sustainability

MDPI

Article

Forest Aboveground Biomass Estimation and Response to Climate Change based on Remote Sensing Data

Yingchang Li [1], Mingyang Li [2,*], and Yuehui Wang [3]

[1] School of History and Culture, Shanxi University, Taiyuan 030006, China
[2] College of Forestry, Nanjing Forestry University, Nanjing 210037, China
[3] Department of Engineering Foundation, Army Academy of Border and Coastal Defence, Xi'an 710108, China
* Correspondence: lmy196727@njfu.edu.cn; Tel.: +86-025-8542-7327

Supplementary Information

Table S1. Description of Landsat data (1999–2014) downloaded and used in this study.

1999	P/R	P124	P123	P122	2004	P124	P123	P122
	R40	L5-19981001	L5-19990911			L5-20040915	L5-20040924	
		L7-19991113	L5-19990927			L5-20041102		
		L7-19990910	L5-20000913			L5-20041118		
	R41	L5-19991020	L5-19990911			L5-20031015	L5-20040924	
		L5-19981001	L5-19990927			L5-20040915		
		L7-19990910	L5-20000913			L5-20041118		
	R42	L5-19981001	L5-19980924	L7-20000914		L5-20031015	L5-20040924	L5-20031120
			L5-19981111			L5-20040915		L5-20041003
			L5-19990911			L5-20041118		L5-20041120
	R43	L5-19981001	L5-19980924			L5-20031015	L5-20040924	
		L5-19981017	L5-19981111			L5-20040915	L5-20041010	
		L7-19990926	L7-19991122			L5-20041017	L5-20050911	
2009	R40	L5-20081129	L5-20080919		2014	L8-20131010	L8-20130917	
		L5-20091015	L5-20090906			L8-20141114	L8-20141006	
		L5-20100916	L5-20091024			L8-20151016	L8-20151025	
	R41	L5-20091015	L5-20090906			L8-20131010	L8-20130917	
		L5-20091031	L5-20091024			L8-20131026	L8-20131014	
		L5-20100916	L5-20101112			L8-20140927	L8-20151025	
	R42	L5-20081028	L5-20080919	L5-20091017		L8-20131026	L8-20130917	L8-20131012
		L5-20081113	L5-20091024	L5-20101004		L8-20141114		L8-20131129
		L5-20091031	L5-20091125			L8-20151016		L8-20141015
	R43	L5-20081028	L5-20091125			L8-20131026	L8-20130917	
		L5-20091031				L8-20151016	L8-20131014	
		L5-20101119					L8-20141006	

Note: P, Path; R, Row; L5, Landsat 5 TM; L7, Landsat 7 ETM+; L8, Landsat 8 OLI.

Table S2. The equations of the vegetation indices used in this study.

No.	Variable Name	Equation	Reference
1	Atmospherically Resistant Vegetation Index	$ARVI = \frac{NIR - [Red - (Blue - Red)}{NIR + [Red - (Blue - Red)}$	[1]
2	Difference Vegetation Index	$DVI = NIR - Red$	[2]
3	Enhanced Vegetation Index	$EVI = 2.5 \times \frac{(NIR - Red)}{(NIR + 6 \times Red - 7.5 \times Blue + 1)}$	[3]
4	Green Atmospherically Resistant Index	$GARI = \frac{NIR - [Green - 1.7 \times (Blue - Red)]}{NIR + [Green - 1.7 \times (Blue - Red)]}$	[4]
5	Green Difference Vegetation Index	$GDVI = NIR - Green$	[5]
6	Green Normalized Difference Vegetation Index	$GNDVI = \frac{(NIR - Green)}{(NIR + Green)}$	[6]
7	Green Ratio Vegetation Index	$GRVI = \frac{NIR}{Green}$	[5]
8	Green Vegetation Index	$GVI = (-0.2848 \times Blue) + (-0.2435 \times Green) + (-0.5436 \times Red) + (0.7243 \times NIR) + (0.0840 \times SWIR_1) + (-0.1800 \times SWIR_2)$	[7]
9	Infrared Percentage Vegetation Index	$IPVI = \frac{NIR}{NIR + Red}$	[8]
10	Leaf Area Index	$LAI = (3.618 \times EVI - 0.118)$	[9]
11	Modified Non-Linear Vegetation Index	$MNLVI = \frac{(NIR^2 - Red) \times (1 + 0.5)}{(NIR^2 + Red + 0.5)}$	[10]
12	Modified Simple Ratio Vegetation Index	$MSRVI = \frac{\left(\frac{NIR}{Red}\right) - 1}{\left(\sqrt{\frac{NIR}{Red}}\right) + 1}$	[11]
13	Normalized Difference Vegetation Index	$NDVI = \frac{(NIR - Red)}{(NIR + Red)}$	[12]
14	Non-Linear Vegetation Index	$NLVI = \frac{(NIR^2 - Red)}{(NIR^2 + Red)}$	[13]
15	Optimized Soil Adjusted Vegetation Index	$OSAVI = \frac{1.5 \times (NIR - Red)}{(NIR + Red + 0.16)}$	[14]
16	Renormalized Difference Vegetation Index	$RDVI = \frac{(NIR - Red)}{\sqrt{(NIR + Red)}}$	[14]
17	Ratio Vegetation Index	$RVI = \frac{NIR}{Red}$	[15]

