Agroclimatic Study of Mountainous Regions and Its Progress in China

Zhang Yangcai (张养才)
Academy of Meteorological Science, State Meteorological Administration, Beijing 100081
Received December 31, 1990; revised June 6, 1991

ABSTRACT

In recent years, the agroclimatic investigations have been made at various temporal and spatial scales in mountainous and hilly regions, and so have the adaptability tests on the crop ecoclimate. A large quantity of reliable and representative data are obtained. Through the synthetic studies on " belt" , " layer" , " topography" and "ecological-type" in mountainy and hilly regions, climate with agriculture ard zonality with non-zonality are closely combined to show the similarities and differences of agroclimatic resources at various layers and with different topography types in mountainy and hilly regions. A general review is given in this paper.

In recent years, attention has been increasingly paid to agroclimatic study on mountainous and hilly regions in China.A symposium on tropical and subtropical hilly lands development and ecological equilibrium was jointly sponsored by 13 societies in 1980. The State Meteorological Administration (SMA) has organized successively the research work on agroclimatic resources in hilly and mountainous regions and its applications since 1982. In 1983, the Chinese Meteorological Society held a symposium on agroclimatic resources in the tropical and subtropical mountainous regions in China. Therefore, investigations of agroclimatic research on various temporal and spatial scales have also been stimulated.

The present paper is focused on the development of the agroclimatic research in the hilly and mountainous regions in China in the past ten years.

I. THE TIME-SPACE DISTRIBUTIONS OF AGROCLIMATIC RESOURCES SUCH AS LIGHT, HEAT, AND WATER IN HILLY AND MOUNTAINOUS REGIONS

The redistribution of solar radiation, water and heat in hilly and mountainous regions is due to the retardation of the horizontal movement of the air over it and its inhomogeneous terrain effects. In recent years, we have done many investigations on climate over mountainous regions and more representative data were obtained. Meanwhile, the horizontal and vertical distributions of the elements such as light, heat and water in hilly and mountainous regions were studied. We found that in winter, the temperature lapse rate on the eastern and southeastern slopes was much larger than that on the western and northwestern slopes of the north-south or southwest-south east high mountain regions; while in summer season, the temperature lapse rate on the northern mountain slope was much larger than that on the southern slope of the east-west mountain range (Weng et al., 1988). In ten mountainous regions of the eastern part of the subtropical zone in China, the lapse rate of the annual mean maximum temperature is larger than that of the annual mean temperature; while the lapse rate of the annual mean temperature is larger than that of the annual mean minimum temperature. Fig.1 shows the vertical distribution of temperature in subtropic mountainous regions

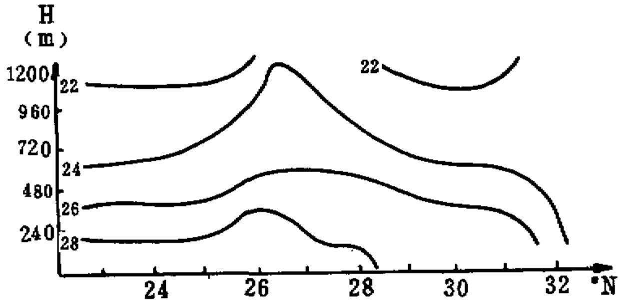

Fig.1. The spatial distribution of the mean temperature (°C) in the subtropical mountainous regions in China in July.

in eastern China in July, there is a relatively high temperature zone extended to a heigh of 1000–1200 meter in 25–27°N where the subtropical anticyclone in July situated (Hao et al.,1989). The temperature lapse rate varies significantly in different mountainous regions, in slope's orientations and in different seasons (Table 1).

