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The effect of irrigated paddy fields to reduce the daytime air temperature in Satte city

幸手市における湛水水田の日中気温の低減効果について

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Abstract: The research was carried out to examine how paddy fields could influence to the climate in the city. In 1993, the air temperature in Satte city of Saitama Prefecture in Japan was investigated both before and after the period of irrigation to the paddy fields. Each record was transferred onto the area map by introducing appropriate isotherms to illustrate a distribution pattern of the air temperature measured. From the aerial photographs, each representative point was confined to the center of the circle with a diameter of 500m and the ratio of the area covered by paddy fields (%) was calculated. To estimate the influence of the paddy fields to the city climate, the relation between air temperature and the land covering ratio of paddy fields was analyzed by the stratified sample regression analysis. The regression equations showed that the cooling effect of paddy fields remarkably changed from before to after the irrigation to the paddy fields. The estimate effect at 10% of the paddy fields covering ratio was 0.10℃ before irrigating to the paddy fields, while 0.20℃ after the irrigation completed.

KEY WORDS: city climate, heat island, paddy field, irrigation, air temperature.

1. Introduction

The most remarkable phenomenon of the urban climate is high air temperature in the central urban areas (Oke 1979). According to the various research carried out previously, this phenomenon has been explained as the reason to cause the climate difference in between urban and rural areas. The heat generated from combustion process, industrial activities, as well as traffic and construction materials or structures found typically in the city was elucidated for this reason. Recently, some studies have shown to reduce such a high temperature problem in the city, usually called as urban heat island. Two possible approaches have been suggested. One is to reduce the ejection heat mass itself while the other is to cool down the city air passively. Due to actual circumstances of the city and the requests from the society, the latter is generally more realistic to choose. Because if someone tries to reduce the ejection heart mass, how he could achieve it without restricting the social activities.

This study attempted to examine the air cooling effect by irrigated paddy fields. The reason to choose paddy fields as a cooling element is due to the unique geographical characteristics typically found in the Japanese suburban cities. In Japan, most of the suburban cities in the plain area were developed among the agricultural lands, in other words, they are surrounded by the lands used for agriculture, so that the ratio of paddy fields in the suburban area is usually very high. It is, therefore, assumed that the air temperature in the suburban cities could be reduced by the evapo-transpiration effect occurred in paddy fields surrounded.

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The effect of an open space has been already found to decrease the level of air temperature in the city. The results showed that the spread of open green spaces could reduce the air temperature in the urban area being compared with the one in the suburbs. The previous reports on the cooling effect of open spaces have been conducted mainly in the huge cities such as Tokyo metropolis (Yamada and Maruta 1989, Nath and Maruta 1995), but the one in the smaller scale like suburban cities has not been examined well yet. The purpose of this study is to investigate the decrease in air temperature in relation to the paddy fields during the irrigation season in the suburban city located on the Kanto Plane in the central Japan. The study would be expected to support the idea that paddy fields could mitigate the severe climate in the city especially under the suburban settings in Japan.

2. Description of the site

Due to both its significance of the paddy fields surrounded and its well developed central part of the city (Fig.1), Satte city in Saitama prefecture was selected as the experimental site. The city sized 33.95km^2 in total is located on the center of the Kanto Plane and the experiment was carried out in part of the city. The site is approximately 15km^2 having 55000 of the residents. The center of the city has been built up mainly for the housing purpose while a majority of the outer is covered by paddy fields with few areas for vegetable production and for groves.

Because the most of the farmers in the city are depending their living on both farming and other jobs, plowing and irrigating of their paddy fields are usually undertaken during the spring break from 29th April to 5 May in Japan. It was considered that the effect of irrigated paddy fields to cool down the city temperature could be easily examined, if the air temperature distribution before and after the irrigation were investigated.

3. Methodology

3.1, Instruments for the air temperature measurement

Hand made automatic thermister thermometer was used to measure the air temperature distributions. The thermister sensor of this thermometer was about 1.5 mm ϕ, accuracy of ± 0.1℃ and response of 1~1.5 second (90%) at well ventilated condition. Sensor part of the instrument was set in stainless steel tube to protect from the influence of solar radiation and its reflection on the air temperature measurement. The stainless steel tube was mounted at 1.5m height level above the car roof. The analyzing unit was made from two parts; a bridge circuit to convert the resistance value of thermister to voltage output, and a recording unit of the average voltage meter. The unit was installed in the car and operated by the car driver.

