An approach to develop new Leaf Area Index (LAI) and soil moisture index using the red-NIR spectral space

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Outlines

- **Remote Sensing**
  - *Introduction to Remote Sensing*
  - *Remote sensing sensors*

- **Red-NIR Spectral Space**
  - *Soil line*
  - *Red-NIR triangle space*

- **LAI and SM Estimation**
  - *Study areas and data*
  - *Method*
  - *Proposed LAI*
  - *Proposed SM index*

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Optical Remote Sensing

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Remote Sensing

- Remote sensing is defined as the measurement of object properties on the earth's surface using data acquired from aircrafts and satellites.

- Remote sensing sensors measure electromagnetic radiation reflected, emitted, or backscattered from the terrain.

- **Why remote sensing**

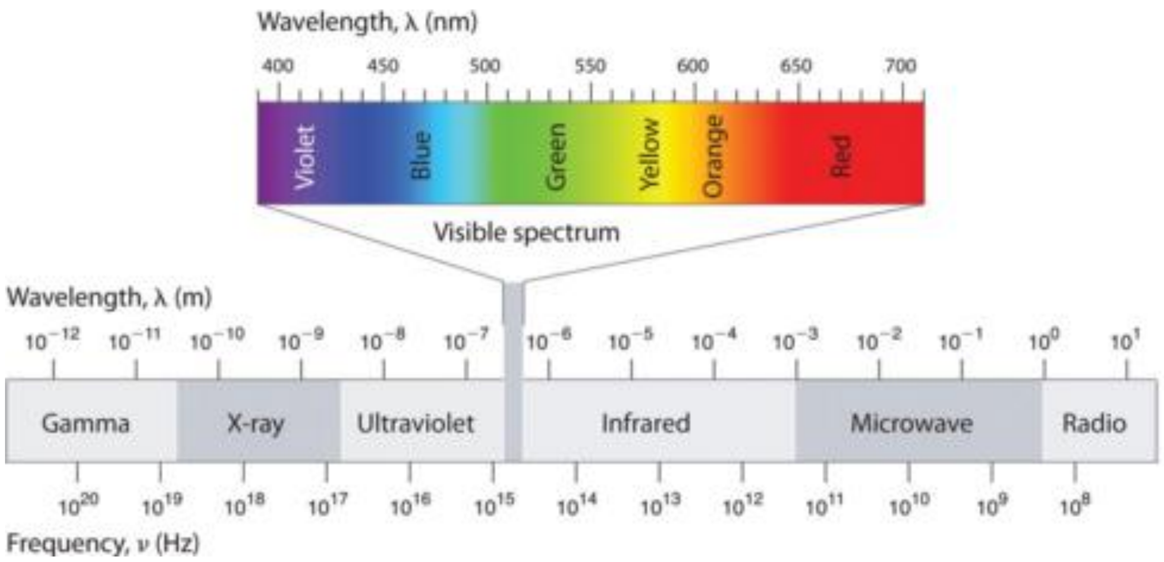
  - Cost effective

  - Repitivity

  - Accessibility

  - Large coverage

  - Time conservation



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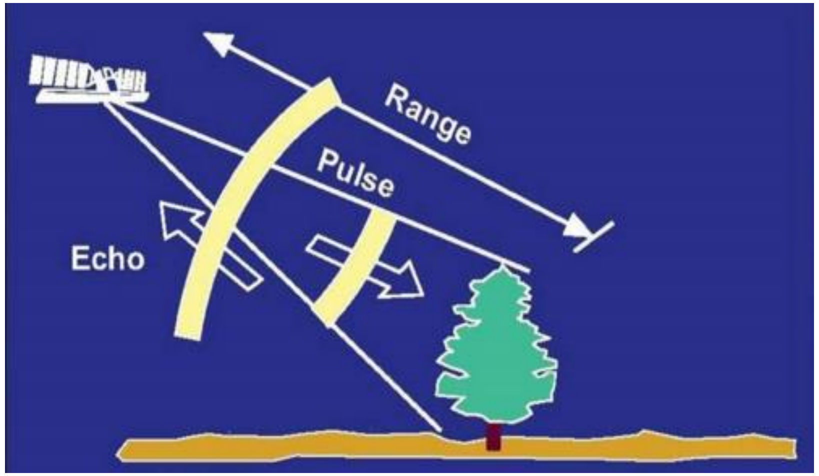
Remote Sensing Sensors

- **Active (e.g. RADAR)**

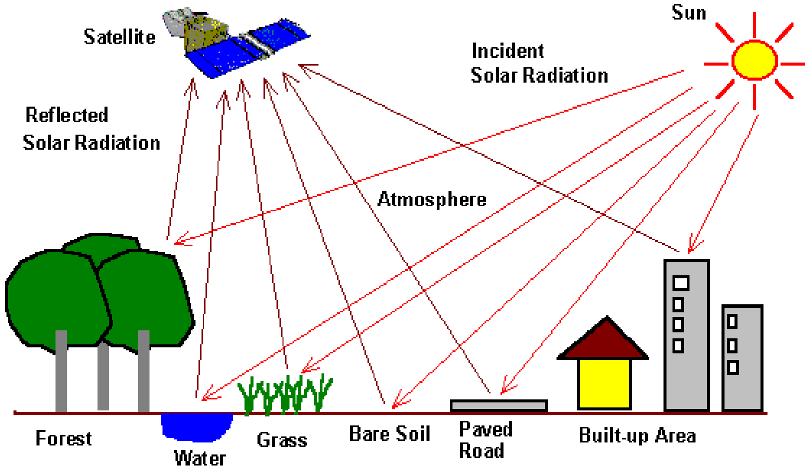
  - has its own source of illumination

  - measures backscattered energy from the targets



- **Passive (e.g. Optical)**

  - Optical sensors measure reflected sunlight in the visible, near infrared, and shortwave infrared bands, all are emitted from the sun



