Remote sensing of crop primary productivity using MODIS and Landsat data

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We found that gross primary production (GPP) is closely related to the total crop chlorophyll (Chl) content. Thus, Chl content can be used as an accurate measure of GPP in crops. We applied a recently developed technique for the remote estimation of Chl content to assess GPP. The model relates GPP to a product of chlorophyll-related vegetation index and incoming photosynthetically active radiation (PAR_{in}). This approach provides accurate estimations of GPP in maize and soybean in both irrigated and rainfed fields by means of MODIS and Landsat data.

Study sites & Data

Study Area

Three AmeriFlux sites (Mead, NE) were studied in 2001 - 2008

Site 1: irrigated continuous maize
Site 2: irrigated maize-soybean rotation
Site 3: rainfed maize-soybean rotation

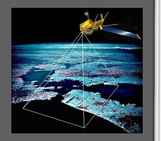
CO_2 Fluxes and Incoming Photosynthetically Active Radiation (PAR_{in})

Each site is equipped with an eddy covariance tower and meteorological sensors to measure net ecosystem carbon dioxide exchange. Daytime estimates of ecosystem respiration R_e were obtained from nighttime CO_2 fluxes vs. temperature relationships. The GPP was then obtained by subtracting R_e from net ecosystem production (*Verma et al., 2005*).

PAR_{in} was measured with point quantum sensors (LI-190, LI-COR Inc., Lincoln, NE) aimed upward, and placed 6 m above the surface. (*Verma et al., 2005*).

Satellite Images – Landsat & MODIS 250 m

Landsat images were atmospherically corrected to produce top-of-canopy reflectance (Masek et al., 2006). Site reflectance values were calculated by averaging all the per-pixel reflectance values within the fields. Daily 250m MODIS surface reflectance data (MOD09Q1) were acquired from 2001 through 2008 for NE study sites.



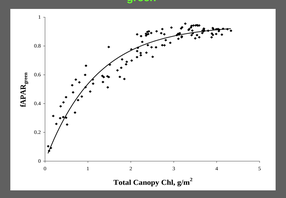
Shortwave Radiation (SW) – Proxy of PAR_{in}

Daily-integrated SW data (NLDAS-2) were substituted for actual PAR_{in} (*Sakamoto et al., 2011*).

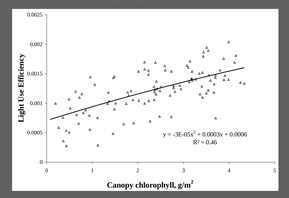
Methodology

Two key physiological properties of crop productivity are light capture ($fAPAR_{green}$) and the efficiency of the use of absorbed light (LUE). These properties are closely related to Chl content . Thus, Chl content relates to GPP, which, in turn, relates directly to photosynthesis (*Gitelson et al., 2006; Peng et al., 2011*).

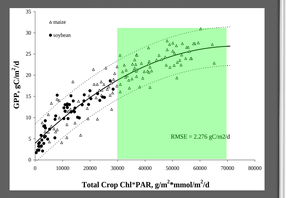
$fAPAR_{green}$ vs. Chl



LUE vs. Chl

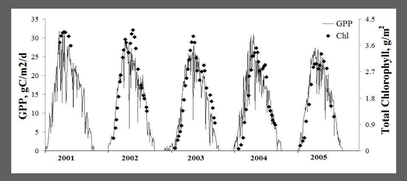


GPP vs. Chl



While $fAPAR_{green}$ remains almost invariant for Chl above 2.3 g/m², LUE increases. This increase in LUE results in an increase in GPP.

Time series of GPP and Chl

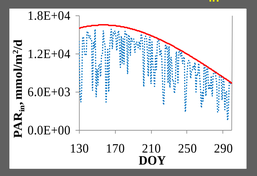


Peng, et al., RSE, 2011

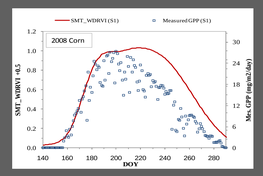
Chl is a good proxy of GPP in crops

High frequency variations of GPP correspond to high frequency variations of PAR_{in} due to change in weather conditions. The discrepancy between VI and GPP after DOY 210 is caused by the significant decline of PAR_{in}. When taking both into account, the product of VI and PAR_{in} relates closely to GPP.

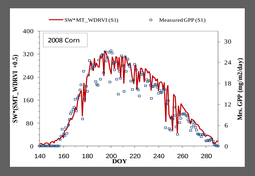
Daily and seasonal variations of PAR_{in}



GPP ∝ VI



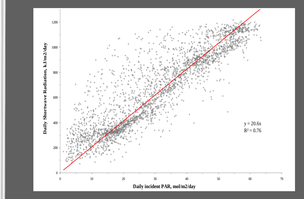
GPP ∝ VI × PAR_{in}



Results

GPP Estimation Using *MODIS 250 m Data*

PAR_{in} vs. SW

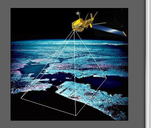


Shortwave radiation is used as a proxy of PAR_{in}. Thus, the model

$$GPP \propto SW \times WDRVI$$

$$WDRVI = (\alpha \times \rho_{NIR} - \rho_{Red}) / (\alpha \times \rho_{NIR} + \rho_{Red}),\ \alpha = 0.1$$ (Gitelson 2004)

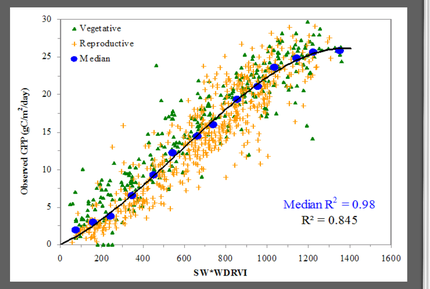
is based entirely on remotely sensed data.



