Improvements of rice and wheat production models by carbon partitioning with multi-satellite imageries and meteorological reanalysis data

Daijiro Kaneko[a*], Peng Yang[b], N. B. Chang[c], Toshiro Kumakura[d]

[a,*]Remote Sensing Environmental Monitor, Inc., 4-5-5, Kamariya-nishi, Kanazawaku, Yokohama, Kanagawa, JAPAN 236-0046 kand.rsem@gmail.com

[b]Key Loboratory of Resources Remote Sensing & Digital Agriculture, Ministry of Agriculture, 12, Zhongguancun South Street, Haidian District, Beijing 10081, P. R. CHINA yangpeng@mail.caas.net.cn

[c] Department of Civil, Environmental and Construction Engineering, University of Central Florida, 4000 Central Florida Blvd. Orlando, Florida, USA 32816-2450 nchang@mail.ucf.edu

[d]Department of Civil and Environmental Engineering, Nagaoka University of Technology, 1603-1, Kamitomioka, Nagaoka, Niigata, JAPAN 940-2188 kumakura@nagaokaut.ac.jp

Abstract – The sustainable crop production is intimately linked with food security as the world population growth remains stable. The recent concern about food scarcity motivates the development of the present system entitled "Remote Sensing Environmental Monitor (RSEM)" leading to the enhancement of the capability for crop yield monitoring. The system includes a photosynthetic sterility crop yield model based on precise land use and cover (LULC) classification of crop field in two eastern Asian countries. The model estimates the photosynthetic fixation of carbon dioxide (CO_2) that is geared toward estimating the rice production in Japan and China with a reasonable accuracy. This study provides daily estimates of the photosynthesis rate (PSN), which is relevant to the CO_2 fixation with the aid of a precise LULC classification. The computational work was carried out based on the MODIS data, NDVI data (i.e., SPOT VEGETATION), solar radiation derived from Japanese Geo-stationary Meteorological Satellite (GMS), and meteorological re-analysis data. The validation of such a model is based on carbon partitioning method associated with particular crop species. The ongoing thrust of improving the RSEM-based crop yield model with the carbon partitioning method has been dedicated to winter wheat using China statistical data. It will be extended to deal with similar estimation in Australian areas for model validation in the near future.

Keywords: rice, wheat, model, photosynthesis, monitoring, carbon, partitioning, remote sensing

1. INTRODUCTION

There is anticipated imbalance between the world food supply and demand in the future due to the challenge of climate change. As a consequence, the circumstances for the stability of the cereals supply are of concern. Many ways can relieve the situation, which include the increase in food production by expansion of the farmlands, increase of crop yields by selective breeding, improvements of production incentive by increasing the agriculture income via deregulation, the proper international trade between nations, and the information sharing of cereals production for a better management. However, there exist difficulties when spatial and temporal information of crop production cannot be generated in time. This study stands up for the possible improvements of information sharing by developing an early warning system to monitoring the cereals production at a timely manner using remote sensing.

Such a system of "Environmental Monitoring using Remote Sensing (EMuRS)" has been under development mainly for Asian paddy-rice so far. It may be extended to cover all three kinds of cereals including paddy-rice, winter wheat, and corn by using a similar approach. In the last few years, China switched the crop management policy by importing soy bean instead of the expansion of production lines for self-support. Demand of these three kinds of cereals was therefore altered in the market with the inclusion of the new consideration of soy bean. The proposed EMuRS system named "Remote Sensing Environmental Monitor (RSEM)" in Figure 1 has been employed to meet multiple purposes including the crop monitoring, desertification assessment, carbon fixation via vegetation photosynthesis, and the promotion for Clean Development Mechanism (CDM) afforestation/ reforestation certifications. The RSEM system is particularly designed so that the photosynthesis models of cereals and vegetations can be applied to handle multiple estimation efforts of paddy-rice, winter wheat, maize, grassland, and forest. The validation processes of the photosynthesis model were completed by using the carbon partitioning method associated with the paddy-rice production. This paper describes the improvements of the wheat model based on the RSEM system. The efforts of estimating winter wheat is different with that of paddy-rice because there are fewer statistical data of wheat yield such that we have to count on the development of a satellite-based wheat yield model in Japan. The current study thus reexamines the suitability of such a photosynthesis model for wheat yield estimation at Shijiazhuang in Hebei province, Northern China. The method entitled Carbon Partitioning for Model Validation (CPMV) used in the case of paddy-rice is still effective for the case of winter wheat given that considerable errors need to be minimized so far. Shijiazhuang is an ideal site of representative winter wheat production zone which is well irrigated. The wheat yield data for validation should be reliable for the carbon partition method despite the obvious errors in the former studies of winter wheat yield analysis. In addition, the separation of crop field of the winter wheat is relatively easy as compared to that of paddy-rice,