Table 1. The Temperature Lapse Rates (°C / 100m) in Major Mountainous Regions in the Eastern Part of the Subtropical Zone in China (1983–1985)

items / orien-tation	temperature (°C)					accumulated temperature (°C)			number of persistence day	major mountain ranges
	Jan.	Apr.	Jul.	Oct.	mean	$\sum t>$ 10°C	$\sum t>$ 15°C	$\sum t>$ 20°C		
south slope	0.48	0.53	0.60	0.64	0.55	222.7	234.3	253.7	6.0	Yunkai Bopingling Nanling * Dabie * * Tianmu Shennongjia Mountains
north slope	0.37	0.48	0.57	0.46	0.48	175.9	174.2	238.3	5.0	
east slope	0.42	0.44	0.61	0.50	0.50	197.6	192.5	218.8	6.4	Xuefeng Luoxiao Mountains
west slope	0.38	0.44	0.47	0.53	0.45	167.4	132.1	182.5	5.6	
mean	0.41	0.47	0.56	0.51	0.50	190.9	183.3	223.3	5.8	

* east and middle part

* * west and peak part

In the same mountainous region, the annual mean temperature lapse rate and the accumulated temperature lapse rate on the southern slope are larger than that on the northern slope, and that on the eastern slope are larger than that on the western slope. The value of the mean temperature lapse rate is the maximum in summer while the minimum in winter, and it is of transitional type both in spring and autumn. The accumulated temperature lapse rate is

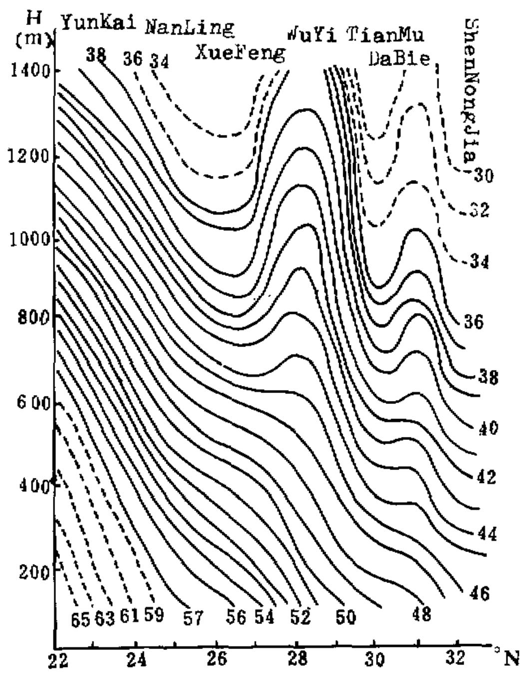

Fig.2. The spatial distribution of the accumulated temperature (>10°C) on the northern slope of the mountain range in the subtropical zone (1984–1985). The interval of isotimic is 100°C.

$\sum t$ 20°C > $\sum t$ 10°C> $\sum t$ 15°C. The number of days of persistent accumulated temperature (10°C) during the growing season is larger on the southern slope than that on the northern slope and that on the eastern slope is larger than that on the western slope. Fig.2 shows the spatial distribution of the accumulated temperature (>10°C) on the northern slope of the mountainous zone in the subtropical zone in China. The location of a mountain range, its orientation, the height above sea level and the vegetation all are of significant effects upon temperature distribution (Zhang et al., 1989). The effect is distinct in a warm season. Therefore, for the layout of agricultural area and the establishment of economic forest and fruit production base on mountainous areas, we must seriously consider the problem of heat deficiency and insufficient growing season due to the sea level elevation. In ten large mountainous regions of the eastern part of the subtropical zone, there is a tendency that the amounts of precipitation increase with the height. There are three patterns of this tendency: (1) a linear pattern, (2) a parabolic pattern, and (3) the precipitation pattern slowly increases over the low mountainous areas and the wind speed increases over the medium and high mountainous regions (Shen et al., 1988). The maximum precipitation usually occurs at the height from 800m to 1200m above sea level. The height of maximum precipitation is higher on the windward side than on the leeward side. However, its change is not distinct with the variation of latitudes (Jiang et al., 1989). The effects of the elevation and orientation of the slope on precipitation distribution are quite similar over the Changbai Mountains in the temperate zone in Northeast China (Ma, 1986).

