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Spatial Correlation Analysis between Climate Factors and Plant Production in Asia

Yukiyo Yamamoto, Jun Furuya, and Shintaro Kobayashi

***Abstract*—**Using 1km grid datasets representing monthly mean precipitation, monthly mean temperature, and dry matter production (DMP), we considered the regional plant production ability in Southeast and South Asia, and also employed pixel-by-pixel correlation analysis to assess the intensity of relation between climate factors and plant production. While annual DMP in South Asia was approximately less than 2,000kg, the one in most part of Southeast Asia exceeded 2,500 - 3,000kg. It suggested that plant production in Southeast Asia was superior to South Asia, however, Rain-Use Efficiency (RUE) representing dry matter production per 1mm precipitation showed that inland of Indochina Peninsula and India were higher than islands in Southeast Asia. By the results of correlation analysis between climate factors and DMP, while the area in most parts of Indochina Peninsula indicated negative correlation coefficients between DMP and precipitation or temperature, the area in Malay Peninsula and islands showed negative correlation to precipitation and positive one to temperature, and most part of India dominating South Asia showed positive to precipitation and negative to temperature. In addition, the areas where the correlation coefficients exceeded |0.8| were regarded as "susceptible" to climate factors, and the areas smaller than |0.2| were "insusceptible". By following the discrimination, the map implying expected impacts by climate change was provided.

***Keywords*—**Asia, correlation analysis, plant production, precipitation, temperature.

I. Introduction

IT is concerned that global warming will adversely affect various ecosystems, human living environment, food production etc. Countermeasures to absorb and retard progression of global warming and technical development for adapting to climate change are urgent issues for the world. As mentioned in the IPCC 4th report, global warming has now undoubtedly progressed, however, the expressions of symptoms would be different by regions.

To assess the impact by climate change, it is necessary to clarify how much current systems depend on climate factors. In this study, we applied spatial correlation analysis using GIS to assess the impact on plant production by climate conditions represented by precipitation and temperature in Southeast and South Asia.

Yukiyo Yamamoto is with the Japan International Research Center for Agricultural Sciences, Ohwashi 1-1, Tsukuba, 305-8686 Japan (phone: +81-29-838 6614; fax: +81-29-838 6614; e-mail: yuki@affrc.go.jp).

Jun Furuya is with the Japan International Research Center for Agricultural Sciences, Ohwashi 1-1, Tsukuba, 305-8686 Japan (e-mail: furuya@affrc.go.jp).

Shintaro Kobayashi is with the Japan International Research Center for Agricultural Sciences, Ohwashi 1-1, Tsukuba, 305-8686 Japan (e-mail: shinkoba@affrc.go.jp).

II. Study Site

Study site locates in the area of latitude 0° to30° N and longitude 60° to 120° E. The coverage was shown in Fig. 1. In this area, the whole country of Vietnam, Laos, Cambodia, Thailand, Myanmar, Bhutan, Bangladesh, Sri Lanka, Singapore, Burney, and some parts of China, Nepal, India, Pakistan, Malaysia, and Indonesia are belonged.

III. Data and Methods

1) Available Dataset for Analysis

Monthly mean temperature and precipitation dataset provided by WorldClim and Dry Matter Productivity dataset provided by VITO, i.e. 'vision on technology' - Flemish Institute for Technological Research, were applied.

WorldClim is a set of global climate layers consisting of monthly total precipitation, monthly mean, minimum and maximum temperature, and 19 derived bioclimatic variables, developed by Hijmans *et al.* They are generated through interpolation of average monthly climate data from weather stations on a 30 arc-second resolution grid, often referred to as 1 km^2 resolution. The study site corresponds to the Tile-28 and Tile-29. The value represents multi-year means for 1950 to 2000. Download is available via http://www.worldclim.org/ [2].

Dry Matter Productivity or DMP products are 10-daily images representing estimates of dry matter of plants, expressed in dekagram/ha/day. DMP is derived from SPOT VGT S10 products with the classical Monteith-model and meteorological data to convert Normalized Difference Vegetation Index (NDVI) to Fraction of Absorbed Photosynthetically Active Radiation (fAPAR). DMP products cover the whole of the world and the period for April 1998 to March 2008. They are provided by raster format with the spatial resolution of 1km x 1km via http://geofront.vgt.vito.be/ [4].