* Corresponding author. This study is funded by a Grant-in-Aid (No. 21580319) for Scientific Research. We wish to express thanks to the Japan Society for the Promotion of Science, of the Ministry of Education, Culture, Sports, Science and Technology.

corn, soy bean, and spring wheat based on crops phenology with the aid of the normalized vegetation index (NDVI). In regard to the photosynthesis model of the cereals production, there are two approaches. One is the distribution study to examine the plant distribution with respect to the photosynthesis rate (PSN) by using both crop yield models and satellite imageries. The other is computation of cereal production based on discontinued spots by on-site models with locally precise area at the farm scale using high resolution satellite data. Some well-known crop yield estimates of maize and soybean were established by combining the SAIL model and MODIS in a county of Illinois, USA (Doraiswamy et al., 2005). Besides, field practices were carried out by calculating water and carbon fluxes using BIOME-BGC model in a North China Plain (Wang, et al., 2005), by predicting a global–scale future change in sown areas using the EPIC model and Geographic Information System (GIS) (Wu et al., 2007), by employing a county-level crop yield model for a U.S. cropland with a linear mixed effect models (Lokupitiya et al., 2007), and by taking advantage but manual efforts of the GIS expression for addressing the CERES-Rice model outputs in China with regard to the climate change impact on rice production (Xiong et al., 2008). With the inclusion of remote sensing technologies, achievements include the net primary production (NPP) with MOD-Sim-Cycle model (Hazarika et al., 2005), continental gross primary production (GPP) by combining MODIS data and AmeriFlux (Yang et al., 2007), and MODIS gross primary production in U.S.A. revised by AmeriFlux data (Xiao et al., 2010). However, these studies only stick to produce NPP without regard to crop yields and how the distributions of the yields could be. Our study provides a systematic development for monitoring the crop yields at the continent scale by the photosynthesis model that has not been widely used elsewhere.

2. MODELS FOR MONITORING CROP PRODUCTION

In our study the PSN can be defined by using Eq. (1a), as shown below, with a Michaelis-Menten type of radiation response function f_{rad_mm} that is proper for estimating wheat and maize production, and another type of radiation response function f_{rad_pc} proposed by Prioul-Chartier (1977), which properly fits the curve of the PSN for paddy rice (Kaneko et al., 2007, 2008).

$$PSN = f_{rad} \cdot f_{Syn}(T_c) \cdot \beta_s \cdot eLAI \tag{1a}$$

$$f_{rad\_mm} = \frac{a_{mm} \cdot PAR}{b_{mm} + PAR} \tag{1b}$$

$$f_{rad\_pc} = \frac{a_{pc} \cdot PAR + PSN_{max} - \sqrt{(a_{pc} \cdot PAR + PSN_{max})^2 - 4m \cdot a_{pc} \cdot PSN_{max} PAR}}{2m} \tag{1c}$$

In those equations, PSN is the photosynthesis rate (gCO_2/m^2/day); PAR stands for the photo-synthetically active radiation (MJ/m^2); β_s is the stomatal opening ratio; a_{mm} and b_{mm} are Michaelis-Menten constants; T_c is the canopy temperature (ºC); $eLAI$ is the effective leaf area index; a_{pc} is the Prioul-Chartier constant; PSN_{max} is the maximum PSN; and m is the curve convexity constant.