In mountainous areas solar radiation and sunshine duration are closely related with the terrain, the orientation of slopes and the height of clouds and fogs. In the ten large mountainous regions of the eastern part of the subtropical zone the linearized variation of the sunshine duration makes up 64%, while the parabolic variation constitues 36%. The linearized variation is mainly located over the mountainous areas of northern and southern subtropics, while the parabolic variation occurs mainly in the middle subtropical mountainous area where there are plenty of rain days (Zhou et al., 1989).

As for agroclimatology "the inversion layer", "the warm sector" and "the humid region" could be regarded as a special agroclimatic environment. For instance, 107 warm sectors were found in the Nanling, Luoxiao, Xuefeng, Wuling mountainous regions in Hunan Province. Among these regions the first class warm sectors account for 3.39% of the province's area. While the second warm sector occupies 6.84% of the province's area (Shen et al., 1989).It can be seen from the annual precipitation graph of small grids that the Nanling, Wuyishan, Daiyunshan, Jiufengshan and Shennongjia mountain areas in the eastern mountainous regions of the subtropical zone belong to a high value–closure rainy region (2200–2400mm). The valleys of Xiangjiang River and Ganjiang River, the Boyang Lake and the Dongting Lake basins belong to the low value region (1250–1500mm) (Jiang et al., 1989). Within the ten mountainous regions of the eastern part of the subtropical zone, the frequency of inversion dekads (which occur when mean dekad minimum temperature increases with height) is 45.9% below 500m, 38.2% between 500–1000m, and only 12.5% above 1000m (Hao et al., 1989). Over the southern slope and northwestern slope of the Wuyishan Mountain 2–3 inversions occur separately below 1000m. The inversions mainly occur in autumn and winter. The inversion–days on which daily minimum temperature increases with height account for 1 / 3 days of the whole year in average and the inversion–days on which diurnal mean temperature increases with height are about 90 days in average (Zhang and Li, 1989).

II. THE STRATIFICATION AND CLASSIFICATION OF AGROCLIMATOLOGICAL ZONES IN MOUNTAINOUS REGIONS

In mountainous regions differences between the vertical and horizontal variations of climatic elements are distinct due to the effect of the elevation, the orientation of slopes, the basin and valley terrain and the landscape of forest and vegetation. In the past, different schemes of agroclimatic zoning are essentially a kind of horizontal classification based on planting. At present, a lot of studies are made on the vertical stratification and classification of agroclimatology in mountainous regions.

Research on agroclimatic stratification in mountainous regions could be classified into four categories: (1) The scheme of principal factors, i.e., to select a key factor as an indicator of stratification. For instance, a single factor such as the annual mean temperature, the accumulated temperature (10°C) or the mean of the annual extremely low temperature is selected as a principal indicator and then different types of climatic layers on the vertical direction of the mountain regions, the vertical belts of freezing injury of citrus, the vertical layers of tea–tree planting and the growing height belts for the single cropping–rice and double cropping–rice (with combination of species for different ripe duration) could be classified (Li, 1984; Lu, 1984; Lu, 1985; Xie, 1988; Wu, 1980). (2) The multi–factor superposition scheme i.e., different agroclimatic layers could be classified with the superposition of multi–climatic factors (Zhang and Li, 1988). (3) Agroclimate–ecological method: investigations of the relationship between agrobiological populations and the climate, their changes with height, and phenological differences could be conducted through agroclimatic surveys and, in turn, layering of the indicative crops which are sensitive to the climate according to their distribution

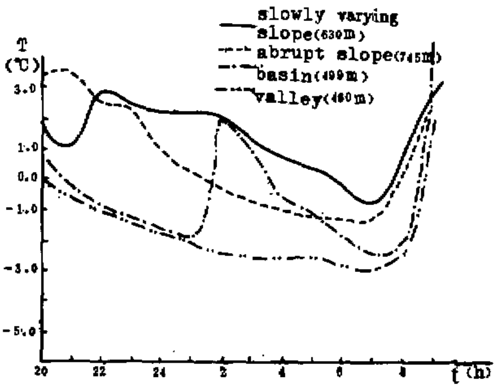

Fig.3. The continuous variation of the minimum temperature under different topographic situation at night and in the early morning.

heights could also be done (Liu, 1984). (4) Fuzzy–cluster analysis: construction of the layering models affected combinatively by multi–factors could be obtained and quantitative calculation of vertical agroclimatic layers with various slpoe–orientations and in different mountain situations could be conducted with fuzzy mathematics and cluster analysis least principle (Ma et al., 1989; Zhang et al., 1988).