2) Methods of Analysis

Multi-year monthly mean precipitation and temperature dataset and 10-days composite DMP dataset in 2000 consisting of 36 scenes were downloaded from each web site, then, they were clipped and joined adjusting to the study site mentioned above. Geographic coordinate was assigned WGS84. For DMP dataset, 10-days composite data were combined and converted into monthly total for the analysis. In addition, Rain-use efficiency (RUE), i.e. the value in which monthly DMP divided by monthly precipitation in each pixel, was calculated [1].

Using the data pairs of monthly DMP and monthly precipitation or monthly mean temperature, the correlation coefficients between DMP and each climate factors were calculated pixel-by-pixel using the following equation. It was regarded that the correlation coefficients implied the susceptibility to climate change on plant production, then, the area assumed to be strongly affected by climate change in future was extracted.

$$\frac{\sum_{i=1}^{n}(c_i - c_{mean})\,(p_i - p_{mean})}{\sqrt{\sum_{i=1}^{n}(c_i - c_{mean})^2}\,\sqrt{\sum_{i=1}^{n}(p_i - p_{mean})^2}}$$

in where ;

c is precipitation or temperature

p is DMP

i is month from January to December

c_{mean} *and* p_{mean} *are mean of 12 months in each pixel*

IV. Results and Discussion

The charts of monthly mean temperature, monthly precipitation, and monthly DMP in the study site (land only) were shown in Fig. 2, Fig. 3, and Fig. 4, respectively. By these charts, the following features were recognized;

i) Monthly mean temperature belonged into the range of 15 to 26°C. For April to September was hypsithermal