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Red-NIR Spectral Space

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Soil Line

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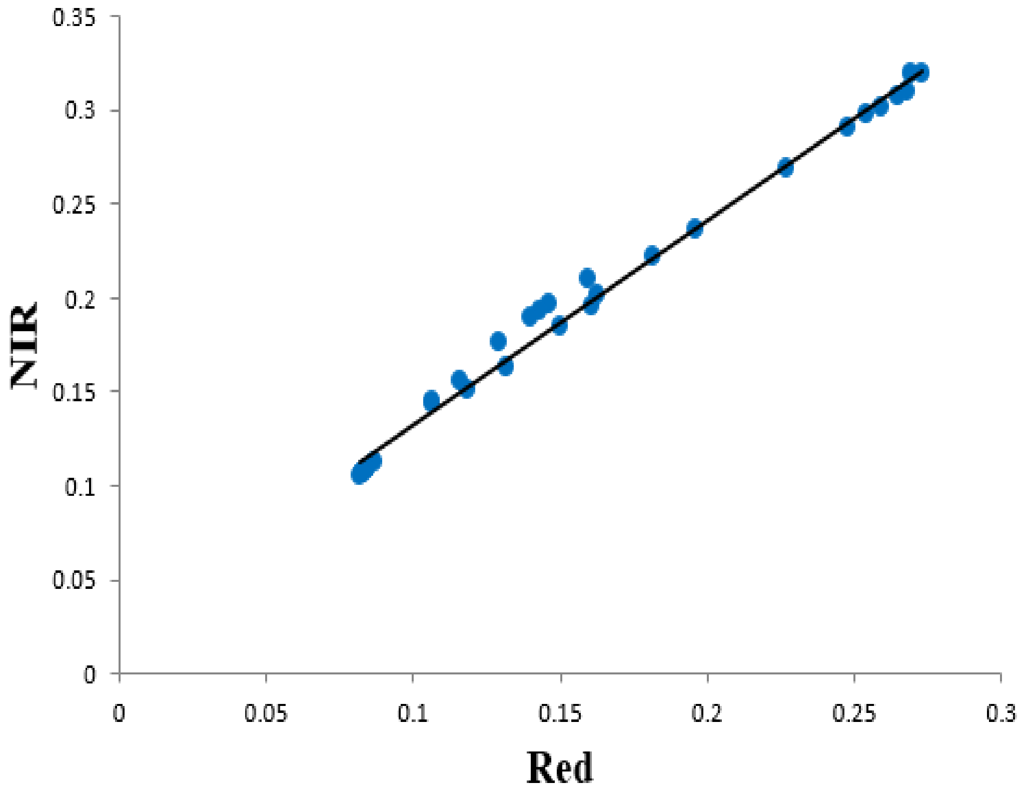
Soil Line: $\boldsymbol{\rho_{NIR} = \gamma\rho_{red} + b}$

Problem:

We cannot define a global soil line, because the length, slope, and intercept of the soil line equation are functions of some parameters, including:

- Soil texture (percent of sand, silt, and clay)
- Soil moisture (dry, moist, saturated)
- Organic matter contents
- Iron oxide content
- Surface roughness



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Soil Line

Solution:

Use the average of five different soil lines.

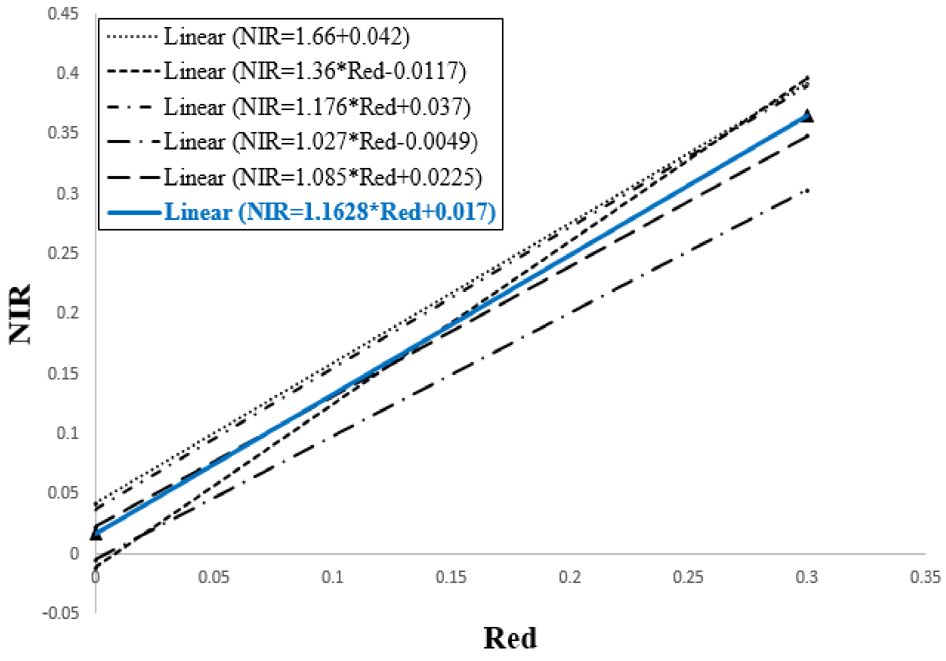

Table 5. Information of five soil lines suggested by different workers.

Reference	Soil type	SL equation	Mean SL
Huete, Post, and Jackson (1984)	Gravel, sand, silt, loam	NIR = 1.166*Red + 0.042	
Galvão and Vitorello (1998)	Silt, clay, sand	NIR = 1.368*Red – 0.0117	
Baret, Jacquemoud, and Hanocq (1993)	Silica sand, peat, clay, pebble	NIR = 1.176*Red + 0.037	NIR = 1.1628*Red + 0.017
Yoshioka et al. (2010)	Silt, clay, sand	NIR = 1.027*Red – 0.0049	
Mobasheri and Bidkhan (2013)	Inorganic clay	NIR = 1.0849*Red + 0.0225	