The unit of the photosynthesis model is the carbon dioxide fixation rate (gCO_2/m^2/day), which is deemed as an integral part of the large scale carbon cycle on the Earth. Note that the temperature response function of the PSN, f_{Syn}, falls down at low air temperatures. The function, f_{Syn}, thus shows a S-shaped curve as defined by Eq. (2), and is well known as the Sigmoidal-Logistic type function:

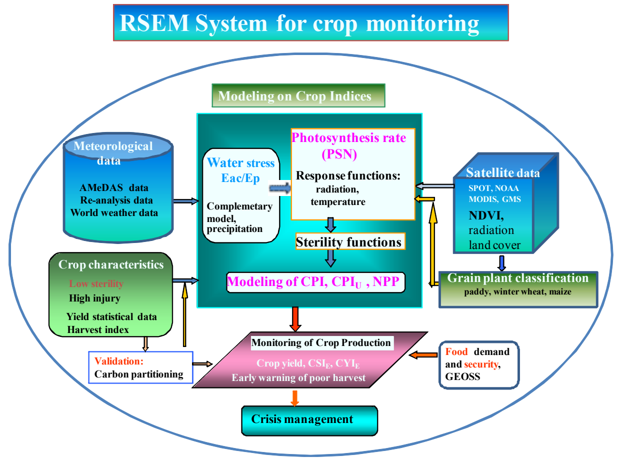

Figure 1. Present components of RSEM System and its flow for crop monitoring using photosynthesis-sterility model using multi-satellites and meteorological data.

$$f_{Syn}(T_c) = \left[\frac{1}{1 + \exp\{k_{syn}(T_c - T_{hv})\}} \right], \tag{2}$$

where T_{hv} is the temperature parameter at half of the maximum photosynthesis rate; and K_{syn} is the gradient of the relation between the function $f_{Syn}(T_c)$ and the air temperature.

The temperature response functions that distinguish the low-temperature sterility and high-temperature injury conditions are defined by the following equations, referring to the curves obtained by Vong and Murata (1997).

$$f_{Lster}(T_c) = 1 - \exp[k_{Lster}(T_{Lster} - T_c)] \tag{3a}$$

$$f_{Hster}(T_c) = 1 - \exp[k_{Hster}(T_c - T_{Hster})], \tag{3b}$$

where , k_{Lster} , is the low temperature sterility constant (dimensionless); T_{Lster} the low sterility limit temperature (ºC); k_{Hster} is the high temperature injury constant; T_{Hster} is the high injury limit temperature (ºC); and T_c is the plant leaf temperature (ºC). Finally, the response function of the integrated temperature sterility effects due to both low and high temperature impacts on grain production is expressed as follows:

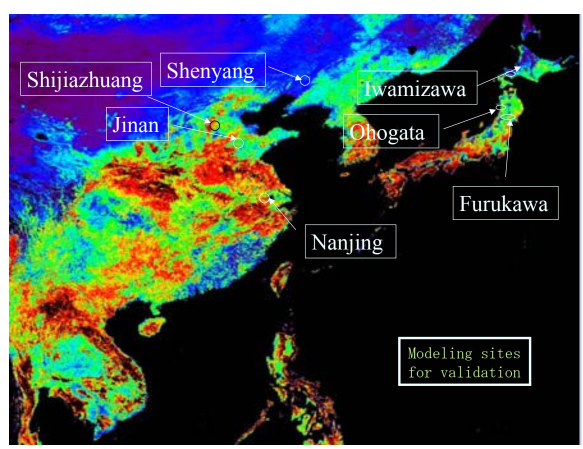

Figure 2. Validation sites in Japan and China.