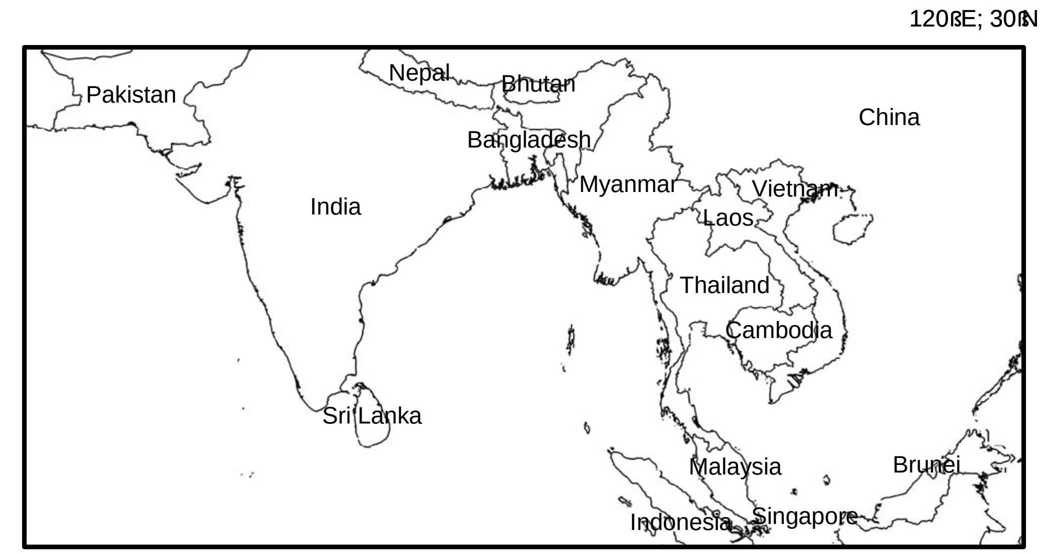


Fig. 1 Study area of analysis

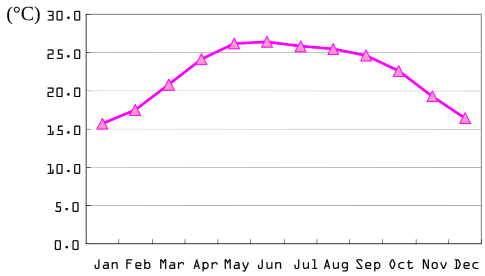


Fig. 2 Average of temperature in the study area

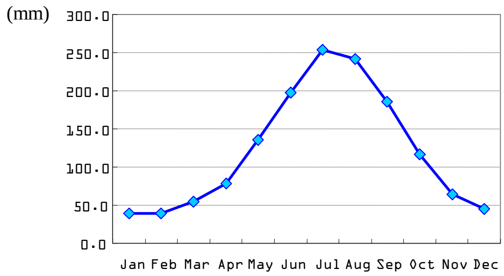


Fig. 3 Average of precipitation in the study area

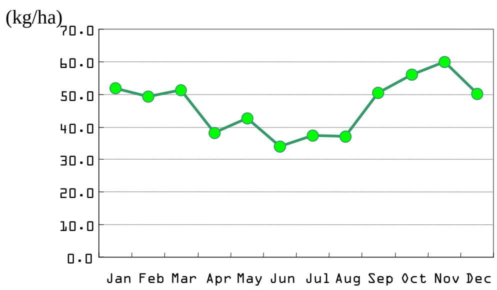


Fig. 4 Average of DMP in the study area

period exceeding 24°C.

ii) Monthly precipitation ranged between 40 - 250mm, and it showed single-peaked pattern with maximum in July and August.

iii) Monthly DMP showed between 30 to 60kg/ha/day, and its peak was October and November.

The gap of peaks of climate factors and DMP might be caused because plants need time to respond and grow following the increasing of temperature and precipitation.

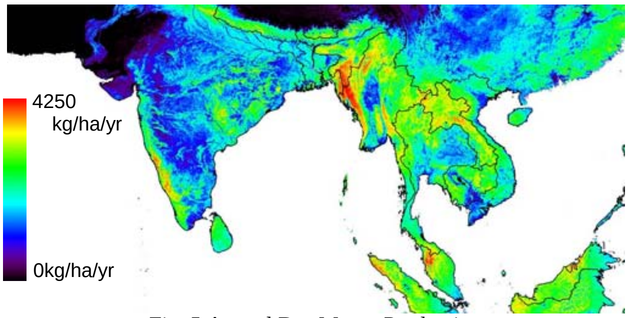
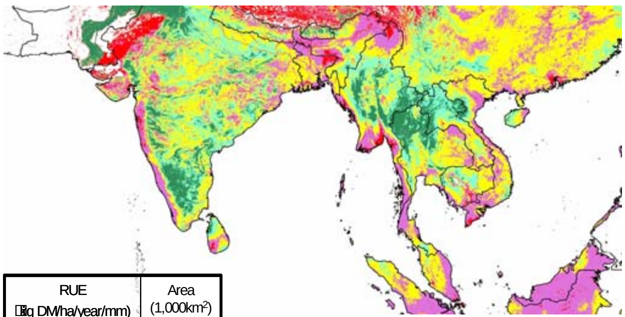


Fig. 5 Annual Dry Matter Production

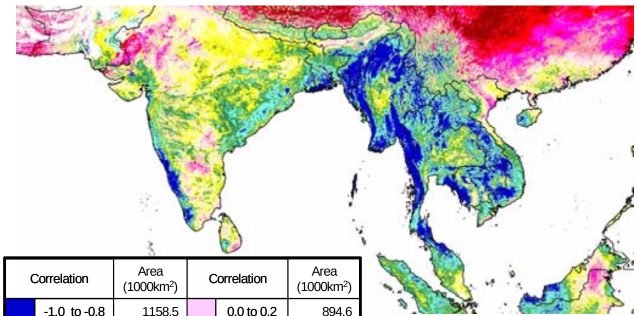


	RUE (kg DM/ha/year/mm)	Area (1,000km^2)
	< 5	669.9
	<10	2632.8
	<15	3942.5
	<20	1896.0
	>=20	1014.1

Fig. 6 Rain-Use Efficiency (RUE): Annual Dry Matter Production produced by 1mm rainfall estimated by annual DMP and precipitation datasets

