CLIMATE CHANGE ADAPTATION STRATEGIES FOR AGRICULTURAL WATER MANAGEMENT IN TAIWAN

ADAPTATION AU CHANGEMENT CLIMATIQUE POUR LA GESTION D'EAU AGRICOLE A TAIWAN

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ABSTRACT

Being a densely populated small island of steep hills, it is very difficult for Taiwan to store water for irrigation use. Approximately 70% of water used for irrigation is drawn from rivers. Planning for water resources allocation and distribution is uncertain due to the uneven temporal and spatial distribution of water and the distinctive dry and wet seasons. Though the annual rainfall has not changed much over Taiwan, there have been more frequent droughts and floods that may be attributed to climate change phenomenon. The impacts of climate change on the agricultural water resources in Taiwan consist of two aspects: water quantity and hydrologic pattern.

For water quantity, the paddy rice grows faster and shortens its total growth period as a result of higher average temperatures. However, as the solar radiation increases, the average total evapotranspiration for each rice-crop period is estimated to rise by 2.1% and 6.8% within the future 30 years and 60 years, respectively. For hydrologic pattern, the climate change will cause more uneven temporal and spatial distribution of rainfalls. In consequence, higher intensity rainfalls and more frequent severe droughts are expected. The extreme weather alters stream flow patterns and reduces the reservoir capacities due to sedimentation. These have made the Irrigation Associations (IAs) dependence on reservoir water supply risky to operate the existing irrigation schemes.

To cope with these issues, the Council of Agriculture in Taiwan has been strengthening the multi-functional irrigation infrastructure; improving the basic environment for agricultural production; developing productive, ecologic and living functions of agricultural water resources; building up national Geographic Information System for irrigation; upgrading irrigation management efficiencies and ensuring full uses of the resources of IAs to develop water resources related industries. The Council plans the following policies: developing the

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new reuse water resource, regulating shift of remaining water, building ponds for storage, strengthening irrigation management and establishing a rule on shift of water resource. To face the climate change effect in future, proposed adaptation strategies and direction for Taiwan's agriculture are: developing sustainable agriculture, ensuring food self-sufficiency for food security, renovating irrigation infrastructure and changing cultivation pattern.

Keyword: *Climate Change, Taiwan, Agricultural Water Management*

RESUME

Etant une île densément peuplée de petits collines escarpées, il est très difficile pour Taiwan de stocker l'eau pour l'irrigation. Environ 70% de l'eau utilisée pour l'irrigation est tirée de rivières. La planification d'allocation et de distribution des ressources en eau est incertaine en raison de la répartition inégale, spatiale et temporelle de l'eau ; et des saisons sèches et humides distinctes. Bien que les précipitations annuelles n'aient pas beaucoup changé en Taiwan, il y a eu des sécheresses et des inondations plus fréquentes qui peuvent être attribuées au phénomène du changement climatique. Les impacts du changement climatique sur les ressources en eau agricole en Taiwan se composent de deux aspects: la quantité d'eau et le modèle hydrologique.

Pour la quantité d'eau, le riz paddy pousse plus vite et il raccourcit sa période de croissance totale en raison de la hausse des températures moyennes. Cependant, comme le rayonnement solaire augmente, l'évapotranspiration totale moyenne pour chaque période de récolte de riz devrait augmenter de 2,1% et 6,8% dans les 30 et 60 futures années, respectivement. Pour modèle hydrologique, le changement climatique va provoquer une répartition plus inégale temporelle et spatiale des précipitations. En conséquence, l'intensité des précipitations plus élevées et plus fréquentes sécheresses sévères sont attendues. Les modèles météorologiques extrêmes modifient le débit et les capacités de réservoir sont réduites dû à la sédimentation. Les Associations Irrigation (IA) sont dépendantes l'approvisionnement en eau des réservoirs. Mais en ce moment l'application des systèmes d'irrigation existants est risquée.