18	Soil Adjusted Vegetation Index	$SAVI = \frac{1.5 \times (NIR - Red)}{(NIR + Red + 0.5)}$	[16]
19	Transformed Difference Vegetation Index	$TDVI = \sqrt{0.5 + \frac{(NIR - Red)}{(NIR + Red)}}$	[17]
20	Visible Atmospherically Resistant Index	$VARI = \frac{Green - Red}{Green + Red - Blue}$	[18]

Table S3. Evaluation criteria of the semivariance analysis and Ordinary Kriging.

No.	Evaluation Criteria	Equation	Reference
1	Residual Sums of square	$RSS = \sum_{i=1}^{n} (s_i - \hat{s}_i)^2$	[19]
2	Mean Error	$ME = \frac{\sum_{i=1}^{n} (v_i - \hat{v}_i)}{n}$	[20]
3	Mean Standardized Error	$MSE = \frac{\sum_{i=1}^{n} \frac{(\hat{v}_i - v_i)}{\hat{\sigma}_i}}{n}$	[20]
4	Root-mean-Square Standardized Error	$RMSSE = \sqrt{\frac{\sum_{i=1}^{n} \left(\frac{\hat{v}_i - v_i}{\hat{\sigma}_i}\right)^2}{n}}$	[20]
5	Average Standard Error	$ASE = \sqrt{\frac{\sum_{i=1}^{n} \hat{\sigma}_i^{\,2}}{n}}$	[20]
6	Total Error	$TE = \lvert ME \rvert + \lvert MSE \rvert + \lvert RMSE \rvert + \big\lvert \lvert ASE \rvert - \lvert RMSE \rvert \big\rvert + \big\lvert 1 - \lvert RMSSE \rvert \big\rvert$	[20]

Table S4. Evaluation of semivariance analysis with different semivariogram models of XGBoost model.

Year	Forest Type	Model	Nugget	Sill	Range (m)	RSS	R^2	Nugget Effect
1999	All	Linear	799.74	1070.26	241916.80	15300.00	0.96	0.75
		Spherical	**70.00**	**859.00**	**189050.00**	**16765.00**	**0.88**	**0.08**
		Exponential	162.00	901.00	183300.00	17700.00	0.65	0.18
		Gaussian	120.00	1165.00	164540.48	40960.00	0.10	0.10
	Broadleaved	Linear	833.77	1095.31	243116.83	11561.00	0.92	0.76
		Spherical	**71.00**	**843.00**	**173850.00**	**12013.00**	**0.90**	**0.08**
		Exponential	111.00	1227.00	159000.00	22890.00	0.56	0.09
		Gaussian	80.00	1225.00	124700.00	43137.00	0.15	0.07
	Coniferous	Linear	862.00	1150.74	244385.00	12642.00	0.88	0.75
		Spherical	121.00	1019.00	120900.00	15825.00	0.71	0.12
		Exponential	**37.00**	**414.00**	**156750.00**	**13829.00**	**0.86**	**0.09**
		Gaussian	129.00	1269.00	103092.00	39795.00	0.11	0.10