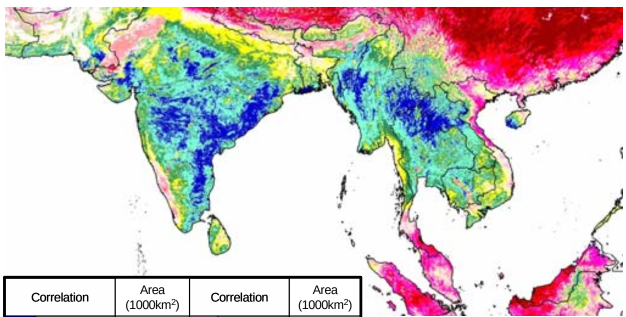
Fig. 5 showed the annual DMP in each pixel. DMP in South Asia including India and Bangladesh etc. were approximately less than 2,000kg/ha, however, in both peninsula and islands in Southeast Asia, the areas exceeding 2,500kg/ha were dominant and some portions more than 3,000kg/ha were also existing anywhere. The results suggest that plant production in Southeast Asia was superior to the one of South Asia. By comparing of RUE representing dry matter production per 1mm precipitation shown in Fig. 6, however, north Thailand, north Laos, Myanmar, and India showed more than 15kg, while many portions in Indonesia, Malaysia, and Brunei were less than 10kg. It implied that plant production efficiencies per unit of precipitation in inland of Indochina Peninsula or India were higher than islands in Southeast Asia.

The correlation coefficient in each pixel between DMP and precipitation or temperature were calculated and classified, to assess the intensity of relation between plant production and climate factors. The correlation to precipitation was shown in Fig. 7, and the one to temperature was in Fig. 8. While the area in most parts of Indochina Peninsula indicated negative correlation coefficients between DMP and both precipitation and temperature, the area in Malay Peninsula and islands showed negative correlation to precipitation and positive one to temperature. In South Asia dominated by India, most parts showed negative correlation to temperature and positive one to precipitation. As it is assumed that the plant production in the areas indicating strong correlation between DMP and climate factors would be easily affected by fluctuation of precipitation and/or temperature, the areas where the correlation coefficients to precipitation and/or temperature were bigger than r=|0.8| were discriminated to assess the susceptibility to climate change. The result was presented in Fig. 9. The areas regarding as susceptible to precipitation and/or temperature were approximately 3,000 km^2 corresponding to 27% of the whole study site. In these areas, the portions showing strong correlations in both factors, i.e. the most susceptible area to climate change, was 485km^2, and they were mainly distributed in the inland of China and the region from eastern Myanmar to southwestern Laos. The areas correlating to one of



	Correlation	Area (1000km^2)		Correlation	Area (1000km^2)
	-1.0 to -0.8	1158.5		0.0 to 0.2	894.6
	-0.8 to -0.6	1539.7		0.2 to 0.4	806.0
	-0.6 to -0.4	1581.6		0.4 to 0.6	693.6
	-0.4 to -0.2	1663.6		0.6 to 0.8	596.7
	-0.2 to 0.0	1338.3		0.8 to 1.0	384.5

Fig. 7 Correlation between precipitation and Dry Matter Productivity



	Correlation	Area (1000km^2)		Correlation	Area (1000km^2)
	-1.0 to -0.8	1093.2		0.0 to 0.2	703.8
	-0.8 to -0.6	2187.1		0.2 to 0.4	793.2
	-0.6 to -0.4	1539.4		0.4 to 0.6	745.2
	-0.4 to -0.2	1115.3		0.6 to 0.8	932.2
	-0.2 to 0.0	697.9		0.8 to 1.0	849.6