3.2. Experimental methods

In 1993, the air temperature in Satte city was investigated on 17, 18, 19 and 25 of April when the paddy fields were not irrigated yet and on 5, 15 and 16 of May when the irrigation was all completed. Being typical to the early summer in Japan, the weather was continuously fine and in good condition throughout the experiment carried out (Table.1). A car traverse method was selected as most

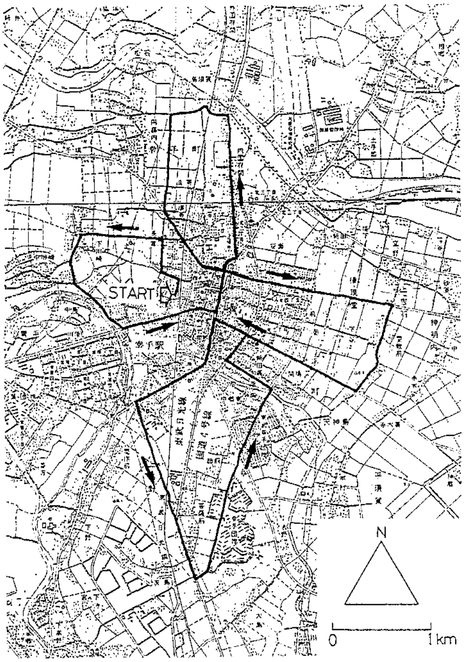

Fig.1 Route for measure air temperature in Satte city.

Table.1 Basic weather conditions at 2p.m.(1993.4.17~1993.5.16)

Date	4/17	4/18	4/19	4/25	5/5	5/15	5/16
Weather	fine	fine	fine	fine	fine	fine	fine
Wind direction	ENE	NNW	ESE	NW	SSE	N	E
Wind speed	1.0m/s	3.0m/s	6.0m/s	6.0m/s	3.0m/s	4.0m/s	1.0m/s

efficient to obtain the adequate series of data. Before the temperature was measured, the thermister thermometer was adjusted by comparing to the accurate and well-ventilated Assmann's aspiratory psychrometer. The air temperature was recorded automatically when the car was passing through the each observation points. The record was accumulated every 10 seconds with constant speed of 40 to 50 km per hour so that over 250 measurements were gathered at one traverse. The measurement was carried out at 2p.m. when the temperature was expected to be the highest in the day. The total length of the observation traverse route was about 20.0km (Fig.1) and the length of the experiment was within 45 minutes respectively. The load less traffic jam was selected as the traverse route, so the influence of an exhaust gas was ignorable.

3.3. Analyzing methods

(1) To clarify the paddy fields distribution in this district the aerial photographs taken by Geographical Survey Institute in 1986 was used and deciphered. The representative points (30 data selected from 250 or more measurements) were confined to the center of the circle with a diameter of 500m. The size of the circle was fixed after the model of precedent investigations (Yamada 1993,1994,1995). Each land surface in the circle was covered by six different components; trees coverage, paddy field, grassland, water surface, bare ground and build-up area. Then the area of each kind % was measured by using cross stripe papers.

(2) Isotherms at 2 p.m. on representative days were superimposed on the map to show the distribution of city temperatures and record the temperature data at representative points.

3-3) To estimate the influence of the paddy field on the city climate, the relation of air temperature and land covering elements, especially paddy field analyzed by stratified sampling simple regression analysis (Okuno et.al. 1971). In this analyze the stratification element was the "day". Some parallel regression lines were made in the same coordinates by this method, each lines indicated the each observing days and arranged them parallel. The gradient ℃／(paddy field covering %) of these parallel lines expressed the average cooling effect of paddy field.

Normal simple regression equation is given by

$Y=b_1+a_1 \cdot X$ ····· first day's regression equation

$Y=b_2+a_2 \cdot X$ ····· second day's regression equation

·····

$Y=b_n+a_n \cdot X$ ····· "n"th day's regression equation

$b_n=\overline{y_n}-a_n \cdot \overline{x_n}$

$a_n=(Sxy/Sxx)_n=\Sigma(x_n-\overline{x_n})(y_n-\overline{y_n})/\Sigma(x_n-\overline{x_n})^2$

Y: Air temperature (℃) X: Ratio of paddy field covering (%)

$\overline{y_n}$: The average "n"th day's air temperature (℃)

$\overline{x_n}$:The average paddy field covering (%)

x_n :Each observing points data of paddy field covering (%)

On the other hand, the stratified sampling simple regression equation is given by