	Mixed	Linear	941.00	1232.43	244314.97	34996.00	0.78	0.76
		Spherical	141.00	1047.00	195000.00	39648.00	0.61	0.13
		Exponential	**49.00**	**1101.00**	**178601.00**	**35734.00**	**0.73**	**0.04**
		Gaussian	161.00	1346.00	196909.00	49705.00	0.10	0.12
2004	All	Linear	974.64	1163.11	244277.59	18542.00	0.90	0.84
		Spherical	**89.00**	**1208.00**	**185538.00**	**19561.00**	**0.85**	**0.07**
		Exponential	144.00	1223.20	214100.00	23526.00	0.69	0.12
		Gaussian	154.00	1423.10	202470.77	33558.00	0.09	0.11
	Broadleaved	Linear	859.82	966.04	242024.81	16151.00	0.96	0.89
		Spherical	155.00	1316.60	113400.00	18171.00	0.83	0.12
		Exponential	**84.00**	**1015.00**	**143117.00**	**16851.00**	**0.92**	**0.08**
		Gaussian	161.00	1516.60	111085.00	31171.00	0.13	0.11
	Coniferous	Linear	990.57	1137.97	244321.73	17835.00	0.93	0.87
		Spherical	124.00	1216.20	112600.00	19530.00	0.62	0.10
		Exponential	**60.00**	**566.00**	**122025.00**	**18772.00**	**0.89**	**0.11**
		Gaussian	153.00	1616.30	193000.00	21540.00	0.12	0.09
	Mixed	Linear	905.83	1242.88	240979.13	34094.00	0.81	0.73
		Spherical	**52.00**	**659.00**	**166552.00**	**37345.00**	**0.77**	**0.08**
		Exponential	123.00	1625.40	151800.00	37867.00	0.65	0.08
		Gaussian	155.00	1225.50	177200.00	42869.00	0.16	0.13
2009	All	Linear	900.88	1037.32	244362.74	15034.00	0.91	0.87
		Spherical	**98.00**	**1042.00**	**165555.00**	**16642.00**	**0.87**	**0.09**
		Exponential	123.00	1621.60	136200.00	16055.00	0.74	0.08
		Gaussian	154.00	1121.50	140500.00	39108.00	0.14	0.14
	Broadleaved	Linear	928.34	1159.35	233417.93	11531.00	0.92	0.80
		Spherical	**63.00**	**951.00**	**184385.00**	**12207.00**	**0.88**	**0.07**
		Exponential	187.00	1297.70	127050.00	14064.00	0.81	0.14
		Gaussian	159.00	1397.00	102700.00	35040.00	0.10	0.11
	Coniferous	Linear	856.30	1003.71	132220.21	17183.00	0.93	0.85
		Spherical	103.00	996.00	121800.00	19603.00	0.75	0.10
		Exponential	**51.00**	**638.00**	**134322.00**	**18835.00**	**0.85**	**0.08**
		Gaussian	93.00	856.00	148532.94	34876.00	0.15	0.11
	Mixed	Linear	858.84	1040.51	233630.11	27742.00	0.86	0.83
		Spherical	**84.00**	**1167.00**	**133768.00**	**32514.00**	**0.78**	**0.07**
		Exponential	17.00	818.80	191900.00	35046.00	0.66	0.02
		Gaussian	123.00	928.90	161281.28	41855.00	0.17	0.13
2014	All	Linear	932.79	1166.55	226552.05	14772.00	0.87	0.80
		Spherical	**77.00**	**967.00**	**173138.00**	**15996.00**	**0.82**	**0.08**
		Exponential	127.00	1126.00	184000.00	16189.00	0.64	0.11
		Gaussian	110.00	823.00	201300.00	30469.00	0.12	0.13
	Broadleaved	Linear	775.47	967.21	138137.75	10011.00	0.92	0.80
		Spherical	121.00	877.00	121800.00	11688.00	0.77	0.14
		Exponential	**51.00**	**892.00**	**144315.00**	**10711.00**	**0.88**	**0.06**
		Gaussian	90.00	877.00	133920.30	38688.00	0.12	0.10
	Coniferous	Linear	967.87	1141.50	135555.04	14014.00	0.84	0.85
		Spherical	124.00	1058.00	139080.00	15423.00	0.70	0.12
		Exponential	**66.00**	**743.00**	**130979.00**	**14094.00**	**0.81**	**0.09**
		Gaussian	71.00	1058.00	140900.00	37423.00	0.13	0.07
	Mixed	Linear	928.61	1208.23	145538.42	37345.00	0.83	0.77