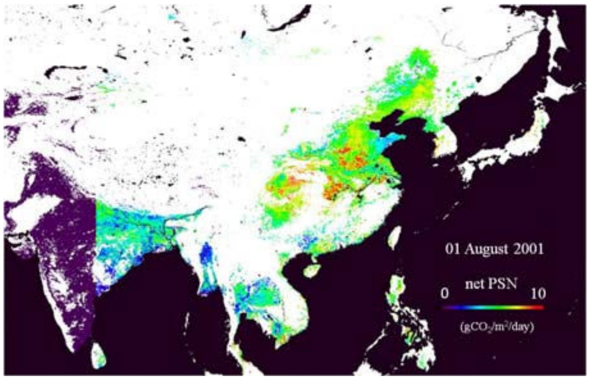

Figure 3. Distribution of photosynthesis rate (CO_2 sequestration) on crop fields in Southeast Asia on 1 May 2001.

$$f_{Ster}(T_c) = \{1 - \exp[k_{Lster}(T_{Lster} - T_c)]\} \cdot \{1 - \exp[k_{Hster}(T_c - T_{Hster})]\} \quad (4)$$

It is necessary to normalize the effective LAI, because the eLAI varies with the vegetation cover ratio, which differs across individual monitoring sites. To discriminate between growth and the proportion of planted crop areas, the present paper defines a standardized NDVI, called the Unit NDVI, by dividing the NDVI by its value corresponding to the average yield over the current season. To transform the unit crop production index (CPI) into a mechanism-based type of grain production index, the unit photosynthesis rate is produced by normalization that must be multiplied by the temperature sterility function F_{Ster}. Integration of the photosynthesis rate over the interval from sowing time point, t_s, to harvesting time point, t_h, defines the unit crop production index (CPI_U) by taking the following mathematical manipulation in Equations (4) and (5) (Kaneko et al., 2009, 2010):

$$CPI_U = F_{Ster}(T_c) \cdot \int_{t_s}^{t_h} PSN_U \cdot dt \quad (5)$$

$$F_{Ster} = \int_{t_f}^{tr} f_{Ster}(T_c) \cdot dt \quad (6)$$

3. DATA COLLECTION AND MODELING ANALYSIS

The air temperature data at test sites are collected by the Automated Meteorological Data Acquisition System (AMeDAS) through Japanese Meteorological Agency. The atmospheric reanalysis data were collected from the European Centre for Medium-Range Weather Forecasts (ECMWF), the National Centers for Environmental Prediction (NCEP) for air temperature, radiation, and evapotranspiration (ET) for stomatal opening ratio. The Japanese Ministry of Agriculture, Forestry, and Fisheries provides grain statistical information, which includes crop situation index (CSI) for the paddy rice at ten sites in support of modeling and monitoring practices. This CSI is the ratio of crop production in a year of problem to the mean annual production for the most recent ten years. Julian days of crop seeding and harvesting were provided from the districts of Agricultural Administrative Bureau of the Japanese Ministry of Agriculture, Forestry, and Fisheries.. Figure 2 shows the distribution of the NDVI in Southeast Asia including Japan derived by SPOT VEGETATION to aid in the present analysis.

Table 1. Validation of the improved photosynthesis model by a carbon weight included in paddy grains.