Layering studies gave the further insights into the agroclimatic resources in mountainous areas which exhibit stereo–multilayer characteristics. The principal–factor method, the superposition method, and the agroclimate–ecological method all are qualitative and semi–empirical so that they are not sufficient for reflecting inherent links among stereo–agrobiological environments. But the fuzzy–cluster analysis can give quantitatively the combinative character over various agroclimatic layers. So it is very important for guiding the development of agricultural resources and applied widely.

As an element of evaluating agroclimatic resources in mountainous areas agrobiological environmental types are considered to be the agroclimatic zoning into three different levels in mountainous areas. Ecological environment types have been classified in accordance with the different frost–averting topographic situations (Jiang, 1984). The hat–shape mountain, bare mountain, mixed–plant mountain and layer–belt mountain were classified based on different mountainous vegetation landscapes (Chen et al., 1984). Therefore this provided the studies on both constant type's and inconstant type's agroecological environment with great benefit. For example, the maps of agroclimatic–topographic investigation at Longquan mountain area in Zhejiang Province showed that the occurring time of the minimum temperature makes 5 hrs lag on an abrupt slope and 7 hrs on a slowly varying slope more behind than in a basin respectively, suggesting that low temperature lasts for a shorter time in slope area while it lasts for a longer time in basin or valley area. (Fig. 3) (Zhang and Li, 1988; Zhang and Li, 1989). Thus it promotes the proper development of medium–small scale mountainous agroclimatic resources that insight is given into the rules about agroclimatic resources with different agroecological environment types.

In recent years, a study was conducted on basic zones, stereo–layering, topographic shapes, and environment and the principles by which zoning can be done in accordance with layering–stereo features. Therefore, the combination of climate with agriculture, zoning aspects, and non–zoning aspects was achived. It is a breakthrough and of a great significance for mountainous agroclimatic study.

III. THE STUDY ON ADAPTABILITY OF CASH CROPS TO CLIMATIC–ECOLOGICAL ENVIRONMENT

A number of studies were carried out on adaptability of productive, high quality cash crops to climatic–ecological environment in many regions. In the Jinggang Mountain area, there was an experiment through which double cropping–rice and hybrid rice were planted, trying to reach 600m of upper limit height for double cropping–rice and below 1000m for hybrid rice's planting (Wu, 1980). In the Hangzhou City, studies were conducted successfully on the optimum planting period and mature period for tomato cropped at various heights based on vertical climatic difference in Tianmu Mountain area to ameliorate the city's vegetable supply in slack seasons, gaining a significant social–economic benefit (Liu et al., 1987). The exploitation base for forest special local products with the aid of meteorological investigations was established to conduct phenological observations and simulation of lentimus mushroom and Jew's–ear. The results disclosed meteorological conditions favorable to the optimum growth and explosive growth for Jew's–ear. The production is 3–5 times higher than that under natural condition due to the effective control of production cycles based on promotion and modification of small–scale climatic condition on the northern slope of Shennongjia Mountain (Ni et al., 1989). Some high–quality tea trees were introduced into the Dabie Mountain area and after testing the tea trees planted in lower mountainous area below 500–1000m grew very well and had both good economic profits and wonderful tea (Wang et al., 1989). The results from some studies showed that agroclimatic–ecological environment has a great potential for productive high–quality tea in mountain areas below 500–1000m in South China (Huang, 1986). Studies were carried out on climatic potential and proper exploitation of citrus' production in various topographic situations such as mountains, waters, plains, and basins in subtropical region (Zhang, 1987). Some studies showed that 1000–1500m is the optimum height for apples such as Yuanshuai apple on the Loess Plateau north of Wei River (Yu et al., 1988). The models of climate–productivities of crops were developed for different heights and slope–orientation in different mountainous areas and the climatic potential for rice, wheat and corn at different heights was evaluated by these models in Yunkai Mountain, Xuefeng Mountain, Dabie Mountain and Shennongjia Mountain areas (Huo et al., 1989). Studies were conducted on climate–ecological conditions and planting heights favorable to cash crops' high–quality production such as Chinese gooseberry, rice, China fir, moso bamboo (Phyllostachys pubescens), tea–oil tree (Camellia oleifera), tung–oil tree (Aleurites fordii), and citrus etc. in subtropical region (Yao et al., 1989).