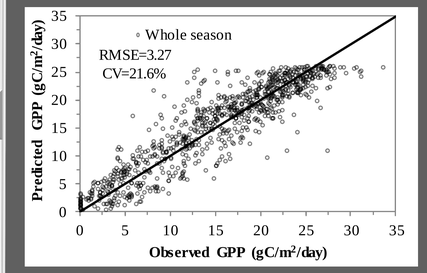
Model Calibration

In order to avoid bias from an uneven distribution of samples, the calibration samples were grouped into 14 classes at 100 SW*WDRVI value intervals. Blue points represent the median values in each class.

Note: R^2 {GPP vs. median SW*WDRVI } = 0.98



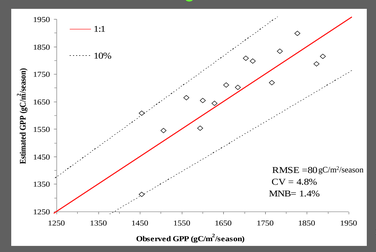
Model Validation



Data set	Model name	N	CV	RMSE	R^2	MNB
Calibration	Whole season	888	19.5	2.91	0.85	9.8
	Vegetative	314	17.2	2.75	0.87	5.1
	Reproductive	574	19.6	2.80	0.85	5.8
Validation	Whole season	888	21.6	3.27	0.83	5.6
	Vegetative	318	17.9	3.00	0.85	1.4
	Reproductive	570	20.9	2.98	0.86	6.9

Growing-season total GPP

Model-derived estimations vs. ground-based observations



Sakamoto, et al., RSE, submitted

The model is capable of estimating the total growing-season GPP with high accuracy.

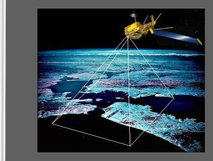
GPP Estimation Using *LANDSAT Data*

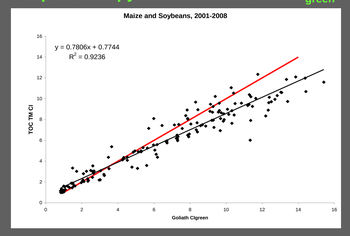
111 Landsat images (TM: 59, ETM: 52) were obtained over Mead NE sites throughout 2001-2008 and atmospherically corrected (Masek et al., 2006).

$$GPP \propto CI_{green} \times PAR_{in}$$

$$CI_{green} = (\rho_{NIR}/\rho_{green}) - 1$$ (Gitelson et al., 2005)

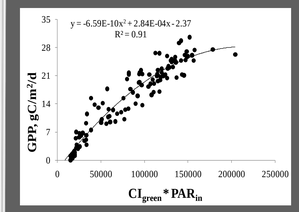
Top of Canopy Landsat vs. *in situ* CI_{green}

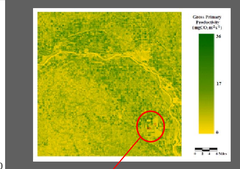




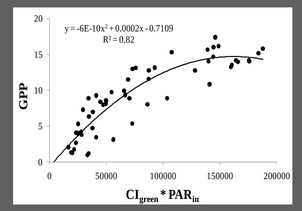
Model Calibration

Irrigated and rainfed maize, Mead, NE, 2001-2008





Irrigated and rainfed soybean, Mead, NE, 2002, 2004, 2006, 2008

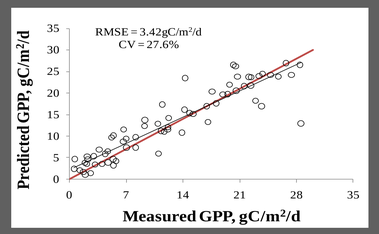


GPP distribution in South-Eastern NE

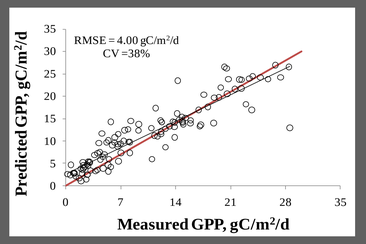
Model Validation

Validation sites:
Rosemount, MN, 2005-2007
Brooks, IA, 2005-2007
Bondville, IL, 2001-2003

Rainfed maize



Rainfed maize and soybean



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CONCLUSIONS

GPP can be estimated as a product of chlorophyll-related vegetation indices and PAR_{in}. The developed technique is capable of accurately predicting widely variable GPP in maize and soybean under both rainfed and irrigated conditions with both Landsat and MODIS data.

Acknowledgements

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