$Y=b_1+a \cdot X$ ····· first day's regression equation

$Y=b_2+a \cdot X$ ····· second day's regression equation

·····

$Y=b_n+a \cdot X$ ····· "n"th day's regression equation

Y: Air temperature (℃) X: Ratio of paddy field covering (%)

$b_n=\overline{y_n}-a_n \cdot \overline{x_n}$

$a=\Sigma(Sxy)_n/\Sigma(Sxx)_n=\Sigma(\Sigma(x_n-\overline{x_n})(y_n-\overline{y_n}))/\Sigma(\Sigma(x_n-\overline{x_n})^2)$

4. Results and Discussions

4.1. Distribution of the air temperature

The isotherm map at 2 p.m. of each observation day is shown in Figure 2.1~2.4 and 3.1~3.3. On 18 April when the paddy fields were not irrigated, the center of the city was 1.0 ℃ warmer than the outer. The isotherm pattern on this day was clear but the temperature difference was not so remarkable.

On 16 May, when the irrigation to the paddy filed was completed, the center of the city was 2℃ warmer than the outer. The area with higher air temperature was associated with the central part of the city.

The result on other days showed similar air temperature pattern to those shown in Figure 2.2 and 3.3. On 18 April, the air temperature was remarkably high, but the pattern and the difference of air temperature was quite alike. It was also clear that the higher air temperature zone always appeared in the most densely built-up area, i.e. the central area of the city, while the lower in the surrounded area of the city. Also the particular isotherm configurations varied on the land use of this district. The difference of the air temperature patterns between before and after the irrigation to paddy fields was remarkable. It was significant that the irrigation increased the cooling effect of the paddy fields examined.

The results of both the pattern of air temperature and the difference of the temperature between the central city and rural area in the summer season presented by the previous report (Yamada 1994) were similar to this result shown in Figure 3.1~3.3.

The reason for the air temperature dropping observed can be considered due to the influence of transpiration and /or evaporation happened in the paddy fields. When the soil surface of the paddy fields was not wet before irrigation was provided, the cooling effect was only little. However, after the paddy fields

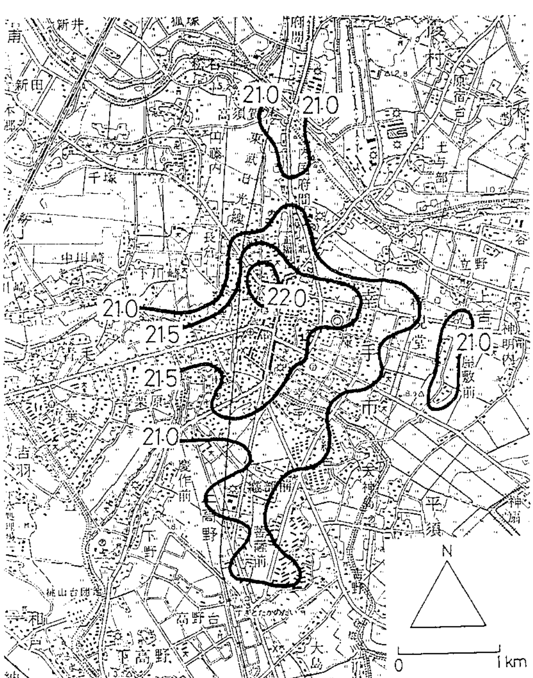

Fig.2.1 Distribution of air temperature at 2 p.m. in Satte city on April 17,1993 (Non-irrigated period)

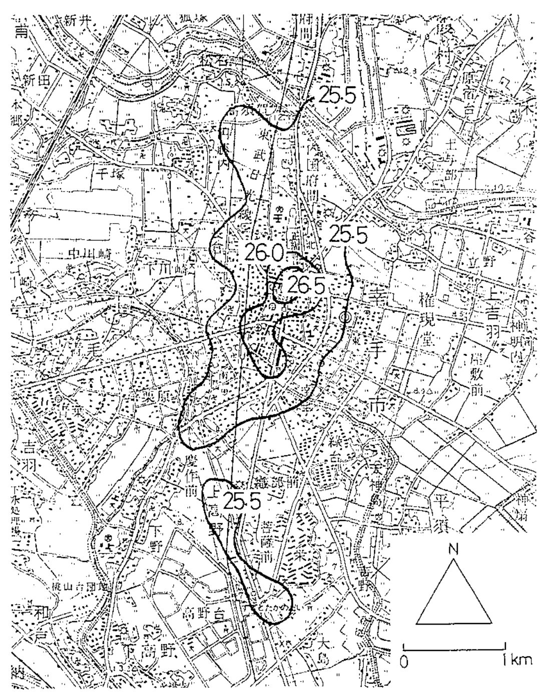

Fig.2.2 Distribution of air temperature at 2 p.m. in Satte city on April 18,1993 (Non-irrigated period)

