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Overview of the Impacts of Climate Warming on Paddy Rice Production in Heilongjiang Province, the north most of China

Jiao JIANG[*], Xu XIAN-BIN[*], Yousay HAYASHI[**], and Fu-lu TAO[***]

Abstract

Cool summer damage, spring drought, high temperature injury, infectious diseases, pests and weeds of paddy rice under ongoing climate warming were discussed using the meteorological data from 1951 to 2005 and taking into consideration the characteristics of the paddy rice in Harbin and Jiamusi in Heilongjiang Province. Based on analyses of actual problems in paddy rice production, we put forward a series of countermeasures utilizing applied technology that we should adopt from now on in order to deal with climate warming, to reduce the loss resulting from disasters, and to realize a stable paddy rice production.

Key words: climate warming, paddy rice production, agricultural disaster mitigation, Heilongjiang Province

1. Introduction

It has become evident from previous studies that our entire Earth is exhibiting a global warming trend (Ichikawa, 2004; IPCC, 2007). Although there have been a lot of reports (Hayashi et al., 2005; Huang, 2005; Wang and Gong, 2001; Wu, 1997; Zhang and Wang, 1995; Zhao and Qin, 2004) on the impacts of the climate warming on the rice production yield, there are very few relevant research reports on the cool climate conditions in Heilongjiang Province, China. Worse still, in this limited number of studies, great discrepancies (Pan et al., 2002; Fang et al., 2004; Wang et al., 2005; Wang et al., 2003; Yao, et al., 2005) can be found among the results concerning the temperature rising during winter and summer; also the quantization of elevation temperature and the extent of impacts on paddy rice yield were not unified or standardized either.

Heilongjiang Province is one of the most important production areas for paddy rice. It is also China's greatest production area for commercial base. Therefore, a continuous stable sustainability and development of the rice production of Heilongjiang Province bears a significant meaning (Jiao and Xu, 2004; Xiao, 2002) in ensuring the food safety in China, particularly in satisfying the Chinese or even the global market demands for rice. The present review is based on the results of the current studies, which include cool summer damage, spring drought, high temperature injury, infectious diseases, pests and weeds for paddy rice, taking into account of the regional climate of Heilongjiang Province and the properties of the paddy rice breed. We also discuss the possible impacts of climate warming in Heilongjiang Province on paddy rice production and put forward concrete countermeasures.

2. Data and Meteorological Backgrounds

2.1. Meteorological Data

The main meteorological data are taken from Harbin Observatory of Songnen Plain, which represents the west of Heilongjiang Province, and Jiamusi Observatory of Shanjiang Plain, which represents the east of Heilongjiang Province. The time frame is the continuous 55 years between 1951 and 2005. Others are all taken from data announced by national meteorological observatories.

As shown in Figure 1, it can be seen that the climate warming of Heilongjiang Province began in the 1970s. From the annual average temperatures during the years 1971 to 2005 for Harbin, an annual increase of 0.065°C/year is obtained. Additionally, we can calculate the annual temperature elevation rates of 0.047°C/year for summer and of 0.077°C/year for winter. The annual temperature rise rate in winter is more than 1.6 times faster than that in summer. Furthermore the summer average temperature during the years 2001 to 2005 is higher than that of the years 1951 to 1970 by 1.19°C, while the winter average is higher by 2.20°C.

2.2. Paddy Rice Production Data

Before a new agricultural crop is named and promoted in China, it has to be put through unified quality control and production tests under the National Seed Management Section. The present investigation employed the relevant cultivation data taken from the production tests. The data mainly include parameters such as the average production level, required active aggregated temperature range, growing period, and number of leaves. We collected 196

[*] Heilongjiang Academy of Agricultural Sciences, Harbin 150086, P.R. China
[**] Graduate School of Life and Environmental Sciences, University of Tsukuba, Tsukuba 305-8572, Japan
[***] Agro-Meteorology Division, National Institute for Agro-Environmental Sciences, Tsukuba 305-8604, Japan

northeast region breeds of paddy rice mass-promoted since the year 1965, and the rice production level data announced by the Heilongjiang Province Statistical Census Department.