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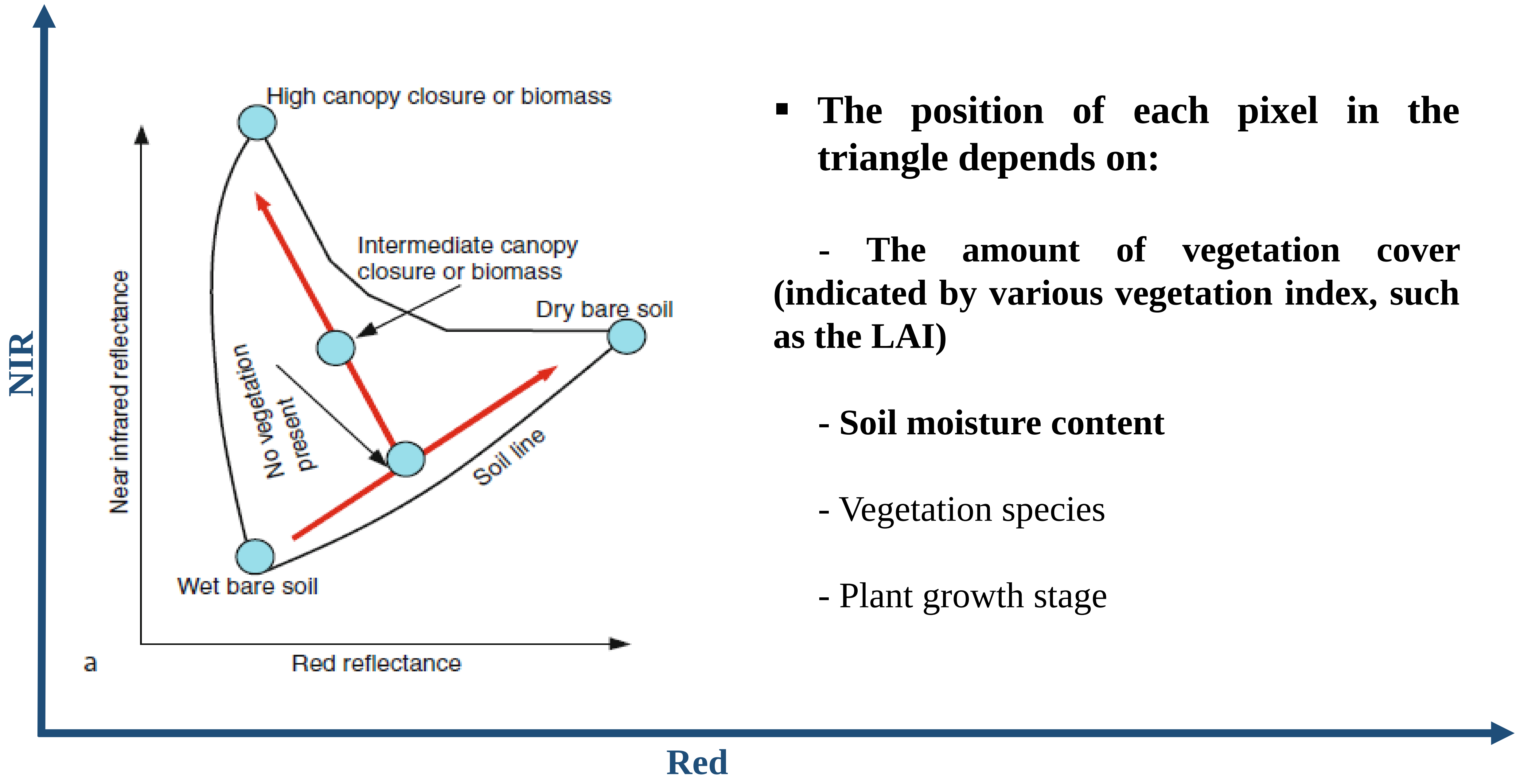
Red-NIR Triangle Space



- **The position of each pixel in the triangle depends on:**

  - The amount of vegetation cover (indicated by various vegetation index, such as the LAI)

  - Soil moisture content

  - Vegetation species

  - Plant growth stage

Red-NIR Triangle Space

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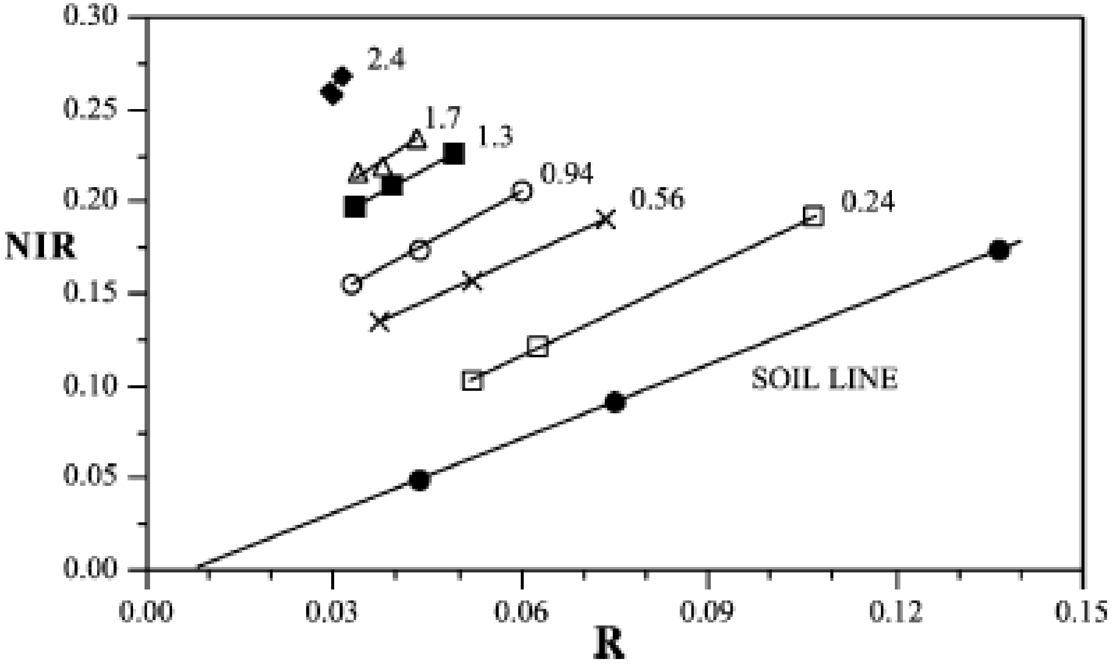
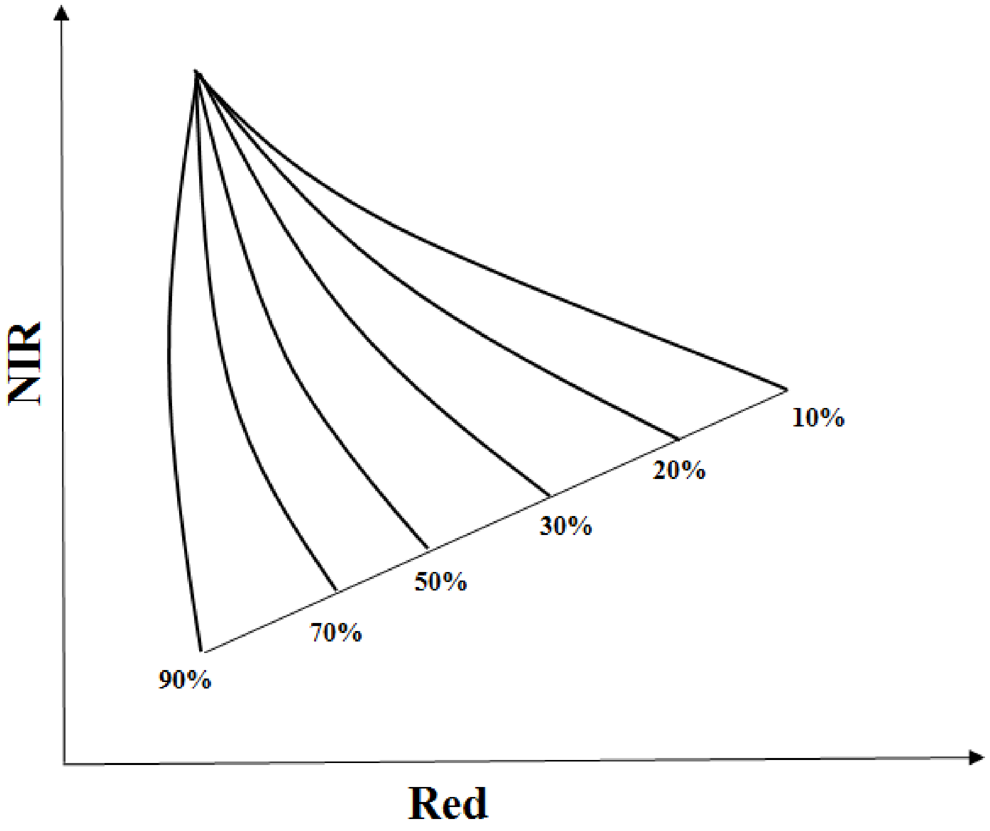