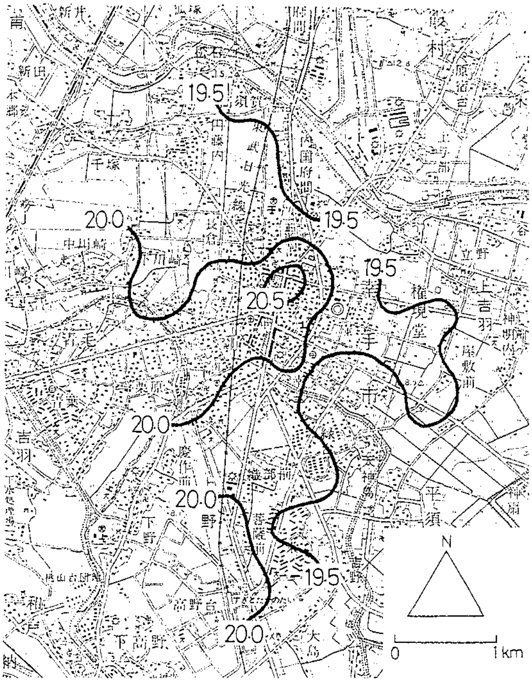

Fig.2.3 Distribution of air temperature at 2 p.m. in Satte city on April 19,1993 (Non-irrigated period)

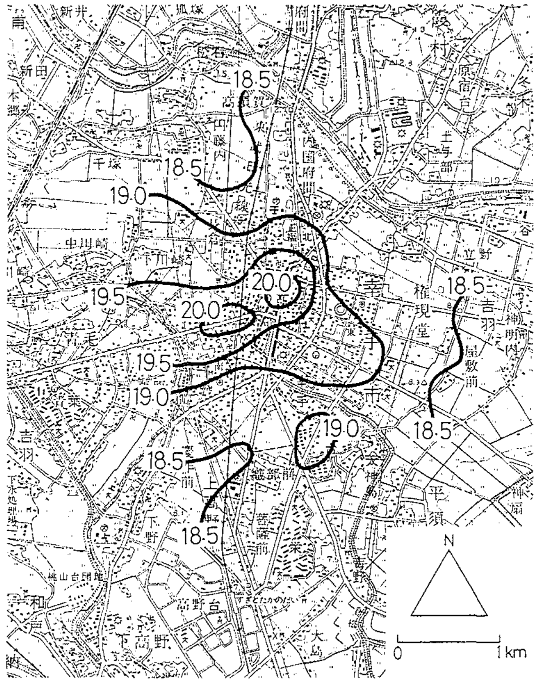

Fig.2.4 Distribution of air temperature at 2 p.m. in Satte city on April 25,1993 (Non-irrigated period)

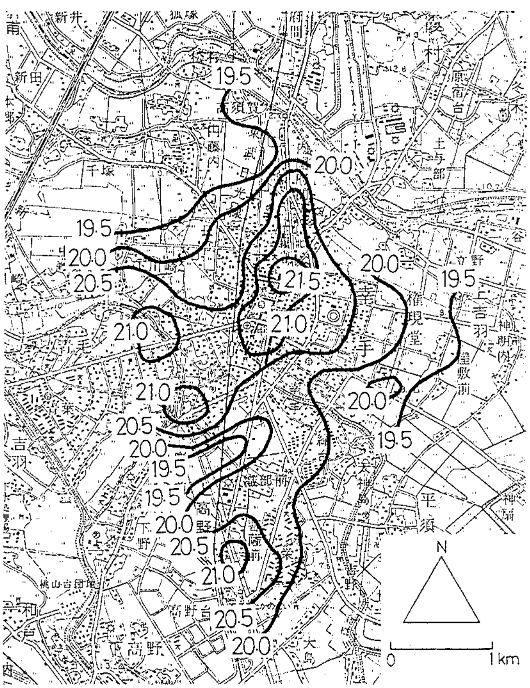

Fig.3.1 Distribution of air temperature at 2 p.m. in Satte city on May 5,1993 (Irrigated period)