3. Results and Basic Discussion

3.1. Production Potential

Breeds of Rice can be classified into different ecological types in accordance with their response to different temperatures and amounts of sunshine. Rice breeds of different regions have different adaptability to the local climate conditions. Heilongjiang Province is geographically located at a high-latitude with a short frost period and low average temperature. The rice crops grown there are all fast ripening breeds (CAAS, 1986; CNRRI, 1989) which are sensitive to temperature and insensitive to sunlight exposure.

As the cultivation period for paddy rice is short, insufficient sunshine energy is the main limiting factor for upgrading the potential production of Heilongjiang Province. On the other hand, effective accumulated temperatures (≧10°C) of the north and south cultivation regions differ as much as 400-500°C. Consequently the cultivation periods of the breeds differ by about 25 days. This indicates that when the accumulated temperature is increased because of the climate warming in Heilongjiang Province, it is possible to improve the productivity by adopting rice breeds with relatively longer cultivation periods or relatively higher required accumulative temperature. In view of this, a climate warming in Heilongjiang Province exerts an advantageous influence by improving productivity of paddy rice.

3.2. High Temperature Injury

When the temperature exceeds an optimal temperature range, paddy rice cultivation suffers. This means that a high temperature induces a negative impact, which is resulting in little ears, a small number of rice grains and a decline of grain weight, and thereby low productivity. The quality of rice is affected also. In general production, the critical parameter (Liang, 1983; Long, 1988) is represented by a daily maximum air temperature exceeding 35°C. With the frequency of the days with maximum air temperature exceeding 35°C in the meteorological data of the years 1971-2000 of the main paddy rice cultivation regions in southern China and northeast China, it can be seen that this high temperature critical value occurs very frequently in rice cultivation regions in southern China. Among these southern regions, Changsha of Hunan Province can reach as high as 61% in the last ten days of July. On the contrary, for northeast regions, such high temperature critical value occurs only on rare occasions in June or July. For Harbin, this occurs only once in a long while. Around the central-north region of Heilongjiang Province, such days over critical temperature are almost nonexistent (Table 1). In the past, when the temperature of the rice cultivation regions was too high, the production level as well as the rice quality of the paddy rice was affected. From the agricultural history of the paddy rice production in Heilongjiang Province, such high temperature injury has never occurred.

The damage of high temperature to paddy rice is mainly on the booting and ripening stages. For the northeast region of China, these stages appear in late July or after. During this period, even for Shenyang, which is located in the southern part of the northeast region, the temperature never reaches the critical level for high temperature injury under the current climate conditions. Now, let'

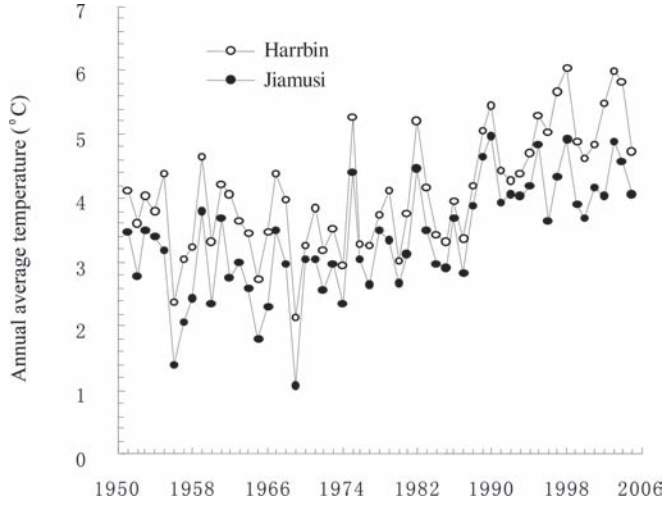

Fig. 1 Changes of the annual average temperature at Harbin and Jiamusi, Heilongjiang Prpvince.

Table 1 Comparison of the Occurrence (day) of extremely high temperature condition (1971-2000).