The amount of vegetation cover (LAI)



Soil moisture content

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LAI and SM Estimation

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Study Area and Data for LAI study

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Study area:

5 sites of BigFoot project

Field data:

BigFoot LAI data (539 data)

Satellite data:

Landsat ETM+ (14 images)

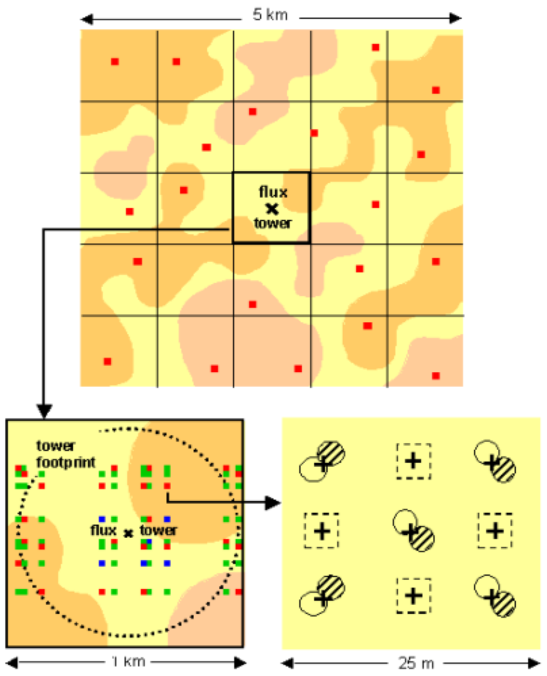
Geometric correction:

DOQs (1m pixel size)

Radiometric correction:

Fmask algorithm

ENVI/FLAASH



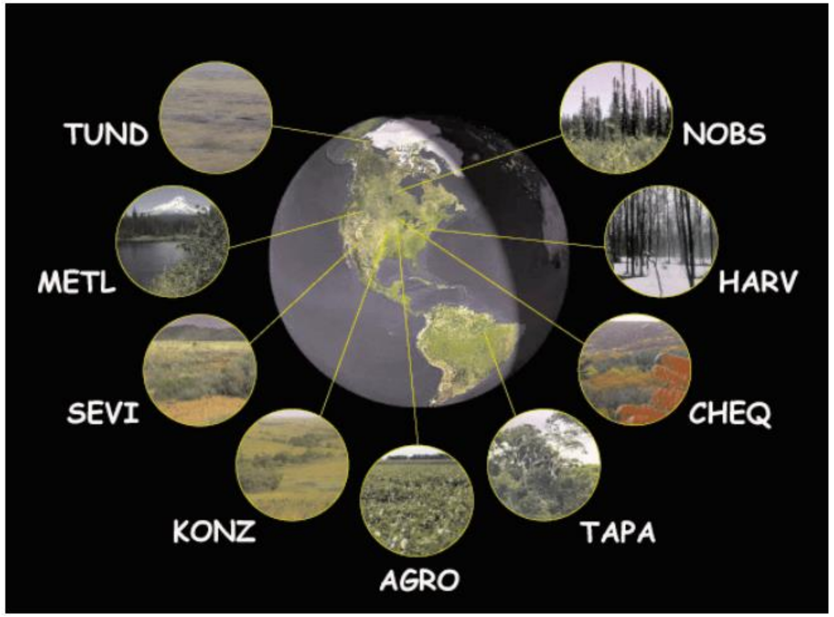


Table 1. The information about five sites of BigFoot campaign (study area).

Site name	Latitude	Longitude	Location	Vegetation type
AGRO	40.00662	−88.29103	Champaign, Illinois	Corn, soybean, fallow
HARV	42.53825	−72.17138	Peter sham, Massachusetts	Eastern hardwood, eastern hemlock, red pine, old field meadow
KONZ	39.08228	−96.56025	Manhattan, Central Kansas	Tall grass Prairie, Short grass Prairie, Shrub community
SEVI	34.3602	−106.7003	Belen, NM, USA	Black gramma, blue gramma
TUND	71.2808	−156.6122	Barrow, AK, USA	Arctic tundra

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Study Area and Data for LAI study

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Study area:

Mississippi and Birmingham (25 sites)

Field data:

SCAN volumetric SM data at the depths of 5, 10, 20, 50, 100 cm (171 data)

Satellite data:

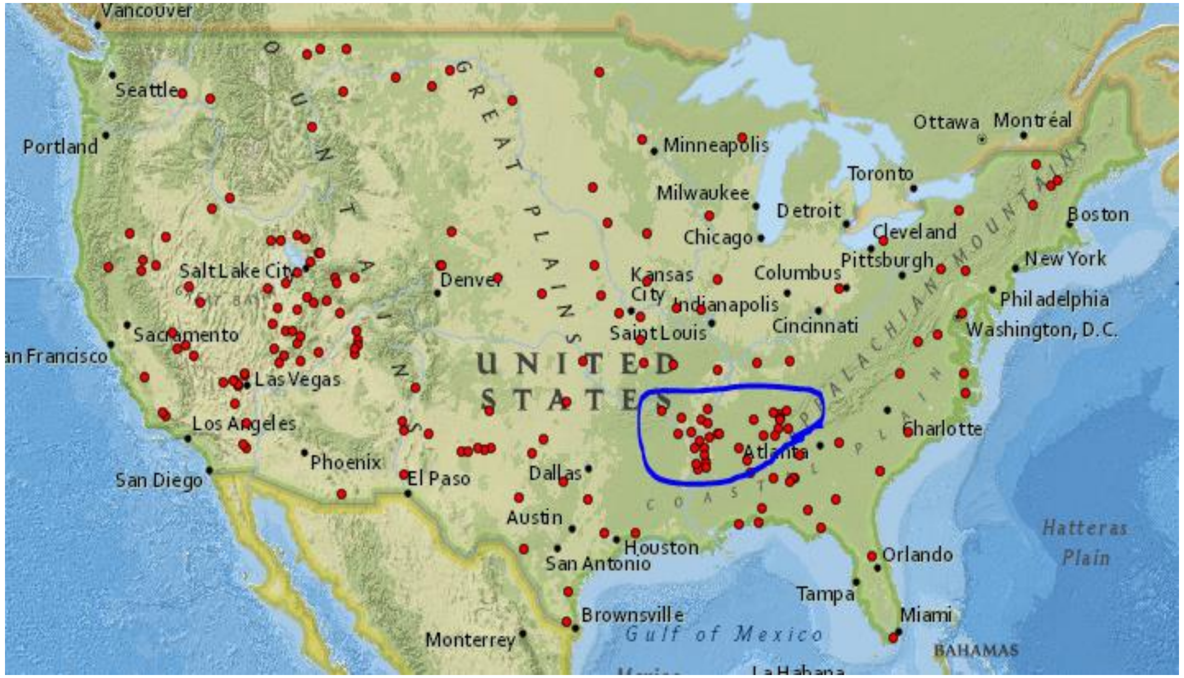
Landsat-8 (Level 1T) (32 images)

Geometric correction:

Not performed (12 meters circular error)

Radiometric correction:

ENVI/FLAASH



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Method

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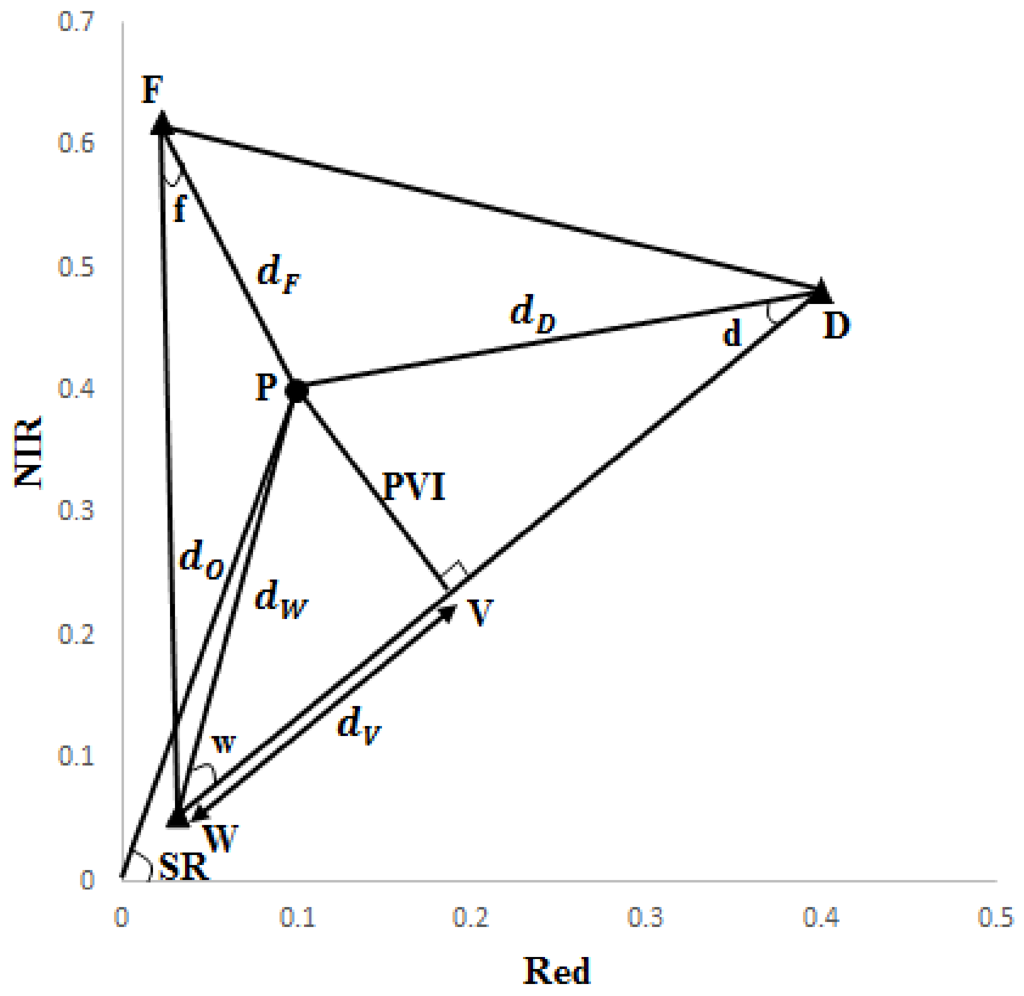
Basis:

- There are many parameters in this triangle, which could be useful for estimation of LAI or soil moisture.

- we can use a combination of these parameters instead of some well-known and simple indices, such as: PVI and PDI.

Question:

Which one of these ten parameters could be useful for LAI and SM estimation?



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Method

Answer:

1) Those parameters that produce isolines or isocurves which are parallel or almost parallel to the soil line are useful for **LAI** estimation.

Correlation between each of the ten parameters used in this study for LAI estimation and in situ LAI data.

parameter	d_D	d_V	d_O	d_W	f	$\boldsymbol{d_F}$	**d**	**w**	**PVI**	**SR**
Correlation coefficient (R)	0.17	0.08	0.22	0.12	0.16	**0.5**	**0.44**	**0.3**	**0.48**	**0.39**

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2) Those parameters that produce isolines or isocurves which are vertical or almost vertical to the soil line could be useful for **SM** estimation.