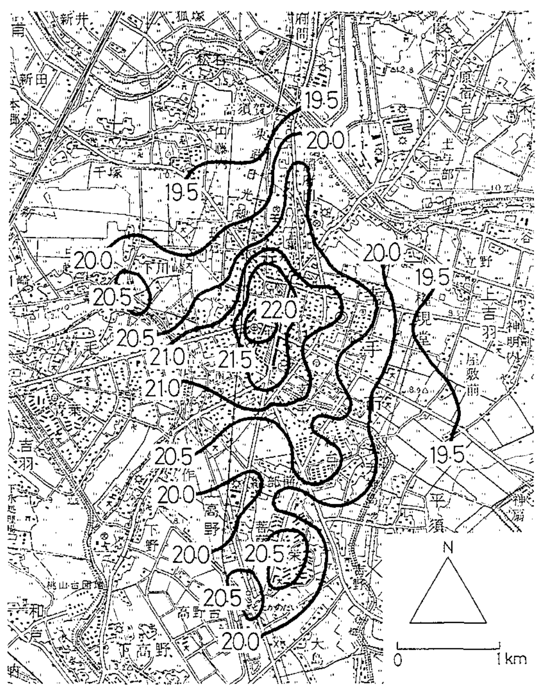

Fig.3.2 Distribution of air temperature at 2 p.m. in Satte city on May 15,1993 (Irrigated period)

were irrigated, they became like "pond" with a full of water so that the cooling effect was remarkably increased..

This effect is convenient to heat island cities, because in the cold season the paddy filed area is dry open space and less cooling effect but it turns into a wet grassland area and can exhibit a remarkable cooling effect during the hot season. For this reason, paddy fields could be regarded as a "flexible cooling element".

4.2. Relation between ratio of paddy fields and the air temperature

The dependent and independent variable data of seven days in Table.1 were calculated to find the relationship between paddy field covering ratio and air temperature. By using stratified sampling simple regression analysis, the relationship between the paddy field covering ratio and air temperature was calculated. Table 3.1 and 3.2 have shown the simple regression equation of each experimental day on the upper part and the stratified sampling simple regression equation at the bottom. Before the irrigation period, air temperature reduced by 0.10℃ respectively at the ratio of paddy filed covering increased by 10 % (Table 3.1) while by 0.20℃ after the irrigation period (Table 3.2). The correlation coefficients or the F-values showed high values and significant at the 1% level. In addition, the relation of air temperature and paddy field coverage areas (%) on each day were shown in Figure 4 and 5.

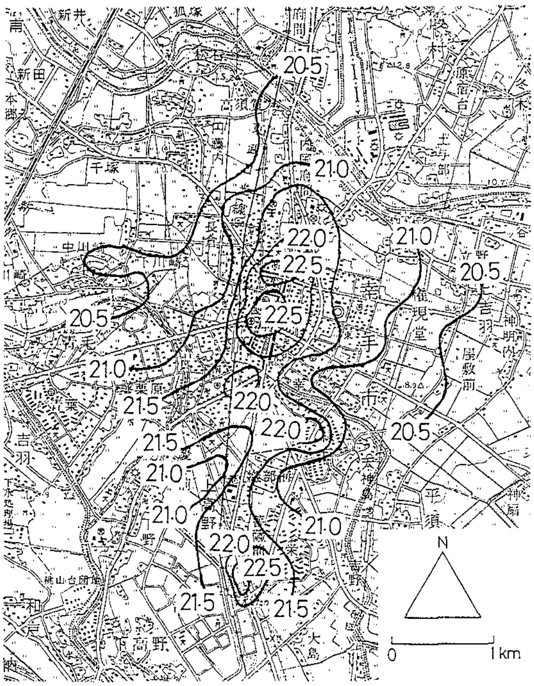

Fig.3.3 Distribution of air temperature at 2 p.m. in Satte city on May 16,1993 (Irrigated period)

Compared to the two results, the respectively value of the air temperature reduction after the irrigation was just twice bigger than the one before the irrigation. This result also agreed with those obtained from the isotherm maps.