Area	Station	Latitude	June			July			August			September		
			1-10	11-20	21-30	1-10	11-20	21-31	1-10	11-20	21-31	1-10	11-20	21-30
South	Changsha	28 12'	3	5	12	36	41	61	51	34	34	15	4	1
	Hangzhou	30 14'	2	5	10	31	38	47	35	24	17	8	2	0
Northeast	Shenyang	41 46'	-	-	1	2	4	-	-	-	-	-	-	-
	Changchun	43 51'	-	-	1	2	1	-	-	-	-	-	-	-
	Harbin	45 51'	-	-	1	1	1	-	-	-	-	-	-	-
	Hailun	47 26'	-	-	1	-	-	-	-	-	-	-	-	-

s look at the statistical results of the daily maximum air temperature of Harbin and Jiamusi from 1996-2005. From late July to August, even when the climate became warm, a temperature exceeding 35°C has never occurred. The average maximum air temperatures of Harbin and Shenyang differ by 2.1°C. Because of this, even if the climates to become warmer, Heilongjiang Province still is not going to have a severe problem of high temperature injury for paddy rice.

3.3. Cold Weather Damage

Only fast ripening rice breeds with ripening periods coincident with the frostless period can be cultivated in Heilongjiang Province (Zhang, 1998). In addition, as Heilongjiang Province belongs to the continental climate, the air temperature rises and falls drastically. The deviation of the effective accumulated temperature fluctuates as much as ±300°C. Paddy rice is more susceptible to more frequent low temperature, once every 4 years on the average (Zu and Zu, 1999; Ma, 1996). For paddy rice, during the booting stage or flowering stage, if there is a consecutive period of 3 to 5 days of minimum air temperature lower than 17°C or an average temperature of not more than 20°C, then the cool summer damage due to floral impotency will result. Inadequate accumulated temperature during the cultivation period leads to a significant delay in cultivation. And even cool summer damage due to delayed growth can be caused if affected by early frost coincidentally (Jiao, 1994). Cold weather damage induced by cool summer is the main meteorological disaster affecting the production level and quality of paddy rice in the Heilongjiang Province. For regions of higher latitude and lower accumulative temperature, this kind of damage is severer.

The cool summer damage due to floral impotency is mainly associated with the cold temperature in late July and early August. Using the statistical data of minimum temperature of Jiamusi during this period, using equation (1), we can introduce a meteorological index CDI:

$$D = \sum_{i=1}^{n} (w_1 - w_2), \quad (1)$$

here D is the CDI (Cold Damage Index) due to floral impotency for paddy rice, w_1 is a minimum temperature which is less than 17°C, w_2 is 17°C, the critical temperature for impairment type of cold weather damage, n is the number of days with a minimum temperature which is less than 17°C (Jiao, 2002).

It is clear that, despite the fact that the climate is exhibiting a global warming trend, in the critical period during which the paddy rice is cultivated, the frequency of a temperature which is lower than the CDI does not show any sign of declining in Heilongjiang Province (Figure 2). In view of this, at present, one still cannot be absolutely certain that possibility of the cool summer damage due to floral impotency is weakened. For example, in 2002, Shanjiang Plain in eastern Heilongjiang Province had reported an extensive area of cool summer damage due to floral impotency. Even when global warming continues to worsen, cold weather damage still continues to be one of the most influential meteorological disaster in Heilongjiang Province (Jiao et al., 2004).

3.4. Spring Drought

Property of the rainfall in Heilongjiang Province has several characteristics. First, the annual precipitation is relatively little. Second, the rainfall season fluctuates. Third, the annual precipitation varies greatly from year to year. For most regions, the annual precipitation is only equivalent to that in northern Japan, or about 40% of the rice cultivation region of southern China. Take Harbin for example: the average annual precipitation is approximately 530 mm. Minimum monthly precipitation is in January: only 3.7 mm. The maximum is in July: 160.7 mm. Figure 3 shows that there are three different periods defined by a balance between precipitation and potential evaporation, which exert significant influences on the paddy rice production in Heilongjiang Province. The existence of a spring drought period indicates that, under the circumstance of not adequate water pumping systems of irrigation water but relying on natural rainfall, the area of paddy rice cultivation in Heilongjiang Province cannot function normally. Late May is the period for transplanting. The soil plowing and soil aeration preceding