Correlation between each of the ten parameters used in this study for soil moisture modeling and in-situ soil moisture data.

parameter	$\boldsymbol{d_D}$	$\boldsymbol{d_V}$	$\boldsymbol{d_O}$	$\boldsymbol{d_W}$	**f**	d_F	d	w	PVI	SR
Correlation coefficient (R)	**0.43**	**0.40**	**0.38**	**0.37**	**0.36**	0.28	0.19	0.15	0.11	0.04

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Method

The linear regression equations obtained from different combinations of the five parameters:

$$LAI = \alpha_1 \times SR + \alpha_2 \times PVI + \alpha_3 \times d_F - \alpha_4 \times d - \alpha_5 \times \mathrm{w}$$

$$SM = \beta_1 \times d_D + \beta_2 \times d_V + \beta_3 \times d_O - \beta_4 \times d_W - \beta_5 \times \mathrm{f}$$

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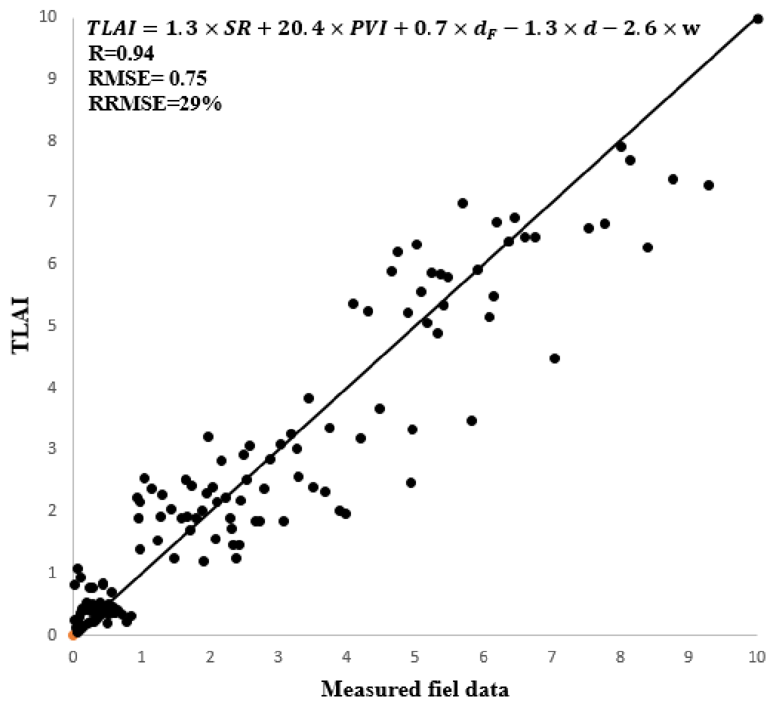
TLAI

- 404 field data for modeling (train)

- 135 field data for model evaluation (test)

- The model for estimation of the LAI was named the **Triangle Leaf Area Index (TLAI)**



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Limitation of TLAI

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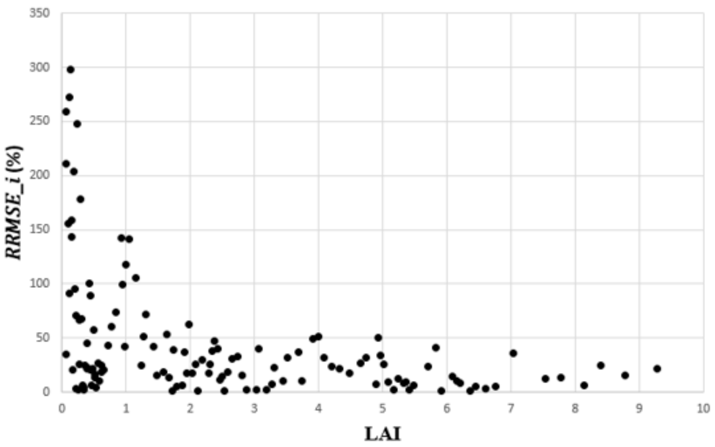
Problem:

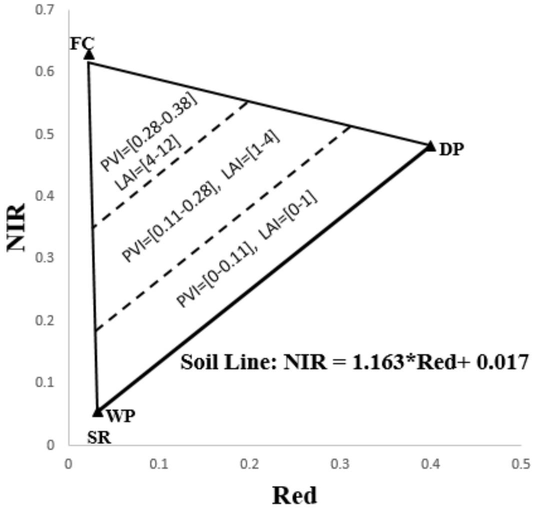
- The RRMSE is higher for smaller LAI values
- TLAI is less accurate for LAI values less than one (LAI < 1) in comparison with LAI > 1

Solution:

- Classify the triangle to different regions and assign a particular index for each region
- The new index was named the **Modified TLAI (MTLAI)**



Percentage of relative RMSE for the test data.



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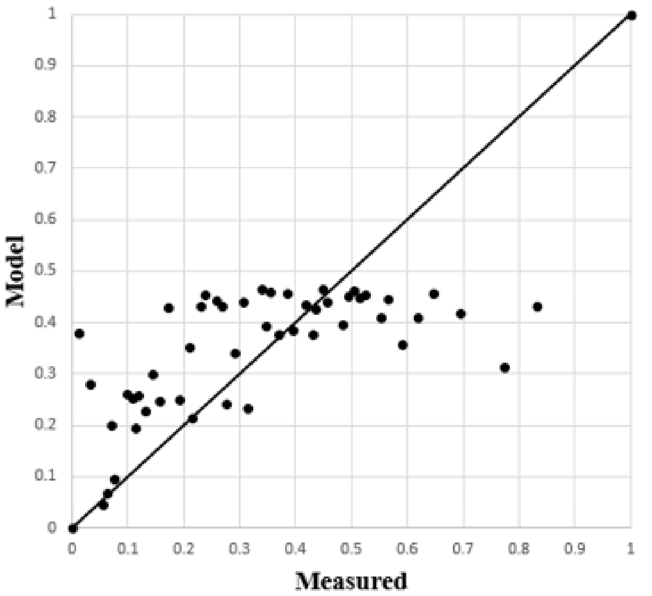
MTLAI



Region (1)

LAI=[0-1]

PVI=[0-0.11]

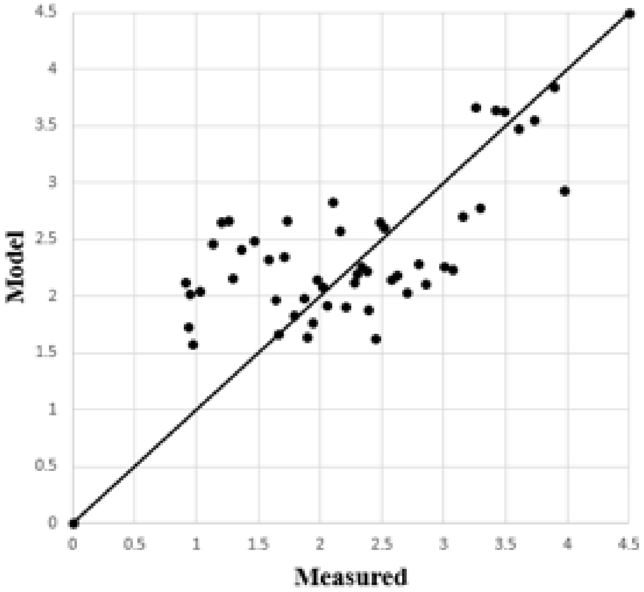
$$LAI = -19.64 \times \mathrm{PVI} - 33.5 \times d_F + 34.51 \times d_V + 7.94 \times \mathrm{f} + 0.25 \times \mathrm{w}$$