Pour faire face à ces questions, le Conseil de l'agriculture à Taiwan renforce l'infrastructure d'irrigation multifonctionnel, améliore l'environnement de base pour la production agricole, développe les fonctions productives, écologiques et celles de vie, des ressources en eau agricole; crée le Système national d'information géographique pour l'irrigation ; met à jour des efficacités de la gestion d'irrigation et garanti l'utilisation complète des ressources des IA pour développer les industries nécessitant les ressources en eau. Le Conseil prévoit les politiques suivantes: le développement des ressources nouvelles de la réutilisation de l'eau, la régulation le déplacement de l'eau restante, la construction de bassins de stockage, le renforcement de la gestion d'irrigation et l'établissement d'une règle sur le transfert des ressources en eau. Pour faire face aux effets du changement climatique à l'avenir, des stratégies d'adaptation et les orientations proposées pour l'agriculture de Taiwan sont les suivants: développer une agriculture durable, assurer l'autosuffisance alimentaire pour la sécurité alimentaire, la rénovation des infrastructures d'irrigation et le modèle de culture en mutation.

Mot clés: *Changement climatique, Taïwan, gestion des eaux agricoles.*

1. INTRODUCTION

In its 4th Evaluation Report, the UN Intergovernmental Panel on Climate Change (IPCC) stated that climate change will increasingly worsen the water resources and food security around the world (IPCC, 2007). The impacts of climate change are not only associated with flood and drought frequency, but also hydrologic pattern changes, which heighten the difficulty in saving rainfall and operating water resources. It is difficult to save rainfall for future uses due hilly terrain, uneven temporal and spatial distribution of rainfall and river flow, distinctive dry and wet season and raising temperatures that increases the demand for more irrigation water. With continuing growth of world water consumption (UNEP, 2002), food consumption in each country was predicted to increase by average 9% by 2030 (FAO, 2002). Couple with this, when one considers the reduction in food production in major food producing countries due to various causes in recent years (IFPRI, 2009), the world's food supply is going to be critically constrained. Thus, many countries are attempting to ensure food supply self-sufficiency for reason of food security. In this regard, keeping of sufficient water supply rates becomes the key policy for water resources. Because of the situation of limited water resources during the dry season in Asia as well as the implications of climate change, the issue of assurance of food security while coping with the competitions from industrial and domestic water uses are imperative. This is a pressing matter of concern for many countries including Taiwan that uses significant amounts of water for agriculture.

2. IMPACT OF CLIMATE CHANGE ON AGRICULTURAL WATER MANAGEMENT

2.1 Agricultural water management in Taiwan

The average annual rainfall in Taiwan is about 2,500 mm, which is 2.5 times the world average. However, being a densely populated small island with steep hills, the water share per capita in Taiwan (4,074 m^3/year) is just one fifth of the global average, ranked as the 18th among the most water-deficiency countries (ESI, 2005). Moreover, it is very difficult for Taiwan to store water for irrigation use, of which about 70% is drawn from rivers, and to allocate and distribute water resources due to uneven temporal and spatial distribution of water and distinctive dry and wet seasons. Form observation of the tendency of current climate change, although the total annual rainfalls have not changed drastically in Taiwan, its distribution patterns over the years show a trend of more frequent drought and flood events (Fig. 1).

In Taiwan, the Irrigation Associations (IAs) manage irrigation water for paddy field. The water used for irrigation comes from river and reservoir and it is allocated to the respective sections after calculating their water demand. The IAs adopt rotational irrigation when water was insufficient. Sometimes, the agricultural policy indicated that fields were to be left fallow for water resource management.

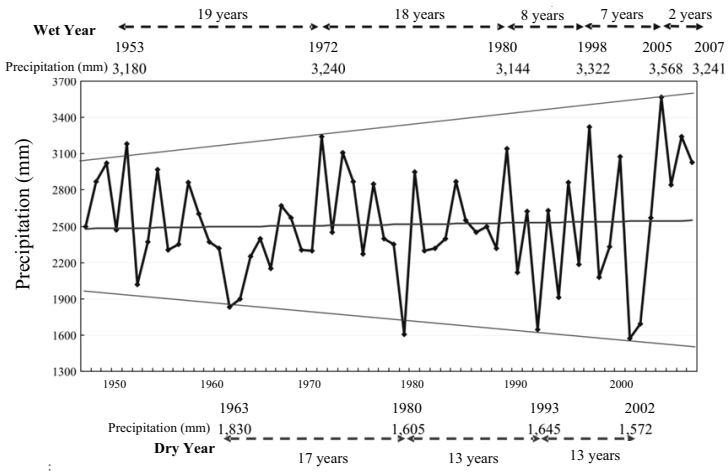

Fig. 1. Trend of increasing droughts and floods in Taiwan based on observed average annual rainfalls

