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REVIEW
Overview of Recent Effects of Global Warming on Agricultural Production in Japan

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Abstract

To determine the effects of recent warming trends on agricultural production in Japan, in 2003 and 2005, surveys of the public institutes of agricultural research in 47 prefectures were conducted. The results suggest that recent warming trends have already significantly affected nearly all types of crops and livestock in Japan. All 47 prefectures reported warming effects on fruit tree cultivation and over 70% of prefectures recognized the effects on rice, vegetable and flower cultivation. Horticultural crops and rice are likely to be more sensitive to global warming than other agricultural crops and livestock. Our survey elucidated many effects of recent warming, such as phenological changes in many crops, increases in fruit coloring disorders and incidences of chalky rice kernels, reductions in yields of wheat, barley, vegetables, flowers, milk and eggs, and alterations in the type of disease and pest.

Discipline: Agro-meteorology/Horticulture
Additional key words: fruit trees, livestock farming, rice, vegetable, wheat

Introduction

Climate change may significantly affect production in agricultural systems. The Intergovernmental Panel on Climate Change (IPCC)[9] estimated that the global average surface air temperature will rise by 1.8-4.0ºC during the 21st century due to increases in atmospheric concentrations of greenhouse gases. Agricultural production will likely suffer serious negative effects from this warming trend. For example, regions favorable for fruit cultivation are going to move gradually northward and the climate of what are now the main production sites may become unsuitable for cultivation by the mid-21st century[25].

Accordingly, the potential effects of continued global warming on agricultural production must be examined. Crop responses to high temperatures can be accurately estimated from ecological experiments in controlled environments (i.e. greenhouses); however, such experiments are not feasible given the abundant crops and varieties cultivated throughout Japan. Even if they were possible, on-site verification is also required. The IPCC[9] has reported that the global mean temperature rose at a rate of 0.74ºC over the 20th century. The Japan Meteorological Agency[10] has reported that the mean temperature in Japan rose at a rate of 1.06ºC per century for approximately the same period, clearly accelerating after 1990. Therefore, the general effects of global warming can be estimated by collecting and analyzing data from various agricultural systems on production changes due to this recent temperature rise.

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Surveys have been carried out to determine the actual influence of global warming on fruit tree production[27] in 2003 and on other agricultural productions[26] in 2005. The objective of this review was to characterize the effects of recent warming on agricultural production by using these survey results to better understand the current situation and the future impacts of global warming in Japan.

Survey of the effects of global warming

To gather information concerning phenological changes, yield reductions, quality deteriorations and other problems in agricultural production due to recent climate change in Japan, a survey within public institutes for agricultural research was conducted in 47 prefectures. Various agricultural crops were compiled in five surveys: rice; wheat, barley, and soybeans; fruit trees; vegetables and flowers; and livestock and forage crops. Some research projects of each institute were conducted jointly in response to the survey, which included multiple-choice and open-response questions on the influence of recent warming. In the multiple-choice questions, the research projects asked about several changes in crops or livestock such as the increase in chalky kernels in race production as well as about the assumed causes for which three options (recent warming, the others or unknown) were offered.

A survey form on fruit trees was sent to prefectural institutes for fruit tree research in July 2003 and survey forms on other crops and livestock were sent to the corresponding prefectural institutes in July 2005. The fruit trees, vegetables/flowers and livestock/forage crop surveys were sent to all 47 prefectures. The rice survey was sent to all but one prefecture (Tokyo) in which rice is not a major agricultural crop. The wheat/barley/soybean survey was sent to 44 prefectures. All surveyed institutes replied by November 2003 (fruit trees) or November 2005 (other crops and livestock).

The number of prefectures reporting a recent change and assuming that it had been caused by warming was counted in each multiple-choice question. After the answers for the open-response question had been divided into certain categories, the number of prefectures reporting identical categories was counted.

Summary of warming effects on agricultural crops and livestock

The number of prefectures recognizing at least one change caused by recent global warming is presented in Fig. 1. All types of crops and livestock were reportedly affected by warming.