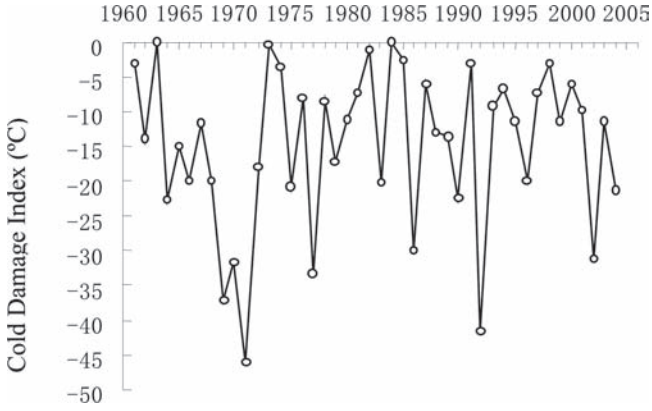

Fig. 2 Change of CDI due to floral impotency on the rice yield in Heilongjiang Province.

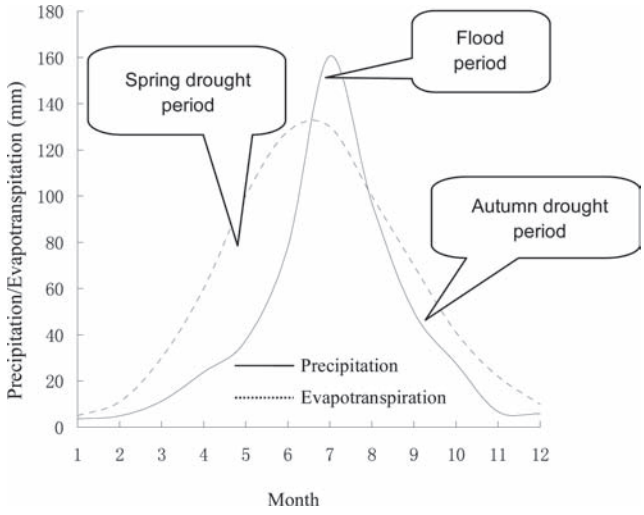

Fig. 3 Three representative periods for drought (deficit of water) and flood (excess of water) in Harbin.

transplanting requires a large amount of water. Whether or not one can secure enough water in spring for soil plowing and soil aeration, and enough water for the first half cultivation period after transplanting, is the critical limiting factor for determining the cultivation area.

Heilongjiang Province is a place with little snow falling in winter, and little rainfall in springtime. Then evaporation amount excesses precipitation during winter. Thus, in spring, most rivers are suffering from shortage of water. Worse still, the rainfall rate during this period fluctuates drastically. In the past, droughts occurring in paddy rice production have led to severe damage, with the worst cases leading to farm abandonment, or even the phenomenon of extensive area of forced shifting from paddy field farming to dry field farming.

Because of the associated temperature elevation and fluctuations in precipitation, global warming may further worsen the possibility of spring drought and may cause disadvantageous influences to paddy rice. In Heilongjiang Province, there are quite a few big plains. Generally, availability of water control is below 10% in proportion, as rivers have gentle running slopes. Constructing of water reservoirs, "Save up water surplus in summer for using in spring peak period," is the key in solving the stable production of paddy rice.

3.5. Infectious Diseases, Pests and Weeds

Before 1983, the cultivation area for paddy rice in Heilongjiang Province was approximately 0.2 million hm^2, which is about 2% of the total agricultural area. Paddy rice cultivation used to be only a very minor planting. In addition, because of the severely cold winter, summer paddy rice was cultivated with a short cultivation period and lower required temperature. For this reason, the extent of infectious diseases had been relatively small. In 2006, the cultivation area for paddy rice in Heilongjiang Province has reached approximately 2 million hm^2, which is about 20% of the total agricultural area as shown in

Figure 4. For many regions, paddy rice has become a consecutively and intensively cultivated crop in extensive area. The damage to paddy rice production caused by infectious diseases and bugs has become a pressing problem that calls for special attention (Wang, 2006; Xin et al., 2004).