RMSE=0.353

RRMSE=105.59%

R=0.633

The results of 5P-LAI3:
RMSE=0.369, RRMSE=110.45%, R=0.565



Region (2)

LAI=[1-4]

PVI=[0.11-0.28]

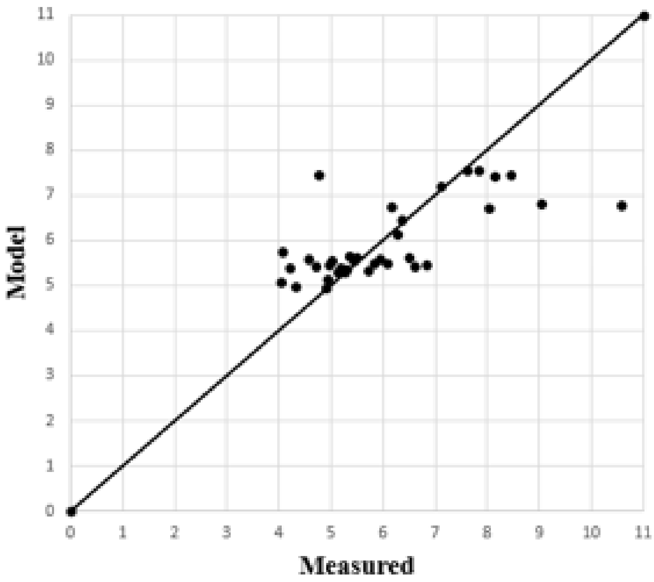
$$LAI = -11.43 \times d_F + 14.9 \times d_D$$

RMSE=0.736

RRMSE=32.97%

R=0.629

The results of 5P-LAI3:
RMSE=0.749, RRMSE=33.56%, R=0.623



Region (3)

LAI=[4-12]

PVI=[0.28-0.38]

$$LAI = -22.57 \times PVI + 24.91 \times d_D - 49.13 \times d_W + 27.96 \times \mathrm{d}$$

RMSE=0.872

RRMSE=14.45%

R=0.696

The results of 5P-LAI3:
RMSE=0.916, RRMSE=15.18%, R=0.629

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MTLAI

If PVI=[0-0.11] then:

$$LAI = -19.64 \times PVI - 33.5 \times d_A + 34.51 \times d_H + 7.94 \times \alpha + 0.25 \times \gamma$$

Else if PVI=[0.11-0.28] then:

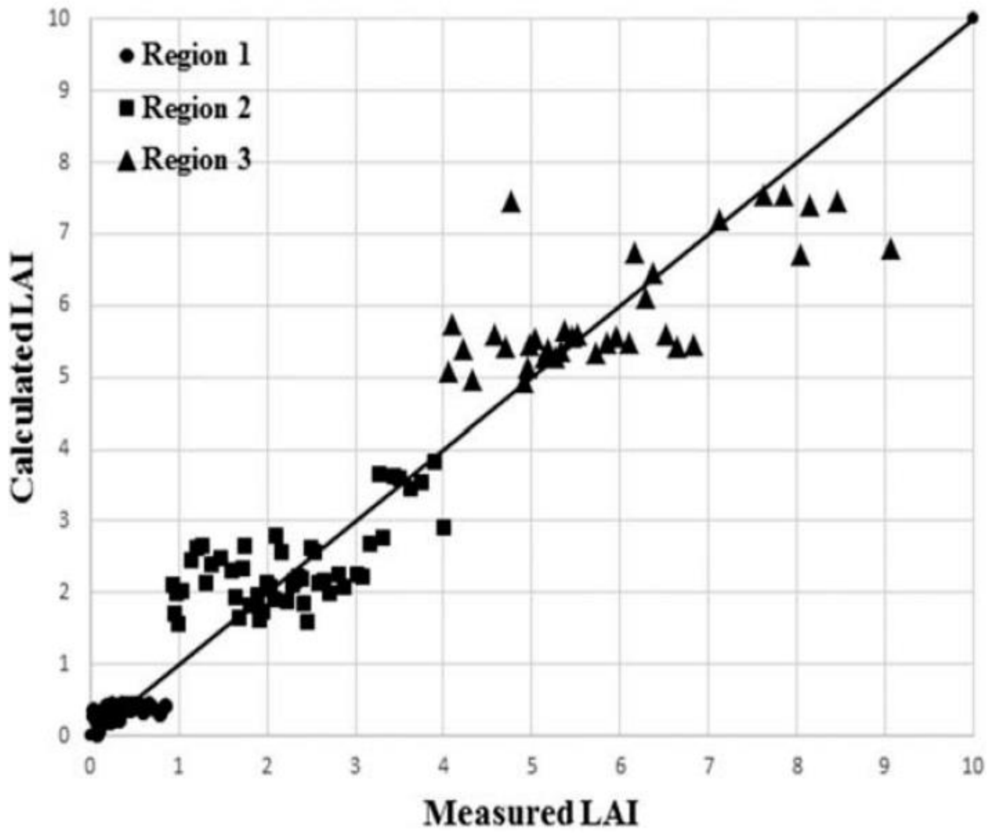
$$LAI = -11.43 \times d_A + 14.9 \times d_B$$

Else if PVI>0.28 then:

$$LAI = -22.57 \times PVI + 24.91 \times d_B - 49.13 \times d_C + 27.96 \times \alpha$$

RMSE=0.66, R= 0.96

The overall RMSE is decreased from 0.75 to 0.66, R increased from 0.94 to 0.96, and RRMSE decreased from 29.95% to 25.98% compared to the TLAI.