Nation		Japan			China	Japan			China	Variable and formulae
Province		Hokkaido	Akita	Miyagi	Jiangsu	Hokkaido	Akita	Miyagi	Jiangsu	Province
region		Iwamizawa	Ohogata	Furukawa	Nanjing	Iwamizawa	Ohogata	Ohosaki	Nanjing	region
grain		paddy	paddy	paddy	paddy	paddy	paddy	paddy	paddy	grain
Harvest Index		0.42	0.488	0.507	0.529	0.42	0.488	0.507	0.44	HI
year		2001	2001	2001	2001	2003	2003	2003	2003	Good harvest year
model type		PC	PC	PC	PC	PC	PC	PC	PC	Michaelis-Menten(MM), Priestl-Chartier(PC)
Validation site scale		County	County	County	Province	County	County	County	Province	scale effects
Evaluation from plants	grain areas (ha) 10^3 (ha)	27.0	32.6	45.6	2010	25.9	31.8	44.8	1841	A_{grain}
	grain Production 10^3 (t)	139.7	189.70	247.2	16933	100.6	170.8	163.5	14046	P_{grain}
	Yield (t/ha)	5.18	5.68	5.42	8.42	3.89	5.37	3.65	7.63	Y_Y
	Dry_W_y (t/ha)	3.72	4.08	3.89	6.05	2.79	3.86	2.62	5.48	$Y_{DW}=Y_Y$*0.718
	Ratio C/Carbohydrate	0.444	0.444	0.444	0.444	0.444	0.444	0.444	0.444	R_{CCh}=72/162
	Carbon_y (t/ha)	1.65	1.81	1.73	2.69	1.24	1.71	1.16	2.43	$Y_C=Y_{DW}$*R_{CCh}
	Carbon_fixation_Grain (Production) $\times10^3$ (t)	44.6	59.1	78.9	5403	32.2	54.5	52.2	4482	$C_{FGP}=Y_{DW}$*R_{CCh}*A_{grain}
Evaluation from this model, CO_2	CO_2 fixation (Model) (gCO_2/m^2)	3159	3246	2962	4256	2722	2784	2719	3886	F_{Sht}
	CO_2 fixation (β s) (gCO_2/m^2)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	F_{SB}
	CO_2 fixation (tCO_2/ha)	31.59	32.46	29.62	42.56	27.22	27.84	27.19	38.86	F_{Sgs}
	Respiration_night (tCO_2/ha)	13.05	13.41	12.23	17.58	11.24	11.50	11.23	16.05	Paddy: $R_n=F_{Sgs}$*0.413 Wheat: $R_n=F_{Sgs}$*0.143
	Carbon respiration_night (tC/ha)	3.56	3.66	3.34	4.80	3.07	3.14	3.07	4.38	R_{nc}
	Net fixation (tCO_2/ha)	18.54	19.05	17.39	24.98	15.98	16.34	15.96	22.81	$F_{net}=F_{Sgs}-R_n$
	Net provincial CO_2 fixation (Million t)	0.50	0.62	0.79	50.2	0.41	0.52	0.72	42.0	$F_{NPC}=F_{SB}$*$A_{grain}/10^6$
Evaluation from this model, Carbon	Ratio C/CO_2	0.273	0.273	0.273	0.273	0.273	0.273	0.273	0.273	R_{CCO}=12/44
	Net C fixation (t/ha)	5.06	5.20	4.74	6.81	4.36	4.46	4.35	6.22	$C_{FM}=F_{net}$*R_{CCO}
	C_fixation_aboveGround (t/ha)	3.82	3.93	3.58	5.15	3.29	3.37	3.29	4.70	$C_{MAG}=C_{FM}$*0.756
	C_fixation_Grain-only (t/ha)	1.61	1.91	1.82	2.72	1.38	1.64	1.67	2.16	$C_{MGt}=C_{MAG}$*HI
	Provincial C fixation_Grain_Model $\times10^3$ (t)	43.4	62.2	82.9	5477	35.8	52.1	74.7	3983	$C_{MGA}=C_{MGt}$*A_{grain}
	Provincial C_fixation in whole grain plant $\times10^3$ (t)	136.5	169.4	216.2	13695	112.9	141.7	195.0	11452	$C_{MPA}=C_{FM}$*A_{grain}
Ratios and errors	Carbon fixation ratio in Grain (model/yield_data)	0.97	1.05	1.05	1.01	1.11	0.96	1.43	0.89	$R_{CGF}=C_{MGt}/Y_C$
	Estimation Error (%)	-2.9%	5.3%	5.1%	-1.4%	11.5%	-4.4%	43.2%	-11.1%	(1-R_{CGF})*100