Fields growing paddy twice a year (1st crop: Feb. to May and 2nd crop: July to Nov) have a high water demand. The rainfall is unable to meet the water requirements for the existing farming systems, particularly for the transplanting and growing stages of the 1st crop, usually in the dry season (Fig. 2). For the irrigation associations, which do not have any reservoir to store rains in the summer season, the water supply in their service areas will decrease in dry season. And if there is industrial water demand, the irrigation water is further compromised. In the dry season, the policy includes two parts; stopping irrigation and providing farmers with subsidy for fallow and allocating the irrigation water resource to meet the industrial water demand.

In the past Taiwan's agricultural policy have stopped irrigating many times and that severely impacted the groundwater recharge. The government had selected this kind of agricultural water management due to the problem of insufficient water, and fallow area have increased in these years.

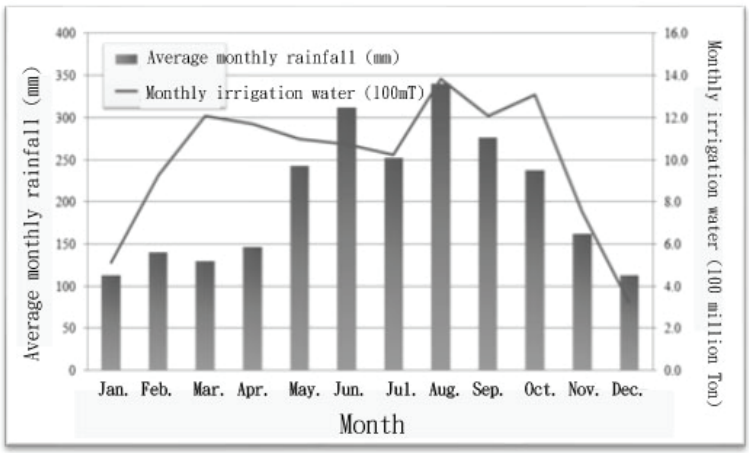

Fig. 2. Average monthly rainfalls and irrigation water in Taiwan (2002~2008)

2.2 The Impact of climate change on agricultural water management

The scope of the impacts of climate change on the agricultural water resources in Taiwan may cover two aspects: water quantity and hydrologic pattern.

(1) Water quantity

As the largest consumer of water resources in Taiwan, agricultural irrigation water is the most severely affected. Evaporation is increased by rising temperature, and extra irrigation water is needed. Taiwan has experienced a temperature increment of 1.3^{0}C per 100 years. The rate of increase in temperature in Taiwan is higher than world's mean temperature rise of 0.74^{0}C in 100 years. It shows that irrigation water need will increase year by year. The paddy rice may grow faster with a shortened total growth period, but with increased solar radiation the average total evapotranspiration (ET) for each rice-crop period is estimated to rise by 2.1% and 6.8% within the future 30 and 60 years, respectively.

(2) Hydrologic pattern

Climate change brings frequent extreme rainfall and droughts. Climate change not only causes agricultural water management issues, but also severe economic loss. The extreme rainfall is as a result of increase in the frequency of typhoons and drought spells are more pronounced in dry season. After analyzing the rainfall data of 179 typhoons during the period 1970 - 2006, the results show that the frequency of huge typhoon during 2000~2006 is more obvious than during 1970~1999. The frequency has increase by a factor of 3. Typhoons with huge rainfall cause flooding and affect the capacity of reservoirs. For instance, when Typhoon Morakot hit Taiwan in 2009, the cumulative rainfall in the southern region reached 2800 mm in only two days. The heavy rainfall led to a loss of around NT$1.502 billion in total. In addition, the heavy rainfall triggered severe landslides as well as erosion of hill slopes, which eventually caused heavy siltation in the southern Zengwen Reservoir - the largest reservoir in Taiwan. The total volume of siltation in the reservoir exceeded 90 million cu. m, which reduced the reservoir capacity by one sixth and thus adversely influenced the water availability for agricultural use.