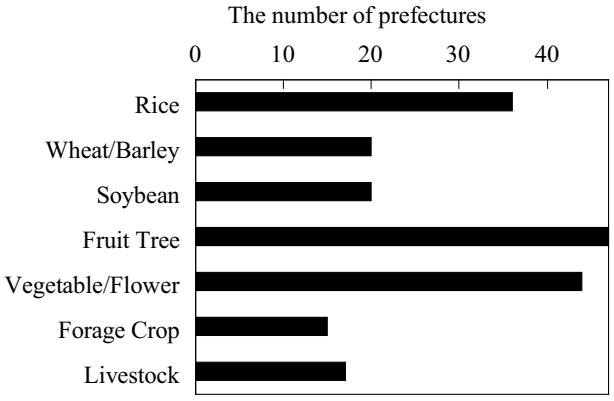

Fig. 1. Number of prefectures reporting at least one change in agricultural production caused by recent warming

All 47 prefectures reported warming effects on fruit tree cultivation and over 70% reported effects on rice and vegetable or flower cultivation. Approximately 20% of prefectures described the effects of recent warming on wheat, barley or soybean crops, and livestock farming. These results suggest that recent warming trends have already significantly affected nearly all types of crops and livestock in Japan. Although it is difficult to make a direct comparison among crops and livestock, horticultural crops and rice are likely to be more sensitive to warming than other agricultural products.

It is unclear in this survey when the change had been caused. The Japan Meteorological Agency[10] has indicated that the air temperature in Japan clearly rose after 1990. Many changes reported in this survey may be caused by post-1990 warming.

Warming effects on cereals and soybeans

Major responses to the survey questions on rice are presented in Table 1. Thirty prefectures reported reductions during the period between the planting and heading of rice, which previous studies demonstrated are shortened by high air temperatures[5]. These reductions indicate that recent warming has altered the crop calendars of rice.

Many prefectures also reported the increased prevalence of chalky rice kernels. This phenomenon may be one of the key problems caused by global warming in rice production, because rice grain declines in quality when mixed with chalky kernels. In addition, an increase in the grain fissuring of rice was reported in east and west Japan. It is known that incidences of chalky kernels and grain fissuring of rice increase under high air temperature[14,30].

Table 1. The number of prefectures that reported recent changes caused by warming in cereal and soybean cultivation

Changes	Rice	Wheat or barley	Soybean
Reduction in period between planting and heading[1)]	30		
Increase in chalky kernels[1)]	22		
Increase in grain fissuring[1)]	6		
Reduction in yield and quality by shortening of ripening period[1)]		3	
Increase in lodging[1)]		1	
Increase in delayed stem senescence[1)]			4
Increase in spikelet sterility[1)]	1		1
Increase in freezing injury and late frost damage[1)]		2	
Change of disease and pest status[2)]	25[3)]	11[4)]	15[5)]

[1)] Results from multiple-choice question
[2)] Results from open-response question
[3)] Increase in the incidence of rice bugs (14 prefectures) and sheath blight disease (4 prefectures) etc.
[4)] Increase in the incidence of fusarium head blight (9 prefectures) etc.
[5)] Increase in the incidence of Spodoptera litura (7 prefectures) etc.

In response to the questions concerning recent warming and rice cultivation, 25 prefectures reported a change of disease and pest status such as increases in pecky grain damage and the incidence of rice-plant skippers and sheath blight. The relation of disease and insects to high air temperature is not as simple as crops. However, Kiritani[11] suggested that the recent warming has increased the annual total of generations, reproductive activity and food of rice bugs in Japan.

Unlike rice cultivation, no changes were found in wheat, barley and soybeans common to most prefectures. However, three prefectures reported that the yield and quality of wheat or barley had been reduced by the shortening of the ripening period. A few prefectures also cited increases in the frequency of freezing injury, late frost damage and lodging caused by premature growth in mild winters for wheat or barley. A previous study showed that high temperatures during maturation reduced the final grain weight, mainly through early cessation of kernel growth[16]. It is also common knowledge that mild winters cause freezing injuries and late frost damage[29].

Some prefectures reported an increase in the delayed stem senescence of soybeans. It has been demonstrated that inhibition of the growth of reproductive organs caused by high temperatures is involved in the occurrence of delayed stem senescence[13].

Increased sterility of rice and soybeans due to high temperatures, which may reduce the yield[12,15], were recognized by only one prefecture, respectively. However, over 10 prefectures reported changes of the disease and pest status of wheat, barley or soybeans caused by recent warming. In answer to the open-response questions, several prefectures documented increases in *Fusarium* head blight on wheat and common cutworms on soybeans.