4. RESULTS OF THE CROP PRODUCTION INDICES

Figure 3 shows the distribution of PSN in terms of CO_2 fixation on crop fields during the most severe drought conditions in the Northern China Plain. With of MODIS LULC data, classification of the crop fields was made possible for those four crops including rice, winter wheat, spring wheat, and other crops, by using a decision-tree method with two factors: vegetation phenology and water surface detection based on the Land Surface Water Index (LSWI). The efforts of LULC classification associated with seasonal variations of PSN and CPI can be found out in a greater detail in the literature (Kaneko et al. 2007 and 2010). Table 1 shows a validation of the present photosynthesis rice model by carbon weights present in rice biomass of cellulose $(C_6H_{10}O_5)_n$ and starch. Validation using the carbon partitioning method confirms a good agreement between the computed amounts of carbon fixation in rice and winter wheat grains and those

Table 2. Validation of the improved photosynthesis model by carbon weights included in paddy grains considering sterility.

Prefecture	Hokkaido		Akita		Miyagi		Variable and formulae
County	Iwamizawa		Ohogata		Ohosaki (Furukawa)		Province
year	2001	2003	2001	2003	2001	2003	year
harvest situation	Good harvest	Bad harvest	Good harvest	Bad harvest	Good harvest	Bad harvest	harvest situation
Validation site scale	County	County	County	County	County	County	scale effects
Yield (t/ha)	5.18	3.89	5.68	5.37	5.42	3.65	
Net fixation (tCO_2/ha)	18.54	15.98	19.05	16.34	17.39	15.96	C_{FMt}
C_fixation_Grain-only (tC/ha)	1.61	1.38	1.91	1.64	1.82	1.67	Y_T
Carbon_y (tC/ha)	1.65	1.24	1.81	1.71	1.73	1.16	Y_C
CSI	101	79	102	94	103	69	CSI
Carbon fixation ratio in Grain (model/yield_data)	0.97	1.11	1.05	0.96	1.05	1.43	$R_{CGF}=C_{MGt}/Y_C$
Sterility correction factor subtracted by photosynthesis effect	-	0.84	-	0.99	-	0.74	f_{ster}=(CSI+CSI100*0.05)/CSI100
Carbon fixation ratio in grain corrected by sterility	no sterility	0.880	no sterility	0.890	no sterility	0.988	R_{CGF}*CSI/100
	no sterility	0.936	no sterility	0.947	no sterility	1.060	R_{CGF}*f_{ster}
Estimation Error (%)	-2.7%	11.5%	5.3%	-4.4%	5.1%	43.2%	E_{SYN} without sterility
	-8.0%	-6.4%	-0.2%	-5.3%	0.0%	6.0%	$E_{SterSYN}$ with sterility

sequestrated in harvested yields in Japan and China. The average differences between carbon contents in harvested rice and calibrated carbon fixation estimated by the model are -2.7%, 5.3%, and 5.1% at validation sites of Iwamizawa, Ohogata, and Ohosaki (Furukawa) in 2001 in Japan (Table 2).

According to the measurements of the FLUXNET observation tower for paddy-rice at Mase, Tsukuba by Saito (2005), the maximum photosynthetic rate, PSN_{max}, was 39 (gCO_2/m^2/day). In addition, Net PSN_{max} of 36.53 (gCO_2/m^2/day) was measured by the chamber experiment with half openness (Sakai, 2001). Net PSN_{max} in daytime was 43.62 (gCO_2/m^2/day) from the modeling outputs. Reduction of night respiration rate of 7.64 (gCO_2/m^2/day) associated with the PSN_{max} was 39 (gCO_2/m^2/day) that is similar to the computed PSN_{max}. Comparisons between the computed PSN_{max} and the measured counterparts in a chamber and FLUXNET confirm a fairly good agreement, which supports the validity of the model using the carbon partitioning method. In the case of winter wheat, the estimation error in Table 3 was highly improved to 0.6 % and -3.4% in 2003 at Shijiazhuang. However, more yield data are needed for validation of winter wheat model. We are preparing two typical sites of Kataning near Perth in Western Australia and Laventon in Victoria states for more studies in the future.