Table.2 Minimum-maximum values of dependent variable and percent area of independent variable from observation points within the circles (500m diameter) on April 17 to May 16,1988 in Satte Cit

Variable data	Minimum-maximum values
Air temperature at 14:00	18.3~26.6℃
Ratio of Green coverage	6.7~98.0%
Ratio of Open space	9.0~99.9%
Ratio of Tree coverage	0.0~ 7.6%
Ratio of Grassland	0.0~11.3%
Ratio of Paddy field	0.0~96.3%
Ratio of Bare ground	0.0~12.4%
Ratio of Water surface	0.0~ 4.1%

Table.3.1 Regression equations between Air temperature (Y) and the ratio of paddy field covering (X). (Non-irrigated period)

Date	Regression equation	Correlation coefficiect/F-Value	
4/17	Y=-0.011(±0.0025)X + 21.66	r=-0.64	F(1,28)=19.7
4/18	Y=-0.008(±0.0022)X + 25.85	r=-0.58	F(1,28)=14.2
4/19	Y=-0.013(±0.0029)X + 20.40	r=-0.65	F(1,28)=20.8
4/25	Y=-0.009(±0.0025)X + 19.35	r=-0.55	F(1,28)=12.0
SSS*	Y=-0.010(±0.0013)X + C		F(1,115)=66.6

* stratified sampling simple regression equation

Table.3.2 Regression equations between Air temperature (Y) and the ratio of paddy field covering (X). (Irrigated period)

Date	Regression equation	Correlation coefficiect/F-Value	
5/ 5	Y=-0.018(±0.0027)X + 21.08	r=-0.79	F(1,28)=46.0
5/15	Y=-0.021(±0.0021)X + 21.46	r=-0.89	F(1,28)=95.1
5/16	Y=-0.021(±0.0030)X + 22.09	r=-0.79	F(1,28)=47.8
SSS*	Y=-0.020(±0.0015)X + C		F(1,86)=175.0

* stratified sampling simple regression equation

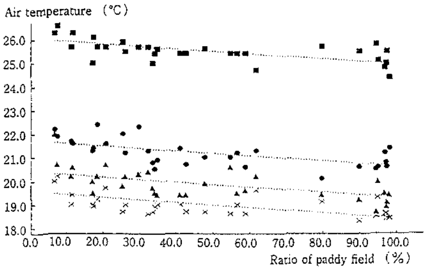

Fig.4 Relation between air temperature and the ratio of paddy field covering at 2 p.m. in Satte city, on April 17,18,19 and 25,1993 (Non-irrigated period)

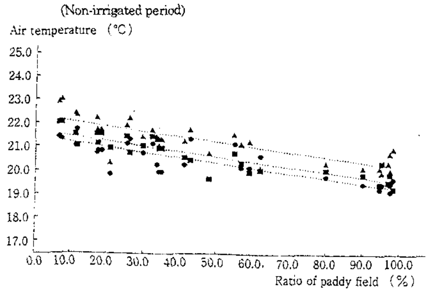

Fig.5 Relation between air temperature and the ratio of paddy field covering at 2 p.m. in Satte city, on May 5,15 and 16,1993 (Irrigated period)

5. Conclusion

Many factors might operate to increase the temperature in the urban area. The most obvious one is people's artificial heating from their dwelling exhausting the energy to the atmosphere as heat. The other considered includes the physical stricture of the city such as asphalt, concrete and brick buildings crowded in the urban area together. Thus the roads and the buildings in the city could store much of the solar energy incident upon them during the day. Furthermore in the city, there is virtually no vegetation or wet soil surfaces that could soak up some of the solar heat by the evapo-transpiration effect found in the rural area. A lack of evapo-transpiration could lead the result of the higher air temperature in the crowded city than in the open space area.

The cooling effect of open spaces has been previously studied by many researchers. The effect by tree coverage is generally greater than the one by grasslands. Bare grounds or a tiny water surface normally shows little effect while larger sized water surface, especially river showers show large effect (Nath and Maruta 1995, Yamada and Maruta 1989, Yamada 1993, 1994, 1995)..

A paddy filed is a kind of grassland but it is exceptionally unique as the structure of its surface changes throughout the season. In spring, a dry bare land is dramatically changed into a grassland by being filled up with water. The cooling effect (In this paper "the cooling effect" meant to reduce a daytime air temperature) of paddy fields was not known before and this paper has clearly demonstrated it for the first time. The cooling effect of paddy fields changes remarkable from before and after the irrigation carried out. Before irrigating to the paddy fields, the effect was 0.10℃ where 10 % of the area covered by the paddy fields while 0.2℃ after the irrigation. The effect of paddy fields after irrigation was as large as the one found in the land covered by trees within the limits of this investigation (Nath and Maruta 1995, Yamada and Maruta 1989, Yamada 1993, 1994). It was a remarkable cooling effect compared to the any other elements of land surface structures.

The result of this study suggests that in the suburban cities, landscape planners could regard paddy fields as one of the effective cooling element for the heat island phenomenon, and the level of its effectiveness could be expected as same as the one provided by the forests.

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