Warming effects on fruit trees

Many kinds of responses to survey questions on fruit trees were reported (Table 2). The budding and flowering periods were accelerated on almost all tree species. The harvesting period changed, not only to earlier but also later than before. The harvesting periods of the Japanese pear, peach and Japanese apricot were earlier than normal. That of the persimmon tended to be later.

Thirty-two prefectures stated that fruit skin coloring had been delayed and disordered for apples, grapes, persimmons and satsuma mandarins. Conversely no delays or disorders of fruit coloring were reported for the Japanese pear, peach and Japanese apricot.

Delayed endodormancy breaking and disorder of budding were not reported in open fields but only when forcing the culture of Japanese pears and grapes. Warming in autumn and winter makes it possible to delay the budding and flowering periods by delaying the endodormancy breaking. Such endodormancy breaking inhibition by high temperature is common knowledge[3,21,31].

Changes of fruit quality such as enlargement, reduction of acid and persimmon astringency, softening of flesh, tendency to spoil rapidly and increased sunscald were described on a number of tree species. Conversely few changes of soluble solids content were cited.

Table 2. The number of prefectures that reported recent changes caused by warming in fruit tree cultivation

Changes[1)]	All species[2)]	Japanese pear	Peach	Japanese apricot	Apple	Grape	Persimmon	Satsuma mandarin
Acceleration of budding and flowering	29	12	2	4	4	1	4	8
Acceleration of harvesting	17	9	4	1	1		1	1
Delay of harvesting	4				1		3	
Delay of fruit coloring	32				11	20	7	6
Delay of endodormancy breaking or budding in forcing cultutre	6	3	2			3		
Delay of flower bud initiation in forcing culture	5							5
Fruit size enlarging	9			1	2	1	3	3
Reduction of acidity and astringency	10	1			1		2	4
Softening of flesh	9				7		3	
Spoiling rapidly	8				3		1	4
Increase in sunscald	7	2	1		4	2	2	1
Increase in freezing injury	10	3	3	2	4			
Decrease in freezing injury	14							10
Increase in late frost damage	14	5	1	2	3		2	
Decrease in late frost damage	4				1	1	1	
Change of disease and pest status	26[3)]							

[1)] All results from open-response questions.
[2)] The number of prefectures which indicate about more than one species (including other species than indicated in the right column)
[3)] Increase in the incidence of fruit bugs (9 prefectures), rust mite (6 prefectures) and apple ring rot (4 prefectures) etc.

Those changes, except for increased sunscald, mainly extended to only tree species for which fruit coloring had been delayed and disordered. However, the increased sunscald extended to almost all tree species. These results suggest that the tree species are classified into two types based on the responses of fruit development to recent global warming. One group is the earlier development type and the other is that of prolonged development. The former is a tree species in which both flowering and harvesting periods had accelerated; these include Japanese pears, peaches and Japanese apricots. The latter is a tree species in which the flowering period had accelerated, but not the harvesting period; this type includes apples, persimmons, grapes and satsuma mandarins. Fruit qualities of the prolonged development type had clearly changed, for example coloring disorder, enlargement, reduction of acid, softening and tendency to spoil rapidly.

It has been known that accumulation of pigments such as anthocyanin and carotenoid in pericarps is generally advanced under low temperatures[1,2]. The harvesting period of fruit of the prolonged development type is often determined by the degree of coloring. The delay of skin coloring is the reason why the harvesting period of this type had not accelerated. Change of fruit quality such as enlargement, reduction of acid, reduction of soluble persimmon tannin content, softening of flesh and tendency to spoil rapidly might be caused by extension of the fruit developing period. Therefore most of these changes in fruit quality are more noticeable in the prolonged development type rather than that of earlier development.

The sunburn of the fruit was described in both types, because it is caused by a rise in the fruit surface temperature[24] rather than the extension of the fruit developing period.

The incidence of freezing injury and late frost damage differed between regions. Increases in freezing injury and late frost damage were reported in more prefectures in northern Japan than in western and southern Japan. High temperatures in autumn inhibit cold hardening[6,20], which may explain why freezing injury was more prevalent in north Japan, which is a cold area. The increase in late frost damage in the cold area might be caused by the acceleration of budding and flowering. The earlier budding and flowering results from greater exposure to low temperature. Many prefectures documented a change of disease and pest status, such as increased incidence of spider mite and changes in the kinds of shield bug.