Investigations indicate that day temperature of Taiwan will increase by more than 2^{0}C at the end of the 21st century. There will be more days with temperature higher than 32^{0}C in summer. Statistics of drought events occurring from 1982 to 2009 provided by the IAs revealed that during the past 10 years, the numbers of years that rice crop suffered from droughts and water shortages were 4 compared to 2.9 during 1992~2001. Consequently, those which depended on run-of-river sources have been facing mounting difficulties in drawing water for irrigation due to worsening erratic river flows. In Taiwan, the rice land for the 1st crop needs to be kept fallow due to drought sometimes, and the 2nd crop usually suffers from yield loss due to typhoon or torrential rain. The extreme weather has heavy influence on rice yield. As a result, climate change leads to reduce food yields.

2.3 Adaptation strategies for agricultural water management

Climate change has affected countries around the world. Many countries have formulated adaptation strategies to cope with their agricultural water resources problems. These strategies may be categorized into the following six: 1. investment in irrigation infrastructure,

2. upgrading water resource utilization systems, 3. development of water-saving technologies, 4. strengthening of early warning and countermeasure systems, 5. adjustment of farming patterns, and 6. improvement of crop varieties (Table 1).

Table 1. Categories of contemporary national adaptation strategies for agricultural water resources in the world.

Strategy	Country/ Organization	Program
Investment in irrigation infrastructure	China	• Improvement of irrigation infrastructure through judicious development and optimized layout of water resources.
	Japan	• Effective utilization of existing irrigation facilities to ensure the essential water supply capacities.
	NAPAs	• Upgrading of the management and maintenance of existing water resources supply systems, and building of dams for irrigation.
	India	• Promotion of construction of farm ponds and other water storage facilities.
Complement to the water resource application system.	Japan	• Redistribution of water rights. • Strict management and adjustment of existing water uses in the event of abnormal water shortage.
	Israel	• Saving of 10% to 15% irrigation water by irrigation water pricing.
	UK	• Equitable distribution of water resources during droughts.
	Germany	• Stipulation of the methods for levying the charges of agricultural water resources and discharge of waste water into irrigation canals. • Establishment of mechanism for allocation of and compensation to the agricultural water shifted to industrial use during droughts. • Stipulation of specifications and policies for management of water rights.
	France	• Scheduling of national water saving periods, and with authority's stipulations that all irrigation water use quantities should meet government' criteria; such as in certain areas are only permitted to be irrigated at night during the designated period.
Strengthening of the early warning and response system	UK	• Conduction of long-term research of and assistance to decision makers in identification & clarification of the impacts of climate change on agriculture and industries, and rations of impacts & uncertainty. • Assessment of the damage in agricultural sector in terms of monetary values.

	Japan	• Identification of high-risk areas of water shortage by means of assessment of their vulnerability, and then execution/improvement of adaptation strategies.
	Australia	• Assessment of the vulnerability of regions as well as agriculture and impact of extreme climate on agricultural production, thereby effectively integrating related factors including climate change impact, risk management, water resources and irrigation facilities for development of tools for decision-making.
	NAPAs	• Implementation of monitoring programs for water quality and quantity, and comprehensively planning of management system for agricultural water uses.
	UNPD	• Defining the priorities of various adaption programs and integrating the models for irrigation and agriculture, to accommodate the anticipated impacts of climate change on water resources and irrigation water.
Development of water-save technology	China	• Promotion of water-save measures in northern and northwestern regions of China.
	Israel	• Extension of the ration of water saving and automatic irrigation system facilities to a total of 90%.
Improvement of crop varieties	China	• Selection and cultivation of drought-tolerant crop varieties.
	Japan	• Improvement of crop cultivation techniques.
	Spain	• In coping with poor harvests of cereal grains caused by high temperature and drought in summer, agricultural departments to formulate measures for adjustment of farming patterns to relieve agricultural damage and loss and hence to enhance food security.
	NAPNs	• Implementation of crop diversification, including introducing of drought-tolerant crops.
Adjustment of farming system	China	• Adjustment of cropping system.
	UK	• Saving agricultural water uses through changes of crop categories and farm management & operations.
	Japan	• Shifting of the crop cultivation areas and control of the environment of husbandry sites.
	the Netherlands	• Setup of long-term plans for the farmlands with elevations below sea levels.
	European Union	• In the northern Europe (Scandinavia), promotion of the agricultural management improvement projects for adaptation to relatively longer crop growing seasons. • Extension of crop rotation area.
	UNPD	• Adjustment of crop growing and harvest seasons.