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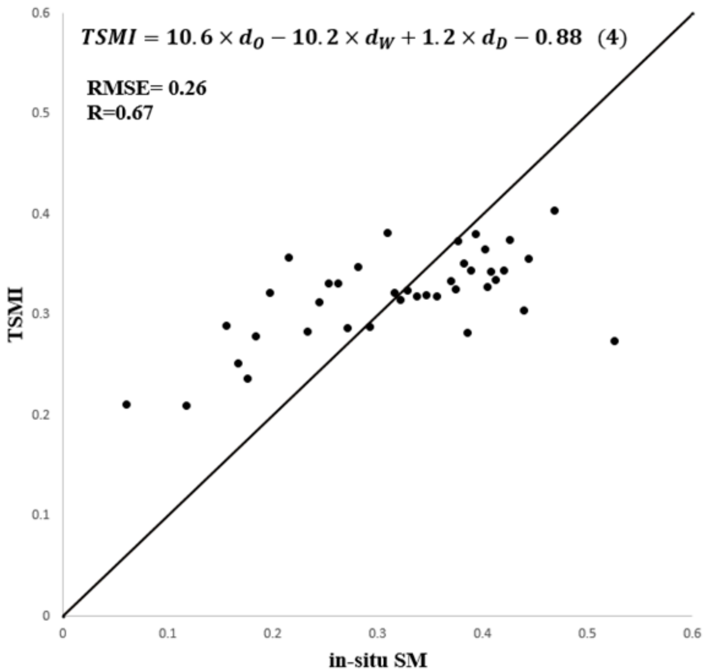
TSMI

- 129 field data for modeling (train)

- 42 field data for model evaluation (test)

- The model for estimation of SM was named the **Triangle Soil Moisture Index (TSMI)**



Field soil moisture measured data versus TSMI predicted values.

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Limitation of TSMI

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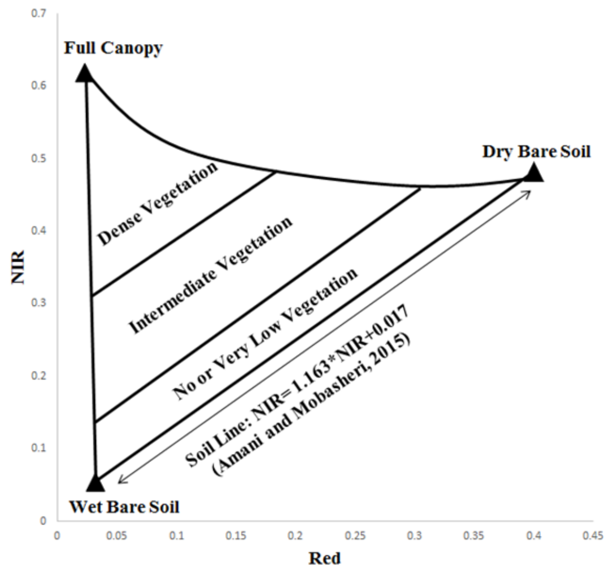
Problem:

- TSMI does not consider vegetation interference in SM assessment

- May only give accurate results when there is no or low vegetation cover in the pixel

- This can be found in the regions near the soil line in NIR-red spectral space.



Distribution of reflectance values in NIR-red triangle space.

Solution:

- The fraction of soil cover (F_s) in each pixel should be added to the TSMI as a modification parameter

- This new index was named as **Modified TSMI (MTSMI)**

$$\begin{cases} R_{red} = F_s . R^s_{red} + F_v . R^v_{red} \\ R_{NIR} = F_s . R^s_{NIR} + F_v . R^v_{NIR} \\ F_s + F_v = 1 \text{ and } F_s \geq 0, F_v \geq 0 \end{cases}$$

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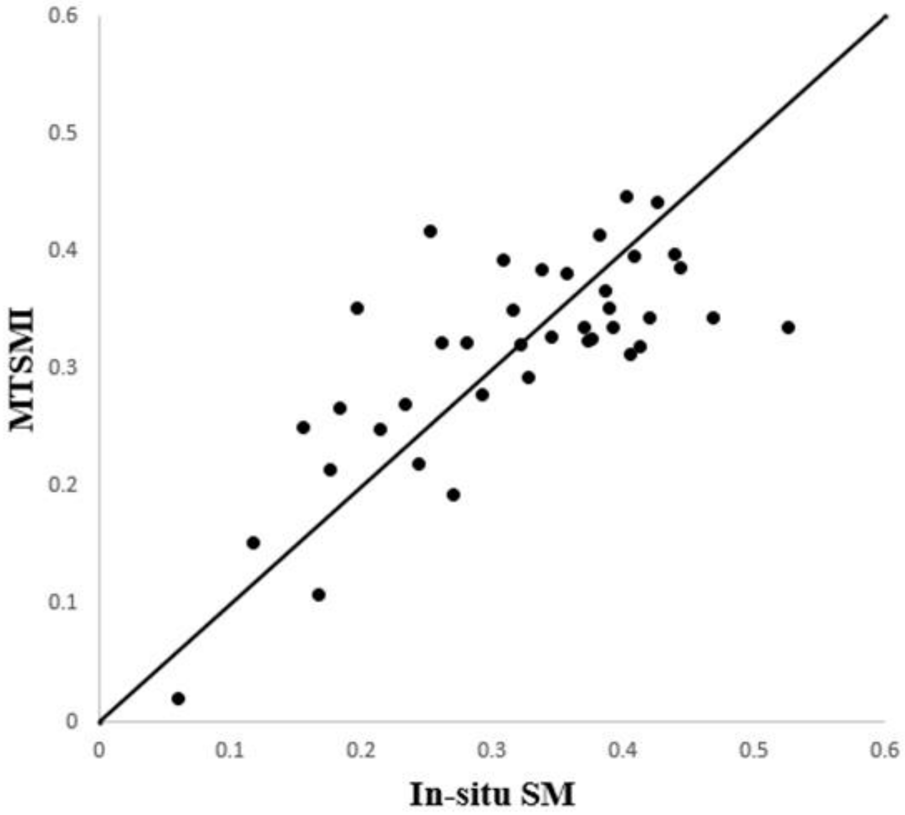
MTSMI

$$MTSMI = 17.8 \times d_O - 17.2 \times d_W + 0.96 \times d_D - 0.97 \times F_S - 1$$

RMSE= 0.24 , R= 0.74

The RMSE is decreased from 0.26 to 0.24, and R increased from 0.67 to 0.74, compared to the TSMI.



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TSMI and MTSMI in Different Depths

Correlation between TSMI, MTSMI predicted soil moisture and those measured at five different depths.

Index	Statistical parameters	5cm	10cm	20cm	50cm	100cm
TSMI	RMSE	0.26	0.3	0.29	0.34	0.38
	R	0.67	0.62	0.57	0.5	0.5
MTSMI	RMSE	0.24	0.27	0.27	0.32	0.36
	R	0.74	0.61	0.65	0.59	0.6

- Both TSMI and MTSMI concluded better accuracy at 5 cm depth.

- As we move to the lower layers, the correlation almost decreases gradually.

- MTSMI almost had better accuracy compared to TSMI at all depths.

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Thanks

Question?

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