Table 3. Validation of the present photosynthesis model by a carbon weight included in winter wheat grains.

Nation		China			Variable and formulae
Province		Hebei			Province
region		Shijiazhuang			County
grain		w_wheat			grain
Harvest Index		0.41			HI
year		2001	2003	2005	Poor harvest year
model type		MM	MM	MM	Michaelis-Menten(MM), Prioul-Chartier(PC)
Validation site scale		Province	Province	Province	scale effects
Evaluation from plants	grain areas (ha) $\times10^3$ (ha)	2580	2193	2505	A_{grain}
	grain Production $\times10^3$ (t)	11227	10188	11503	P_{grain}
	Yield (t/ha)	**4.35**	**4.65**	**4.59**	Y_T
	Dry_W_y (t/ha)	3.12	3.34	3.30	$Y_{DW}=Y_t*0.718$
	Ratio C/Carbohydrate	0.444	0.444	0.444	R_{CCh}=72/162
	Carbon_y (t/ha)	**1.39**	**1.48**	**1.47**	$Y_C=Y_{DW}*R_{CCh}$
	Carbon_fixation_Grain (Production) $\times10^3$ (t)	3583	3251	3671	$C_{FOP}=Y_{DW}*R_{CCh}*A_{grain}$
Evaluation from this model – CO_2	**CO_2 fixation (Model)** (gCO_2/m^2)	**2358**	**2272**	**2364**	F_{Mr}
	CO_2 fixation (β s) (gCO_2/m^2)	1929	1785	1954	$F_{Mβ}$
	CO_2 fixation (tCO_2/ha)	**19.29**	**17.85**	**19.54**	F_{Mgt}
	Respiration_night (tCO_2/ha)	2.76	2.55	2.79	Paddy: $R_{tC}=F_{Mgt}*0.413$ Wheat: $R_{tC}=F_{Mgt}*0.143$
	Carbon respiration_night (tC/ha)	0.75	0.70	0.76	R_{tG}
	Net fixation (tCO_2/ha)	**16.53**	**15.30**	**16.74**	$F_{net}=F_{Mgt}-R_N$
	Net provincial CO_2 fixation (Million t)	42.7	33.6	41.9	$F_{NPC}=F_{Mt}*A_{grain}/10^6$
Evaluation from this model – Carbon	Ratio C/CO_2	0.273	0.273	0.273	R_{CCo}=12/44
	Net C fixation (t/ha)	**4.51**	**4.17**	**4.57**	$C_{FMt}=F_{net}*R_{CCo}$
	C_fixation_aboveGround (t/ha)	3.41	3.15	3.45	$C_{MFaG}=C_{FMt}*0.756$
	C_fixation_Grain-only (t/ha)	**1.40**	**1.29**	**1.42**	$C_{MGt}=C_{MFaG}*HI$
	Provincial C fixation_Grain_Model $\times10^3$ (t)	3605	2836	3544	$C_{MGA}=C_{MGt}*A_{grain}$
	Provincial C_fixation in whole grain plant $\times10^3$ (t)	11631	9151	11435	$C_{MtA}=C_{FMt}*A_{grain}$
Ratios and erors	**Carbon fixation ratio in Grain (model/yield_data)**	**1.01**	**0.87**	**0.97**	$R_{CGF}=C_{MGt}/Y_C$
	Estimation Error (%)	**0.6%**	**-12.8%**	**-3.4%**	$(1-R_{CGF})*100$

5. CONCLUSIONS

Modern grain production estimation is related to food security that is linked with energy and water supply, global warming, and biological diversity. The present study improves photosynthesis model for paddy-rice and winter wheat by assimilating multi-satellite imageries and meteorological reanalysis data in our RSEM system. These models applied to paddy rice and winter wheat in Asia confirms the integrity of the carbon partitioning method applied in both Japan and China. The average differences between carbon contents in harvested rice and calibrated carbon fixation estimated by the model are -2.7%, 5.3%, and 5.1% at validation sites of Iwamizawa, Ohogata, and Ohosaki in 2001 in Japan. In the case of winter wheat, the estimation error was highly improved too. However, more crop yield data are needed for validation of winter wheat model in the future.