For rice fields in the past, the main disease was Rice Disease (Blast). At present, plant diseases such as bacterial disease (Sheath brown rot) has been frequent plant diseases having caused a lot of damage. In the past, rice fields had only some minor pests such as soil worms and flies (Rice leafminer), which did only insignificant damage during the budding period. At present, the harmful insects (Rice stem borer) have become the frequent cause of severe pest damage to paddy rice. Furthermore, the number of weed types also reveals an increasing trend.

As shown in Figure 1, temperature during wintertime has been rising quickly. The frontier of damage caused by infectious diseases and pests has been shifting to the north. The cases of pests and infectious diseases carried beyond wintertime have increased in number. This may be the fundamental reason why the damage due to infectious diseases, pests and weeds have increased both in terms of number of reported cases and severity. This result is consistent with the previous relevant research reports (Li, 1993; Liu and Gu, 1997) about the impact of global warming on the damage due to infectious diseases, pests and weeds.

3.6. Cultivation Techniques

The cultivation techniques in Heilongjiang Province are now under developing stage. At present, the most popular technique for paddy rice cultivation is “seed budding in dry soil and manual transplantation.” Second comes “seed budding in seed plate and transplantation by machine.” Third comes “direct seed sowing by machine.”

Ratio of “seed budding in dry soil and manual transplantation”, accounts for at least 50% of the total cultivation area, though this percentage is exhibiting a declining trend in recent years. And “seed budding in seed plate and transplantation by machine” accounts for about 40% of the total cultivation area for paddy rice, and this percentage is showing an increasing trend in recent years. This shifting trend is affected by production conditions,

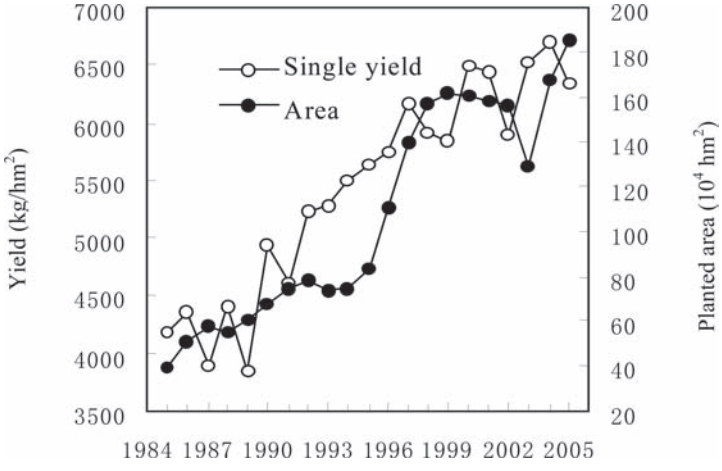

Fig. 4 Changes of the yield and the planted area for paddy rice in Heilongjiang Province.

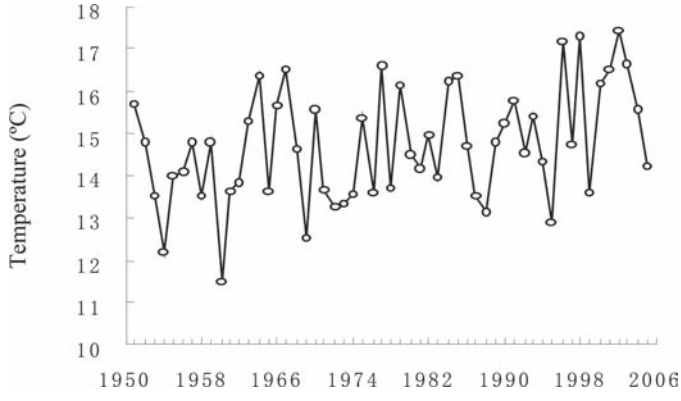

Fig. 5 Change of the average temperature of May at Harbin.

and, in general, is not affected by global warming.