Spherical	116.00	1122.00	141900.00	39476.00	0.60	0.10
Exponential	**74.00**	**902.00**	**153418.00**	**38531.00**	**0.75**	**0.08**
Gaussian	143.00	1122.00	149006.66	42946.00	0.10	0.13

Note: Results of all forest plots with no classification of forest type are abbreviated as "All". The bold type in the table is the best model and parameter. RSS: Residual sums of squares for regression of actual and modeled semivariance values.

Table S5. Evaluation of cross validation of Ordinary Kriging interpolation with different forest types of XGBoost models.

Year	Forest Type	Model	ME	MSE	RMSE	ASE	RMSSE	TE
1999	All	Linear	0.119	0.004	29.976	27.270	1.102	32.907
		Spherical	**0.052**	**0.002**	**29.682**	**27.005**	**1.098**	**32.512**
		Exponential	0.131	0.004	30.125	27.600	1.104	32.888
		Gaussian	0.157	0.005	30.194	27.815	1.101	32.836
	Broadleaved	Linear	0.123	0.004	27.572	26.993	1.099	28.377
		Spherical	**0.043**	**0.001**	**26.790**	**25.799**	**1.092**	**27.917**
		Exponential	0.185	0.005	27.459	26.488	1.124	28.744
		Gaussian	0.203	0.006	27.443	26.724	1.151	28.521
	Coniferous	Linear	0.033	0.011	28.728	27.588	0.996	29.916
		Spherical	0.008	0.010	28.979	27.752	1.000	30.225
		Exponential	**0.118**	**0.004**	**28.345**	**27.022**	**1.047**	**29.837**
		Gaussian	0.065	0.007	28.885	27.673	0.999	30.171
	Mixed	Linear	0.330	0.012	28.989	26.895	1.109	31.534
		Spherical	0.412	0.015	28.824	27.139	1.094	31.029
		Exponential	**0.009**	**0.005**	**28.460**	**26.026**	**1.074**	**30.981**
		Gaussian	0.410	0.014	28.895	27.199	1.095	31.111
2004	All	Linear	0.157	0.005	29.194	26.815	1.011	31.746
		Spherical	**0.069**	**0.003**	**28.530**	**26.598**	**1.007**	**30.541**
		Exponential	0.075	0.003	29.714	27.621	1.075	31.960
		Gaussian	0.119	0.004	29.776	28.670	1.038	31.043
	Broadleaved	Linear	0.436	0.011	26.029	24.464	1.040	28.081
		Spherical	0.401	0.011	26.021	24.426	1.041	28.068
		Exponential	**0.028**	**0.001**	**25.542**	**24.076**	**1.034**	**27.071**
		Gaussian	0.494	0.013	26.954	24.573	1.035	29.878
	Coniferous	Linear	0.127	0.005	27.275	25.776	0.981	28.925
		Spherical	0.124	0.005	27.156	25.758	0.976	28.706
		Exponential	**0.117**	**0.003**	**26.935**	**25.522**	**1.046**	**28.513**
		Gaussian	0.130	0.004	27.200	25.906	0.972	28.657
	Mixed	Linear	0.118	0.004	28.345	27.022	1.047	29.837
		Spherical	**0.101**	**0.002**	**28.265**	**26.826**	**1.037**	**29.843**
		Exponential	0.206	0.007	28.315	26.837	1.053	30.058
		Gaussian	0.175	0.006	28.284	26.674	1.058	30.134
2009	All	Linear	0.306	0.010	28.629	26.295	1.036	31.314
		Spherical	**0.025**	**0.001**	**28.620**	**26.189**	**1.024**	**31.101**
		Exponential	0.346	0.011	28.677	26.554	1.026	31.183
		Gaussian	0.409	0.012	28.758	26.793	0.998	31.146
	Broadleaved	Linear	0.291	0.007	25.232	23.610	1.014	27.166