3. OPPORTUNITIES FOR AGRICULTURAL WATER MANAGEMENT

(1) Adaptation strategies for agricultural water resources

To cope with the previously mentioned problems due to climate change in Taiwan, the Council of Agriculture (COA) has issued the following agricultural administration policies in 2009:

i. Strengthening of multi-functional irrigation infrastructure.

ii. Improvement of basic environment for agricultural production.

iii. Full development of productive, ecological and living functions of agricultural water resources.

iv. Building up national Geographic Information System for irrigation.

v. Upgrading of irrigation management efficiencies.

vi. Full uses of the resources of IAs to develop water resources related industries.

Table 2 displays various measures and emphatic adaptation strategies formulated for agricultural water resources.

Table 2. Major irrigation works in Taiwan & other countries in relation to agricultural water resources adaptation strategies.

Council of Agriculture(COA), Taiwan	Other Countries
1. Renovation & improvement of old irrigation canals and facilities.	Investment in irrigation infrastructure.
2. Conducting integrated planning of farmland consolidation projects by taking into account local industrial cultural, ecological and living environments.	Investment in irrigation infrastructure.
3. Renovation & improvement of irrigation canals and farm drains in previous farmland consolidated areas.	Investment in irrigation infrastructure.
4. Promotion of ecology-based & safety-oriented irrigation infrastructure.	Investment in irrigation infrastructure.
5. Promotion of upland crop irrigation and modernization of its management, and support & guidance to the farmers for constructing pipeline systems for upland crop irrigation.	Develop agricultural water saving technology.
6. Introducing of Geographic Information System, Internet and other electronic-related technologies for application to irrigation management system.	Improvement of water resource application system.
7. Protection of natural paddy environment and improvement of irrigation management system, to increase paddy field's function of groundwater recharge, water retention, and flood mitigation.	Strengthening of water resources utilization system. Augmentation of early warning and response system.
8. Monitoring of water quality in irrigation canals & drains to ensure water quality.	Augmentation of early warning and response system.

(2) Planning strategies for agricultural water resources

The implications of global climate change are unstoppable and the impact on agricultural irrigation water is inevitable. For relaxing the impact, it is useful to invest in irrigation infrastructure to ensure basic irrigation water supply, improving irrigation management and increasing efficiency of water use. Agricultural water resources planned strategies are list below:

I. Developing the new reuse water resource

Agricultural return flow is drained from paddy field. When return flow comes from upper paddy field, a portion of it can be irrigation water that is reused for lower paddy field. The other return flow is flow into the sea. The research estimated that potential return flow can be reuse for industrial water demand in some irrigation section. After storing return flow and treating water quality, it is useful for industrial cooling.

II. Regulating shift of remaining water

Remaining water is produced by IAs that improves irrigation management. The amount of remaining water is decided by rainfall and agricultural policy to name a few. Adjusting time of rotation irrigation and fixing irrigation channels can increase the amount of remaining water.

III. Building the pond for storage

For the frequent extreme rainfall and centralization rainfall in the wet season, building ponds can store more rainfall water. The storage water can supply irrigation to prevent plant fading during the dry season. Ponds that store water will have good groundwater recharge, and groundwater can be pumped for use when water resource is insufficient for use.

IV. Strengthening the irrigation management

Geographic Information System (GIS) can be combined with Management Information System (MIS) to establish a database, and using automatic transmission system to control water conservancy apparatus for check water level. Moreover, to study the adjustment of farming systems in areas with menace of high-risk water deficiency can reduce calamity damage.

V. Establishing the rule on shift of water resource

The industrial section obtains better price for water than agriculture, hence the irrigation water furthers compromise in dry season. The agricultural apparatus should to vitalize the proper use and economic utilization of agricultural water. In addition food security must also be considered.