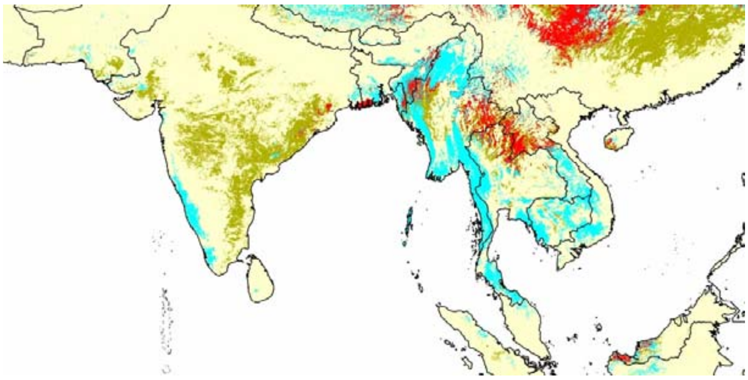
Fig. 8 Correlation between temperature and Dry Matter Productivity

precipitation or temperature were 1,058 km^2 or 1,458 km^2 respectively. The areas susceptible to precipitation were found in the peninsula in Southeast Asia, and the areas to temperature were in eastern China and India.

In addition, to assess how much stable of highly efficient area for plant production, the correlation coefficients to precipitation and temperature in the areas where the RUE was exceeding 20kg/ha were distinguished in Fig.10. The poorly-correlated areas being smaller than r=|0.2| in both factors, where it must be insusceptible to climate change, were slightly flocked in the west portion of Uttar Pradesh province in northern India, however, the area was only 23.8 km^2 corresponding to 2.3% of highly RUE area. On the other hand, 376.7 km^2 corresponding to 37.1% of the high RUE area showed strong correlation to precipitation and/or temperature. In particular, inland of Indochina Peninsula seemed to be susceptible to climate change.

As the above results show, the intensity and positive or negative correlation between plant production and climate factors are different by locations. And the differences must be closely interlinked with susceptibility and vulnerability to climate change. For instance, while the IPCC 4th report mentioned that mean temperature in the world would rise in range of 1.1 to 6.4°C and precipitation in tropical monsoon region would be increased [3], inland of Indochina Peninsula belonging to tropical monsoon region showed negative correlation in both temperature and precipitation in our results. It implies that plant production in the area will possibly decrease when the climate change predicted by IPCC will arise.

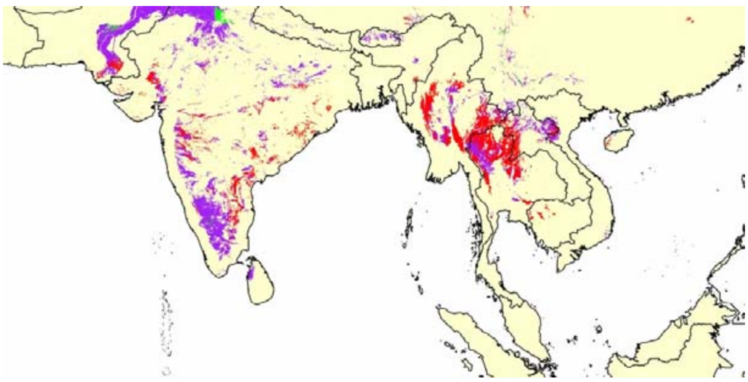
We consider that spatial differences represented by correlation between plant production and climate factors may depend on plant ecosystems and agricultural land use established under current environment. For Indochina region, which land use maps in Thailand, Laos, Cambodia and Vietnam were consolidated, the areas of DMP, RUE and correlations were tallied by land use and shown in Fig. 11. The areas of each land use were shown in Table I. As described in Fig. 5 and Fig. 6, DMP exceeded 2,500kg in vast area of Southeast Asia, and RUE in the northern portion of Indochina Peninsula was more than 15kg. According to the compiling by land use, the categories marked over 2,500kg of DMP and 15kg of RUE were coniferous and deciduous forests. As the forests occupied 55% of areas in Indochina region, high DMP and RUE in the region would be originated to the forests. However, DMP of both forests were high-negatively correlated with precipitation. It implies that the decline of DMP in forest area will be derived from future climate change representing rainfall increasing, and it would be a principal factor to depress the



Susceptibility to climate factors		Area (1000km^2)
	Susceptible	484.6 (4.4%)
	Susceptible to precipitation	1058.3 (9.6%)
	Susceptible to temperature	1458.2 (13.2%)
	Insusceptible	8019.6 (72.8%)