		Spherical	**0.101**	**0.001**	**24.768**	**23.275**	**1.001**	**26.363**
		Exponential	0.251	0.006	25.148	23.571	1.013	26.996
		Gaussian	0.204	0.005	25.139	23.731	1.009	26.765
	Coniferous	Linear	0.071	0.002	26.976	26.369	0.949	27.707
		Spherical	0.029	0.001	26.742	26.176	0.952	27.386
		Exponential	**0.027**	**0.001**	**25.914**	**24.625**	**0.907**	**27.325**
		Gaussian	0.062	0.003	26.984	26.256	0.952	27.825
	Mixed	Linear	0.324	0.011	27.420	26.573	1.020	28.622
		Spherical	**0.124**	**0.005**	**27.256**	**26.425**	**1.012**	**28.229**
		Exponential	0.181	0.007	27.531	26.591	1.016	28.675
		Gaussian	0.242	0.005	27.836	26.625	1.015	29.309
2014	All	Linear	0.173	0.005	30.539	28.381	1.020	32.896
		Spherical	**0.162**	**0.005**	**30.385**	**28.167**	**1.058**	**32.828**
		Exponential	0.188	0.006	30.769	28.601	1.011	33.142
		Gaussian	0.211	0.006	30.619	28.621	1.099	32.934
	Broadleaved	Linear	0.326	0.008	28.669	26.846	0.946	30.880
		Spherical	0.297	0.007	28.611	26.835	0.946	30.745
		Exponential	**0.034**	**0.001**	**28.115**	**26.549**	**0.902**	**29.814**
		Gaussian	0.335	0.008	28.687	26.848	0.947	30.922
	Coniferous	Linear	0.091	0.006	29.179	26.900	0.965	31.590
		Spherical	0.068	0.005	28.806	26.088	0.967	31.630
		Exponential	**0.057**	**0.004**	**28.569**	**26.062**	**0.904**	**31.232**
		Gaussian	0.177	0.007	29.156	26.887	0.964	31.644
	Mixed	Linear	0.129	0.004	29.774	27.903	1.045	31.823
		Spherical	0.128	0.004	29.797	27.991	1.047	31.781
		Exponential	**0.104**	**0.002**	**29.685**	**27.865**	**1.032**	**31.643**
		Gaussian	0.119	0.004	29.908	28.043	1.049	31.945

Note: Results of all forest plots with no classification of forest type are abbreviated as "All". The bold type in the table is the best model and parameter. ME, Mean Error; MSE, Mean Standardized Error; RMSSE, Root-mean-Square Standardized Error; ASE, Average Standard Error; TE, Total Error; RMSE, Root Mean Square Error.