(3) Directs of future strategies for agricultural water resources in Taiwan

Proposed adaptation strategies and direction for Taiwan's agriculture listed as below:

I. Developing sustainable agriculture

The irrigation system of paddy field has important functions which are productive, sustainable and ecological. The paddy field not only produces rice but also protects environment. During the procedure of cultivation, paddy field can play an important role in recharging groundwater, preventing layer sink, adjusting flood, providing food and rest for birds. In addition, it has positive effect on relaxing surface temperature, reducing CO_2 and conserving groundwater. Thus, the paddy field is an important element in the environment.

The current agricultural water resource is hugely impacted by climate change, and managing agricultural water resource must be done more carefully. In the past, large areas have been stopping irrigation and allow fallow as a result of competitions from industrial water uses and insufficient water resources. If irrigation is stopped for a long period of time, groundwater recharge will be impacted and it may cause layer sink. Moreover, the government paid large expenditures to compensate farmers.

II. Ensuring food supply self-sufficiency of food security

A portion of food demand comes from import to satisfy pressure of nation trade and reducing risk, that is, reduction in food production by agricultural calamity. However, increasing import food rate is equal to rely on trade more. This coupled with reduction in food production in major food producing countries due to various causes in recent years (IFPRI, 2009) critically influences the food availability. Consequently, it is extremely risky to rely on excessive overseas trade to buy food. Ensuring food supply self-sufficiency for reason of food security will let countries have more flexibility for climate change impact. In an effort to produce more food, the government must not only provide farmers with the incentive to cultivate, but also keep sufficient water supply rates.

For ensuring food supply security, the most important factor is keeping sufficient agricultural irrigation water supply. From an economic view, water resource used in industries can produce more gain than agriculture. The import food is cheaper than self-production. Therefore earning economic benefits is contradictory to ensuring food supply security. Considering the impact of climate change, the best choice is not always the right one.

III. Renovating irrigation infrastructure

The extreme rainfall can cause breaking of irrigation channels and drainage channels. Furthermore, the reservoir that is used in irrigation will decrease its capacity by reservoir sedimentation. Stones and soils that flood brings will stay in the field hence the field cannot be cultivated. For this reason, active research and developing effective early warning system can reduce damage.

VI. Changing cultivation pattern

In Taiwan, the growing stage of 1st crop is during the dry season while that of the 2nd crop is during the wet season with huge rainfall brought by typhoons. The 1st crop has better yield, hence farmers prefer cultivating the 1st crop. Therefore, in developing a compensation

proposal to regulate cultivation time for matching up wet season, irrigation water management will have more flexibility.

4. SUMMARY AND CONCLUSIONS

As the largest consumer of water resources in Taiwan, agricultural suffers the most. In the dry season, IAs that depend on run-of-river sources have been facing mounting difficulties in drawing water for irrigation due to worsening erratic river flows. If there is industrial water demand, the irrigation water will be more insufficient. On the other hand, for the IAs which depends mainly on reservoir water supply have fewer impacts. But the reservoir capacity is reduced by extreme rainfall and harder to plan irrigation water management. Moreover, during the dry season the shifting of irrigation water resources to satisfy high industrial water demand and stopped irrigation.

To cope with these issues relating to climate change, the Council of Agriculture in Taiwan adapts the following policies: strengthening of multi-functional irrigation infrastructure, improvement of basic environment for agricultural production, full development of productive, ecologic and living functions of agricultural water resources, building up national Geographic Information System for irrigation, upgrading of irrigation management efficiencies, and full uses of the resources of IAs to develop water resources related industries. The Council of Agriculture in Taiwan plans the following policies: developing the new reuse water resource, regulating shift of remaining water, building a pond for storage, strengthening the irrigation management, establishing a rule on shift of water resource. To cope with the effect of climate change in future, proposed adaptation strategies and direction for Taiwan's agriculture are: developing sustainable agriculture, ensuring food supply self-sufficiency for food security, renovating irrigation infrastructure, changing cultivation pattern. Some adapting strategies clash with the existing condition and can prove to be problematic. Therefore, there is a crucial need to find new scenarios or tactics in an attempt to try to settle problem.

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