Susceptible : Correlation between DMP and precipitation (or temperature) > |0.8|

Fig. 9 Susceptible area to climate factors



Susceptibility to climate factors		Area (1000km^2)
	Stable	23.8 (2.3%)
	Moderate	613.6 (60.5%)
	Susceptible	376.7 (37.1%)
	Others (non high RUE area)	

Stable : -0.2 < Correlation between DMP and precipitation (or temperature) < +0.2

Susceptible: Correlation of precipitation and/or temperature > |0.8|

Fig. 10 Stability of plant production to climate change in High RUE area*)

** High Rue area : RUE >= 20 kg DM/ha/year/mm*

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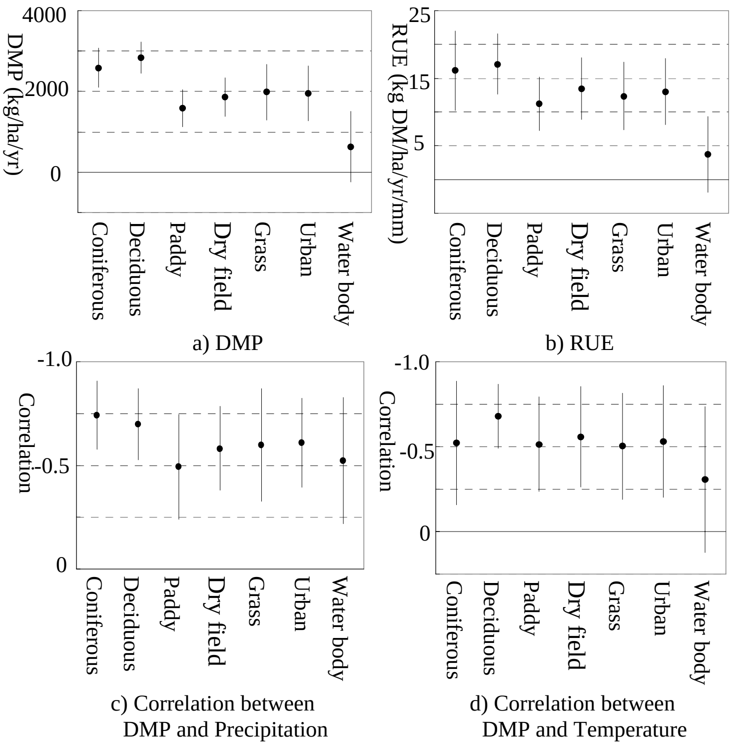

Fig. 11 DMP, RUE, and correlations between DMP and climate factors of land use in Indochina region

TABLE I
AREAS OF LAND USE IN INDOCHINA REGION

Land use	Area (km^2)	Area (%)
1:coniferous	460,253	46.04
2:deciduous	86,345	8.64
3:paddy	202,764	20.28
4:dryfield	109,410	10.94
5:grass	56,395	5.64
6:urban	32,048	3.21
7:water body	52,543	5.26
Total	999,758	100.0

plant production in the whole region. On the other hand, DMP in agricultural lands representing by paddy and dry field showed intermediate correlation, i.e. between -0.5 and -0.6, with both precipitation and temperature. As it is considered that the influence by climate would be different in irrigated farm and rainfed farm, it is necessary to analyze circumstantially to estimate the impact on agriculture precisely.

In our subsequent analysis, it will elucidate what a kind of ecosystems or agricultural land uses have been established in the area highly susceptible to climate change. And the results and predicted climate condition in future will be applied to derive more quantitative and direct impact assessment on the ecosystems, forest and agriculture.

V. CONCLUSION

We employed pixel-by-pixel correlation analysis with comparatively high resolution dataset of 1km grid representing monthly mean temperature, monthly precipitation and dry matter productivity to consider the intensity of relation between climate factors and plant production in Southeast and South Asia. We consider that the results derived by the study, that is, the pixel-by-pixel correlation will be applicable to assess the local vulnerability of climate change.

Besides, data archives of satellite imagery and its derived products increase and downscaling of meteorological models also progresses. They are assembled into various global datasets and provided spatial information through Internet. They are extremely useful for the regional impact assessment by climate change, therefore, we expect further enhancement of these sharable scientific resources.

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