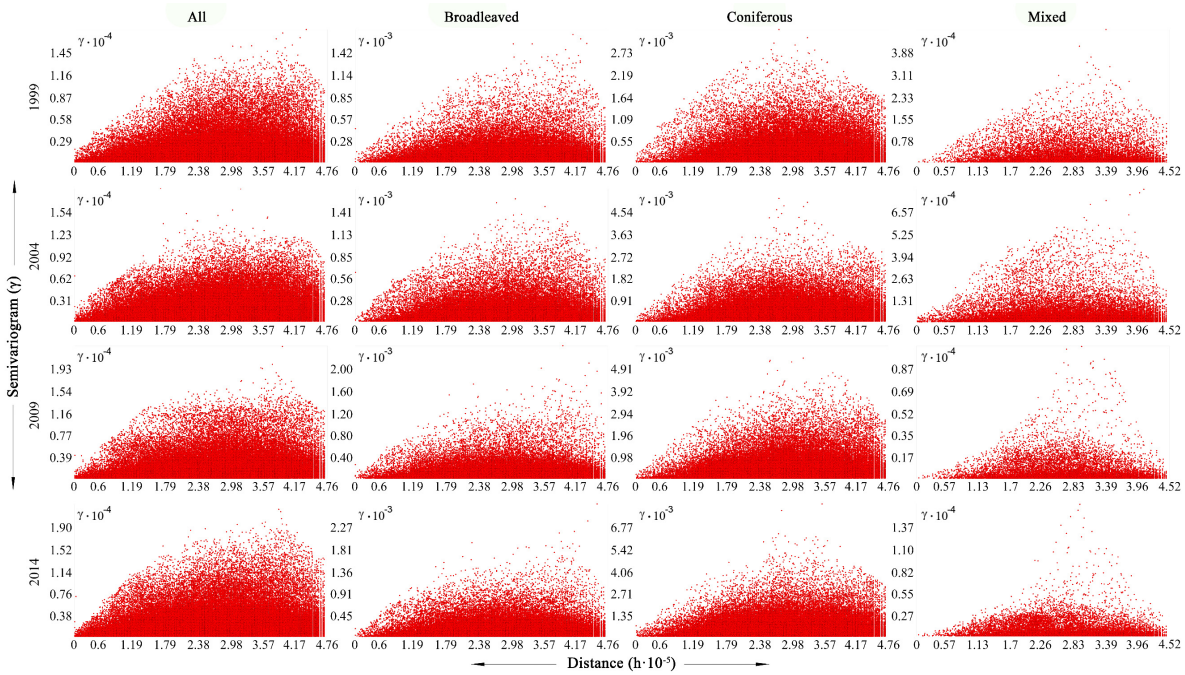

Figure S1. The Semivariogram cloud for different forest types of XGBoost models. All: Results of all forest plots with no classification of forest type; Combined: combined with their respective results of broadleaved, coniferous, and mixed forest.

Table S6. Correlation coefficient between the climate predictor variables and AGB.

Variable Name	AGB	Bio01	Bio02	Bio03	Bio04	Bio05	Bio06	Bio07	Bio08	Bio09	Bio10	Bio11	Bio12	Bio13	Bio14	Bio15	Bio16	Bio17	Bio18
Bio01	-0.50	1																	
Bio02	-0.42	0.16	1																
Bio03	-0.26	-0.30	0.47	1															
Bio04	-0.29	0.49	0.47	-0.73	1														
Bio05	-0.44	0.87	0.33	-0.64	0.83	1													
Bio06	-0.62	0.86	-0.34	-0.16	0.27	0.66	1												
Bio07	-0.12	0.31	0.53	-0.90	0.83	0.69	-0.15	1											
Bio08	-0.47	0.98	0.17	-0.32	0.56	0.86	0.84	0.33	1										
Bio09	-0.47	0.95	-0.20	-0.22	0.27	0.72	0.91	0.14	0.93	1									
Bio10	-0.49	0.95	0.25	-0.51	0.72	0.96	0.73	0.54	0.93	0.82	1								
Bio11	-0.46	0.94	0.11	-0.13	0.24	0.72	0.83	0.19	0.88	0.92	0.85	1							
Bio12	0.23	-0.62	-0.41	0.65	-0.67	-0.79	-0.27	-0.73	-0.60	-0.41	-0.75	-0.58	1						
Bio13	0.41	-0.48	-0.42	0.40	-0.77	-0.76	-0.48	-0.51	-0.70	-0.49	-0.74	-0.43	0.64	1					
Bio14	0.18	0.17	0.15	-0.73	0.57	0.36	-0.28	0.69	0.17	-0.12	0.23	-0.19	-0.56	-0.31	1				
Bio15	-0.14	-0.24	-0.29	0.74	-0.77	-0.53	0.10	-0.76	-0.34	-0.10	-0.42	0.11	0.64	0.54	-0.88	1			
Bio16	0.29	-0.57	-0.60	0.52	-0.79	-0.78	-0.30	-0.70	-0.57	-0.32	-0.75	-0.44	0.86	0.81	-0.42	0.65	1		
Bio17	0.29	-0.21	-0.42	-0.56	0.39	0.13	-0.30	0.44	-0.17	-0.24	-0.10	-0.34	-0.22	-0.16	0.76	-0.72	-0.18	1	
Bio18	-0.16	-0.43	-0.16	0.78	-0.62	-0.62	-0.14	-0.73	-0.46	-0.29	-0.54	-0.31	0.85	0.43	-0.85	0.81	0.56	-0.54	1
Bio19	0.29	-0.14	-0.28	-0.50	0.42	0.16	-0.21	0.35	0.15	-0.16	0.12	-0.30	-0.17	-0.29	0.69	-0.68	-0.10	0.46	-0.46

Note: All variables had a significance level of 0.01 with other variables.