"Direct seed sowing by machine" is being employed by a few farmers in Shanjiang Plain located east of Heilongjiang Province. In the past, Heilongjiang Province used to mainly employ "direct seed sowing." Compared with "seed budding in dry soil and manual transplantation," "direct seed sowing" has a lower and unstable production level. The main cause was attributed to the drastic fluctuation of temperature during spring in Heilongjiang Province. "Direct seed sowing" does not have the stage of seed budding in dry soil. Thus, seeds are more susceptible to low temperature influence during spring. This kind of paddy rice cultivation often suffers from retarded ear growth, low temperature weather damage and early frost. This leads to reduction in production level. In addition, seeds and budding seeds under the low temperature of watery soil are more susceptible to infectious diseases. As a result, despite the fact that "direct seed sowing" in Heilongjiang Province has a lower production cost, the production level cannot be improved much.

Under the condition of climate warming, can the technique of "direct seed sowing" be developed? The most influential month affecting the "direct seed sowing" technique of paddy rice cultivation in Heilongjiang Province is May. As shown in Figure 5, it can be revealed that the temperature of May indicates a slight rising. The annual average temperature of May during the years 2001 to 2005 is only 1.75°C higher than the average temperature during the years 1951 to 1970. And the fluctuations are relatively large. In view of this, even under the climate warming, the temperature fluctuations are still not improved enough for the "direct seed sowing" technique to be feasible for development.

4. Discussion

4.1. Maintenance of production level and accumulated temperature

The north and south extremes of Heilongjiang Province span across 10 degrees of latitude. The frost periods of different rice cultivation regions may differ a lot. The paddy rice breeds cultivated in Heilongjiang Province are all fast ripening and sensitive to temperature. In general, these breeds can only be planted within a narrow temperature range. For paddy rice cultivated in a region of relatively short frostless period and low accumulative temperature, the growth period of the paddy rice is delayed and it is susceptible to low temperature damage and early frost. This often leads to reduction in production level. For paddy rice cultivated in a region of relatively long frostless period and high accumulated temperature, the growth period of the paddy rice is distinctly shortened but biomass gain is also lessened and it is susceptible to premature ears. This also leads to reduction in production level. Thus, in order to recognize the characteristics of each breed and thereby cultivate them accordingly in their respective optimal cultivation regions, Heilongjiang Province has classified the regions into different accumulated temperature zones based on the statistical data.

The classification of accumulated temperature zones plays an important role giving effective instruction on selecting the correct paddy rice breed, lessening the losses due to meteorological disasters. The problem at present is the climate warming. The accumulated temperature parameter for each region has already changed. Agricultural techniques for paddy rice have also shifted from the main traditional "direct seed sowing" way in the past and developed into the present "warm-preserving seed budding and transplantation." Under production consideration, the accumulated temperature zones have to be reclassified. The development of agricultural techniques also calls for the reevaluation of the required meteorological indices for each paddy rice breed. In the past, different groups of people had investigated how to reclassify accumulated temperature zones; however, the different investigation methods had led to quite different results (Agricultural Bureau of Heilongjiang Province, 1981; Seed Administration Bureau of Heilongjiang Province, 1995). This also further complicated the use of accumulated temperature zones as an index in production consideration. The reclassification of accumulated temperature zones, and the unification of agriculture techniques and the index of accumulated temperature zones, are the main countermeasures against climate warming for the time being.

4.2. Constructing Infrastructure and Facilities for Irrigation

Whether or not Heilongjiang Province can solve the spring drought problem, whether or not the cultivation area can continue to expand, the key lies in constructing infrastructure and facilities for irrigation. The well digging irrigation method, which has been employed for a large area in rice cultivation, is no longer promising for development because of the continuous lowering of the underground water table. Transport of water for irrigation from rivers, again, is not reliable because of spring drought and drastic fluctuation in rainfall. For example, during 2000 to 2003, since the water levels in rivers during springtime were so low that it was impossible to take the remaining water out, if there was any water at all. The result was extensive area of dried rice fields.