Strategically, it is very important to strengthen and promote the economy in mountainous areas that studies were carried out on the adaptability of high–quality, productive cash crops to climate–ecological conditions in mountainous areas to disclose climatic zones and heights favorable to valuable cash crops' planting and to convert directly climatic resources in rich to commodity and economic superiorities.

IV. THE PROPOSITION OF SYSTEMATIC RESEARCH METHOD FOR AGROCLIMATE

In order to obtain the representative of climatic and phenological data, further detailed investigation was given on the effects of geographical location, large–scale topographic situation, sea level elevation, and small–scale topographic situation. The temperature, critical temperature, and accumulated temperature were estimated in terms of non–conventional observations. Consequently the synthetic–spliting method and various regressional equations estimating the air temperature over observation–free area were developed (Fu, 1984; Yuan, 1982). The fine grid was used to estimate temperature and rainfall fields at ground surface in terms of modified climatological equation (Shen, 1984; shen, 1986). The research group which conducted the study on agroclimatic resources in the mountainous area over eastern subtropical hills established a climatic observational network to operate both climatic and phenological observations in parallel. The group investigated agricultural topography and made an experiment of crops' adaptation to climate–ecological environment and also developed an agroclimatic data– base and application software for mountainous areas. They used a fine grid method to estimate quantitatively sunshine, thermal, and water resources with an analysis precision which is about 0.2°C for monthly and yearly mean temperatures and is about 5% in plain area and 8% in mountainous area for sunshine duration and precipitation. The problem of combinatively using data from an observation site and field data was solved in mountainous area so that a set of methods was developed for studying mountainous agroclimate, significantly improving the classical methods of analysis. The similarity and difference in agroclimatic resources which exist among various layers and topographic situations were disclosed both by micro–scale and macro–scale in hilly and mountainous areas.

In recent years, new techniques such as satellite observation and remote sensing have been used gradually for the study on agroclimate in mountainous regions. The relationship between both color tunes and textural features in satellite imagery and eco–climatic types was used to give a map of agroclimatic zoning (Gu et al., 1989; Wang,1989). TM's CCT–tape and imagery from LANDSAT–5 were used to interpret and evaluate water–thermal conditions in the mountainous area in northern Fujian Province in conjunction with conventional surface– and upper–air data (Wang et al., 1987). It is shown that doing so has very important implication for promoting the study on agroclimatology in mountainous areas and enhancing research approaches.

V. CONCLUSIONS

A lot of results which are valuable for application have been obtained in the agroclimatic research of the subtropical mountainous areas in China in the last 10 years. Some of them have filled the vacancy in the field of mountainous agroclimatological study in China while some have reached to or approached the advanced level in the studies of the agroclimate in the world in 1980's. Moreover higher requirements will be given to the studies on the structure, function, and proper exploitation of the hilly and mountainous agroecological system and ecological protection as agricultural progresses, further development aiming at earning much more foreign currency. Furthermore by using remote sensing technique we can obtain biometeorological data to study the effects of climatic variable on the general agriculture and ecological system. These studies will make contribution to regional development, construction in mountainous areas, modification of agricultural structure, establishment of specialized production–base, promotion of multi–form operation, and disaster reduction. Also numerical simulation of agroclimate and prediction of agroclimatic resources in mountainous areas are the problems to be deservedly studied.

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