References

1. Kaufman, Y.J.; Tanre, D. Atmospherically resistant vegetation index (ARVI) for EOS-MODIS. *IEEE Trans. Geosci. Remote Sens.* **1992**, *30*, 261–270.
2. Tucker, C.J. Red and photographic infrared linear combinations for monitoring vegetation. *Remote Sens. Environ.* **1979**, *8*, 127–150.
3. Huete, A.; Didan, K.; Miura, T.; Rodriguez, E..; Gao, X.; Ferreira, L.. Overview of the radiometric and biophysical performance of the MODIS vegetation indices. *Remote Sens. Environ.* **2002**, *83*, 195–213.
4. Gitelson, A.A.; Kaufman, Y.J.; Merzlyak, M.N. Use of a green channel in remote sensing of global vegetation from EOS-MODIS. *Remote Sens. Environ.* **1996**, *58*, 289–298.
5. Sripada, R.P.; Heiniger, R.W.; White, J.G.; Meijer, A.D. Aerial Color Infrared Photography for Determining Early In-Season Nitrogen Requirements in Corn. *Agron. J.* **2006**, *98*, 968.
6. Gitelson, A.A.; Merzlyak, M.N. Remote sensing of chlorophyll concentration in higher plant leaves. *Adv. Sp. Res.* **1998**, *22*, 689–692.
7. Kauth, R.J. Tasselled Cap - a Graphic Description of the Spectral-Temporal Development of Agricultural Crops As Seen By Landsat. **1976**, 41–51.
8. Crippen, R. Calculating the vegetation index faster. *Remote Sens. Environ.* **1990**, *34*, 71–73.
9. Boegh, E.; Soegaard, H.; Broge, N.; Hasager, C.B.; Jensen, N.O.; Schelde, K.; Thomsen, A. Airborne multispectral data for quantifying leaf area index, nitrogen concentration, and photosynthetic efficiency in agriculture. *Remote Sens. Environ.* **2002**, *81*, 179–193.
10. Yang, Z.; Willis, P.; Mueller, R. Impact of Band-Ratio Enhanced AWIFS Image to Crop Classification Accuracy. *J. Am. Chem. Soc.* **2014**, *136*, 16132–16135.
11. Chen, J.M. Evaluation of Vegetation Indices and a Modified Simple Ratio for Boreal Applications. *Can. J. Remote Sens.* **1996**, *22*, 229–242.
12. Goel, N.S.; Qin, W. Influences of canopy architecture on relationships between various vegetation indices and LAI and FPAR: a computer simulation. *Remote Sens. Rev.* **1994**, *10*, 309–347.
13. Rouse, W.; Haas, H.; Deering, W. Monitoring Vegetation Systems in the Great Plains With ERTS. In Proceedings of the Third Earth Resources Technology Satellite-1 Symposium; NASA: Washington, USA, 1973; pp. 309–317.
14. Rondeaux, G.; Steven, M.; Baret, F. Optimization of soil-adjusted vegetation indices. *Remote Sens. Environ.* **1996**, *55*, 95–107.
15. Birth, G.S.; McVey, G.R. Measuring the Color of Growing Turf with a Reflectance Spectrophotometer1. *Agron. J.* **1968**, *60*, 640.
16. Huete, A.. A soil-adjusted vegetation index (SAVI). *Remote Sens. Environ.* **1988**, *25*, 295–309.
17. Bannari, A.; Asalhi, H.; Teillet, P.M. Transformed difference vegetation index (TDVI) for vegetation cover mapping. In Proceedings of the IEEE International Geoscience and Remote Sensing Symposium; IEEE, 2002; Vol. 5, pp. 3053–3055.
18. Gitelson, A.A.; Stark, R.; Grits, U.; Rundquist, D.; Kaufman, Y.; Derry, D. Vegetation and soil lines in visible spectral space: A concept and technique for remote estimation of vegetation fraction. *Int. J. Remote Sens.* **2002**, *23*, 2537–2562.
19. Robertson G P. GS+: GeoStatistics for the Environmental Sciences[M]. Plainwell, USA: Gamma Design Software, **2008**.
20. ESRI. ArcGIS Help 10.2: Cross Validation (Geostatisical Analyst)[EB/OL]. http://resources.arcgis.com/en/help/main/10.2/#/na/00300000000z000000/, 2014-03-07.