Worse cases included no water for soil aeration,

delayed seed transplantation, and water shortage after transplantation. The worst cases were abandonment of rice fields, and forced shifting from paddy field farming to dry field farming. Under the warming circumstance of temperature rise and accelerated evaporation, the spring drought of Heilongjiang Province may be deteriorating. Because of this, construction of water reservoirs and water dams to improve the control of the river water, and "save up a water surplus in the spring drought period," is the key to solving the paddy rice drought problem and expanding cultivation area.

4.3. Preventing Infectious Diseases, Pests and Weeds

The damage due to infectious diseases, pests and weeds in Heilongjiang Province is exhibiting a deteriorating trend. With the continuous expansion of cultivation area for paddy rice and the consecutive rotations for rice cultivation, if the climate continues to become warmer, the damage due to infectious diseases, pests and weeds is deteriorating. Attention and prevention of such damage have to be taken, both against reoccurrence of past bad experiences and potentially new types. We must investigate in depth if there is any regularity of outbreaks of damage due to infectious diseases, pests and weeds, under the climate warming situation. We must develop new prevention techniques. At the same time, we must further improve the existing techniques and system, and adopt the corresponding integrated techniques to ensure the preventative effects.

4.4. Introduction of Adaptable Rice Breed and Cultivation Techniques

Crops require suitable climate conditions in order to have a high and stable production level. However, it normally takes at least 10 years to develop a new breed. Based on the past studies that emphasized high production level and high tolerance against low temperature cold weather damage, we are now to develop new breeds that can adapt to relatively warmer temperature, or breeds with a longer growth period for the rice gains. We should also broaden the variety of breeds to ensure that production continues to adapt to climate warming with the new paddy rice breed.

With the climate warming and the consequent soil temperature rise, the microorganisms in soil are also undergoing changes. Thus, the rate of decomposition of humus and release of nutriments in soil will change too. Careful investigations have to be carried out in order to develop a suitable mix of manure or fertilizer with a balanced composition, and the corresponding application method. With the climate warming, the required seed budding size and the transplantation techniques may also undergo changes. The production operational procedures and techniques, which must focus on the harvest timing, have to be adjusted accordingly. Also, these investigations must be in compliance with the studies on integrated production technology against CO_2 emission.

5. Conclusive Remarks

Climate warming has certain advantageous factors for the paddy rice cultivation in Heilongjiang Province. The main advantageous factor is that, with the elevated temperature, we can select a breed with a longer grain growing period in order to improve the potential production level. However, at present, the temperature rising is still limited. Since Heilongjiang Province is a high latitude cold region, there is not enough temperature resources. The accumulative temperature fluctuates drastically from year to year. There is no evident clear decrease in low temperature cold weather damage or early frost. On the contrary, there are increasing trends of disasters of droughts or floods. For example, flooding in the year 1998, early frost in the year 1999, severe spring drought in the year 2001, extensive area of cool summer damage due to floral impotency in the year 2002, local area of cool summer damage due to floral impotency in the year 2003, and infectious diseases and stalk breaking of crops in the year 2005.

These all points to the importance of preventing negative impacts by climate change in order to secure paddy rice production in Heilongjiang Province. One must persistently keep in mind the advisory principle centering on "promoting early ripening and preventing cold weather damage" against disasters robbing our good harvest. When selecting a suitable rice breed, one must adopt "a guarantee rate of 80% of ripening" as the key index for selection criterion.

Finally, the temperature rise started to accelerate more or less around the year 1990. That coincided with the most rapid urban development in Heilongjiang Province. It is necessary to examine closely the causes leading to the climate warming in Heilongjiang Province in order to take the appropriate countermeasures. At the same time, we must develop a mechanism to predict the extent to which the climate is warming up, and research responses utilizing a new paddy rice breed for climate warming, in order to adjust for the appropriate techniques.

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