or average temperature data. Crop yield trends, along with rising temperatures, show decreased and more variable yields with warming temperatures. While not conclusive proof of greenhouse warming vs natural variation, it suggest that if this trend continues we can expect lower more variable yields impacting on supply, quality and pricing. Unless, cultivars and management systems are developed to take variability and heat, both for yield, visual and nutritional quality into account, highly variable, poorer quality, and lower yield may result. Higher temperatures will place more demand for irrigation water and scheduling. Work is required to develop cultivars with more stable yield and nutrient content over widely varying climate conditions.

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Tables

Table 1. Regression of trend in marketable yield (t.ha^{-1})over time of selected vegetables.

Crop	Mean square	P	cv	R^2	Mean yield	Intercept	slope (linear)	slope (quadratic)
Asparagus	2.1	<0.001	15.2	44.8	2	2503	-2.5	0.0006
Broccoli	21.3	0.04	27.9	18.7	7.7	316.5	-0.16	-
Cabbage	386.8	<0.0001	16.1	38.3	29.1	-41410.5	41.9	-0.01
Cauliflower	51.9	0.0279	19.6	8.1	16.3	-89.5	0.05	-
Radish	10	0.177	26.1	4	8.7	-74.1	0.04	
Rutabaga	163.3	0.0049	17.1	18.5	30.7	-20158.6	20.38	-0.005
Carrot	4043.4	0.0001	18.3	70.5	42.7	-62515.2	62.9	-0.015
Onion	382.4	<0.0001	13.5	45.3	29.7	-24771.7	24.99	-0.001
Potato	790.6	<0.0001	11.1	86.3	18.6	-39212	39.56	-0.01
Field tomatoes	2827.5	<0.0001	14.2	81	40	562004.1	-57.65	0.015
Proc tomatoes	790.6	<0.0001	11.1	86.3	18.6	-39212	39.56	-0.01

Table 2. Percentage of variation in yield of selected vegetables explained by climate parameters.

	Ave T ^{0}C		Days >30 ^{0}C		Days < -10 ^{0}C		Total precipitation		Days with precipitation	
Crop	R^2	Slope	R^2	Slope	R^2	Slope	R^2	Slope	R^2	Slope
Asparagus	0.01	-0.04	0.02	0	0.1	0	13.4	0	15.6	-0.01
Broccoli	na	na	7.9	-0.08	8.7	0.11	12.5	0.01	14.5	0.09
Cabbage	7.6	-2.08	17.3	-0.37	24.6	0.47	1.5	0.01	20	0.29
Cauliflower	8.6	-1.32	19.4	-0.23	6.6	0.14	11.2	0.02	26.4	0.19
Rutabaga	19.3	-2.84	26.1	-0.4	4.1	0.17	13.1	0.03	36.7	0.34
Radish	0.1	0	0.8	0.02	7	-0.06	2.4	0	0.6	0.01
Potato	9.9	-0.95	23.6	-0.16	4	0.07	10.9	0.01	1.1	0.02
Carrot	0.7	0.94	0.2	-0.05	1.5	0.18	0.2	0.01	3.5	0.18
Onion	0.7	0.43	0.6	-0.05	0.2	0.03	0.3	0	28.1	0.24
Field tomatoes	2	-0.59	0.04	0.02	0	0.01	2.4	0.02	0.9	-0.08
Processing tomatoes	4.1	-1.13	0.02	0.04	0.2	0.04	0.5	0.01	0.7	-0.06

Figures

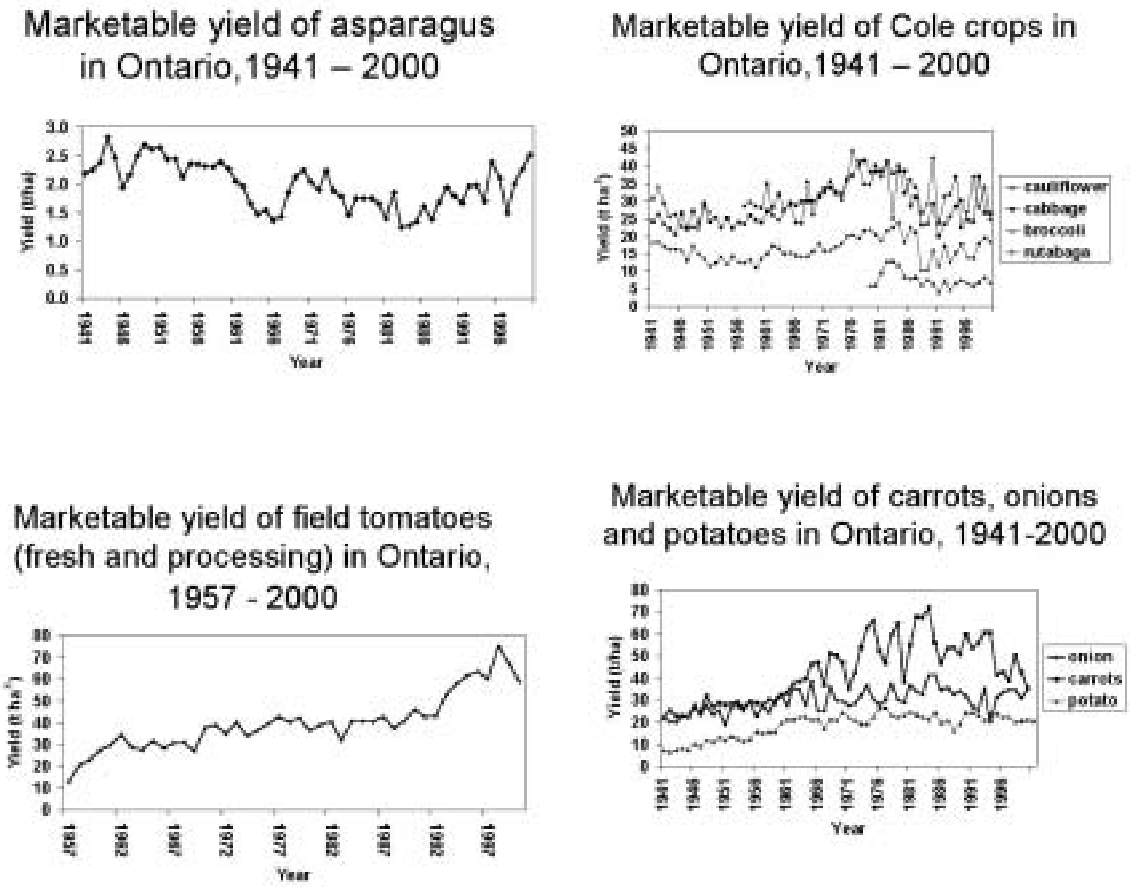

Fig. 1. Trends in yield of selected vegetable crops in Ontario.