REFERENCES

D. Kaneko, T. Kumakura, P. Yang, "Data assimilation for crop yield and CO_2 fixation monitoring in Asia by a photosynthetic-sterility model using satellites and meteorological data," Int. Journal of Global Warming, vol 1, p.p. 179-200, May 2009.

D. Kaneko, T. Kumakura, P. Yang, "Developing a photosynthetic sterility model to estimate CO_2 fixation through the crop yield in Asia with the aid of MODIS data, Ecological Informatics," vol 5, p.p. 390-399, August 2010.

E. Lokupitiya, F.J. Breidt, R. Lokupitiya, S. Williams, K. Paustian, "Deriving comprehensive county-level crop yield and area data for U.S. cropland," Agronomy J., vol 99, p.p. 673-681, May 2007.

F. Yang, K. Ichii, M.A. White, H. Hashimoto, A.R. Michaelis, P. Votava, A. Zhu, A. Huete, S.W. Running, R.R. Nemani, "Developing a continental-scale measure of gross primary production by combining MODIS and AmeriFlux data through Support Vector Machine approach," Remote Sensing of Environment, vol 110, p.p. 109-122, September 2007.

M.K. Hazarika, Y. Yasuoka, A. Ito, D. Dye, "Estimation of net primary productivity by integrating remote sensing data with an ecosystem model," Remote Sensing of Environment, vol 94, p.p. 298-310, January 2005.

M. Saito, A. Miyata, H. Nagai, T. Yamada, "Seasonal variation of carbon dioxide exchange in rice paddy field in Japan," Agr. and For. Meteorology, vol 135, p.p 93-109, December 2005.

H. Sakai, K. Yagi, K. Kobayashi, S. Kawashima, "Rice carbon balance under elevated CO_2," New Phytologist, vol 150, p.p. 241-249, May 2001.

H. Sasaki, T. Hara, S. Ito, S. Miura, M.M. Hoque, M. Lieffering, H.Y. Kim, M. Okada, K. Kobayashi, "Seasonal changes in canopy photosynthesis and respiration, and partitioning of photosynthate, in rice (Oryza sativa L.I) grown under free-air CO_2 enrichment," Plant and Cell Physiology, vol 46, p.p 1704-1712, August 2005.

J. Xiao, Q. Zhuang, B.E. Law, J. Chen, D.D., et al., "A continuous measure of gross primary production for the conterminous United States derived from MODIS and AmeriFlux data," Remote Sensing of Environment, vol 114, p.p. 576-591, March 2010.

W. Xiong, I. Holman, D. Conway, E. Lin, Y. Li, "A crop model cross calibration for use in regional climate impacts studies," Ecological Modelling, vol 213, p.p. 365-380, March 2008.

P. Doraiswamy, T. Sinclair, S. Hollinger, B. Akhmedov, A. Stern, J. Prueger, "Application of MODIS derived parameters for regional crop yield assessment," Remote Sensing of Environment, vol 97, p.p. 192-202, July 2005.

Q. Wan, M. Watanabe, O. Zhu, "Simulation of water and carbon fluxes using BIOME-BGC model over crops in China," Agr. and For. Meteorology, vol 131, p.p. 209-224, July 2005.

W. Wu, R Shibasaki, P. Yang, G. Tan, K. Matsumura, K. Sugimoto, "Global-scale modeling of future changes in sown areas of major crops, " Ecological modeling, vol 208, p.p. 378-390, November 2007.