Table 3. The number of prefectures that reported recent changes caused by warming in open field cultivation of vegetables

Changes[1)]	All species[2)]	Cabbage	Lettuce	Chinese cabbage	Broccoli	Radish	Tomato
Change in growing period	16	4	6	5	4	2	
Increase in growth disorder	8	2	2		3	2	3
Reduction in yield due to slow growth in summer	7				3	1	
Reduction in yield due to shortening of growth period	4		2	1			

[1)] All results from multiple-choice questions
[2)] The number of prefectural which indicate about more than one species (including other species than indicated in the right column)

Warming effects on vegetables and flowers

Major responses to the survey questions for the open field cultivation of vegetables are presented in Table 3. Sixteen prefectures responded that the length of the growing period in agricultural fields had changed; a problem which they attributed to the recent warmer climate. Planning for crop cultivation becomes more difficult due to these changes in the growing period. Several prefectures reported a few additional effects of recent warming in vegetable fields, such as more frequent growth disorders (e.g. bolting of leafy vegetables) and reductions in yield due to slow growth in summer and the shortening of the growing period. It has been known that high temperature accelerates the growth of many kinds of leafy and root vegetables until about 20ºC[17,19]. Bolting and the decrease in yield of many kinds of vegetables also increase under high temperature[4,7,8].

Conversely, in response to the questions for forcing cultures of vegetables and flowers, 23 prefectures responded that recent warming had fueled the need for heat countermeasures and cultivation downtime in forcing cultivation. However, 16 prefectures believed that warming had led to a decline in heating costs during the winter.

Many prefectures reported increases in the incidence of weeds (four prefectures) and diseases/pests (30 prefectures), such as thrips, cabbage armyworms, tobacco budworms and mites. As an advantage of warming, four prefectures indicated extended cultivation periods for fall and winter vegetables.

Warming effects on livestock and forage crops

Major responses to the survey questions for livestock and forage crops are presented in Table 4. Although there were no changes common to many prefectures, several prefectures reported that recent warming had caused decreases in the feed intake, feeding efficiency of livestock, milk yields and hen laying. Several prefectures also described that recent warming had increased deaths due to heat stroke and reproductive disturbances due to summer fatigue. Previous studies have demonstrated that high air temperatures lead to decreased feed intake and body weight gain in cattle, pigs and chickens[18,28,32].

Six prefectures cited that forage crop yields had decreased due to summer growth depletion. Reduced yields of temperate grass were also reported in this survey from prefectures in eastern and central Japan, and reduced corn yields were reported from prefectures in central, western, and southern Japan. These results coincide with those of Sasaki et al.[22] and Seino[23], who studied estimated local changes of crop yields in Japan and predicted decreases in temperate grass and corn yields due to global warming in similar areas of the country.

Several prefectures reported increases in wintertime meat and egg production of chickens (four prefectures) and grass yields (five prefectures). These results suggest that global warming will have various negative effects in summer but several benefits in winter.

Conclusion

This survey indicates that agricultural production has been significantly affected by recent global warming. Air temperature has been on a rising trend following the survey in Japan. The effects of warming reported in this study may be more remarkable now than six or eight years ago. If global warming continues to increase, these problems will increase in frequency and intensity.

Not all judgments by researchers who responded to the survey were right, due to the difficulty in distinguishing them from changes caused by factors other than warming. We believe that detailed follow-up experiments and the development of countermeasures for these problems will be needed to adapt to global warming.

Table 4. The number of prefectures that reported recent changes caused by warming in livestock farming

Changes	Dairy or beef cattle	Pig	Chicken	Forage crop
Reduction in feed intake[1)]	3	1	2	
Reduction in feeding efficiency[1)]	2	1	2	
Increase in reproductive disturbance due to summer fatigue[1)]	2	3		
Increase in death due to heat stroke[1)]	2	1	3	
Reduction in milk yield[1)]	3			
Reduction in milk fat percentage[1)]	1			
Reduction in laying[1)]	2			
Reduction in yield due to summer growth depletion[1)]				6
Change of disease and pest status[2)]	6[3)]	2[4)]	2[4)]	10[5)]

[1)] Results from multiple-choice question
[2)] Results from open-response question
[3)] Increase in the incidence of mastitis (2 prefectures) etc.
[4)] Increase in the incidence of mite (2 prefectures) etc.
[5)] Increase in the incidence of aphid (2 prefectures) etc.

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