Kathmandu, Nepal 14–16 November
REGIONAL CONFERENCE 2024
Climate Responsive Land Governance and Disaster Resilience: Safeguarding Land Rights

YIELD ESTIMATION OF RICE USING MULTISPECTRAL IMAGERY FROM UAV

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Introduction

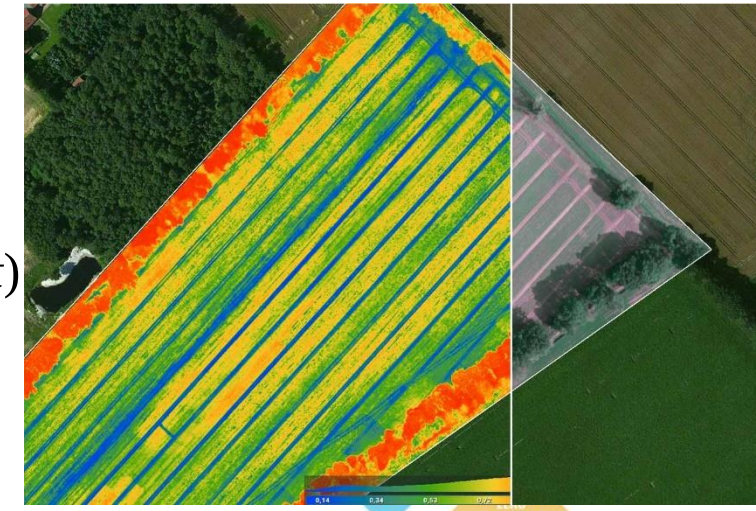
- Agriculture's vital role: Food security, global sustenance.

- **SDG 2. End Hunger (Zero Hunger)** (*THE 17 GOALS | Sustainable Development*)

Promote sustainable agriculture, support small scale farmers.

- **SDG 12. Responsible Consumption and Production**

Sustainable consumption, production and practices, using resources efficiently.



(Internet of Fields: Drones & Variable Rate Application | Pix4D)

- Drone technology revolutionizes: Multispectral sensors optimize data.
- Nepal's agriculture: 66% population; GDP 21.06% (Nepal - *GDP Distribution across Economic Sectors* 2022 | Statista)

Problem Statement

- Nepal faces challenges in ensuring food security with its traditional agricultural practices.
- Conventional rice yield estimation methods lack precision and are time-consuming.
- Inefficient resource allocation hampers productivity and consumer health.

(*Next Farmer*, n.d.)

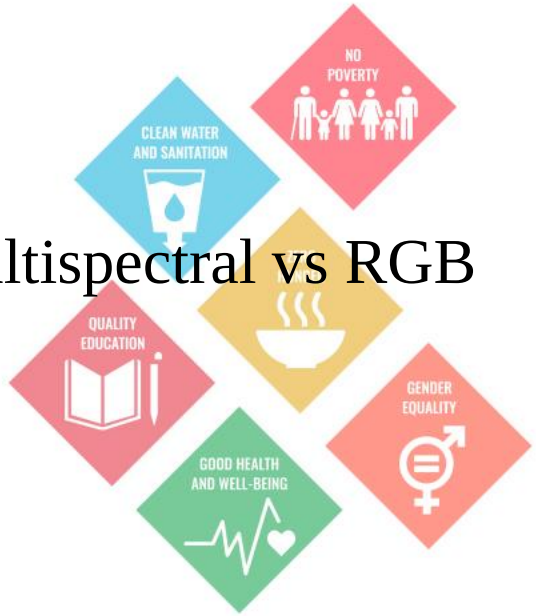
Urgency:

- Nepal's agriculture: a dual challenge of sustainability and productivity.

Objectives:

- To estimate rice yield using regression model based on plant characteristics obtained through UAV-derived vegetation indices and supplementary data like plant height, plant age and various used fertilizers.

- To compare strength of correlation of vegetation indices derived from Multispectral vs RGB sensor.

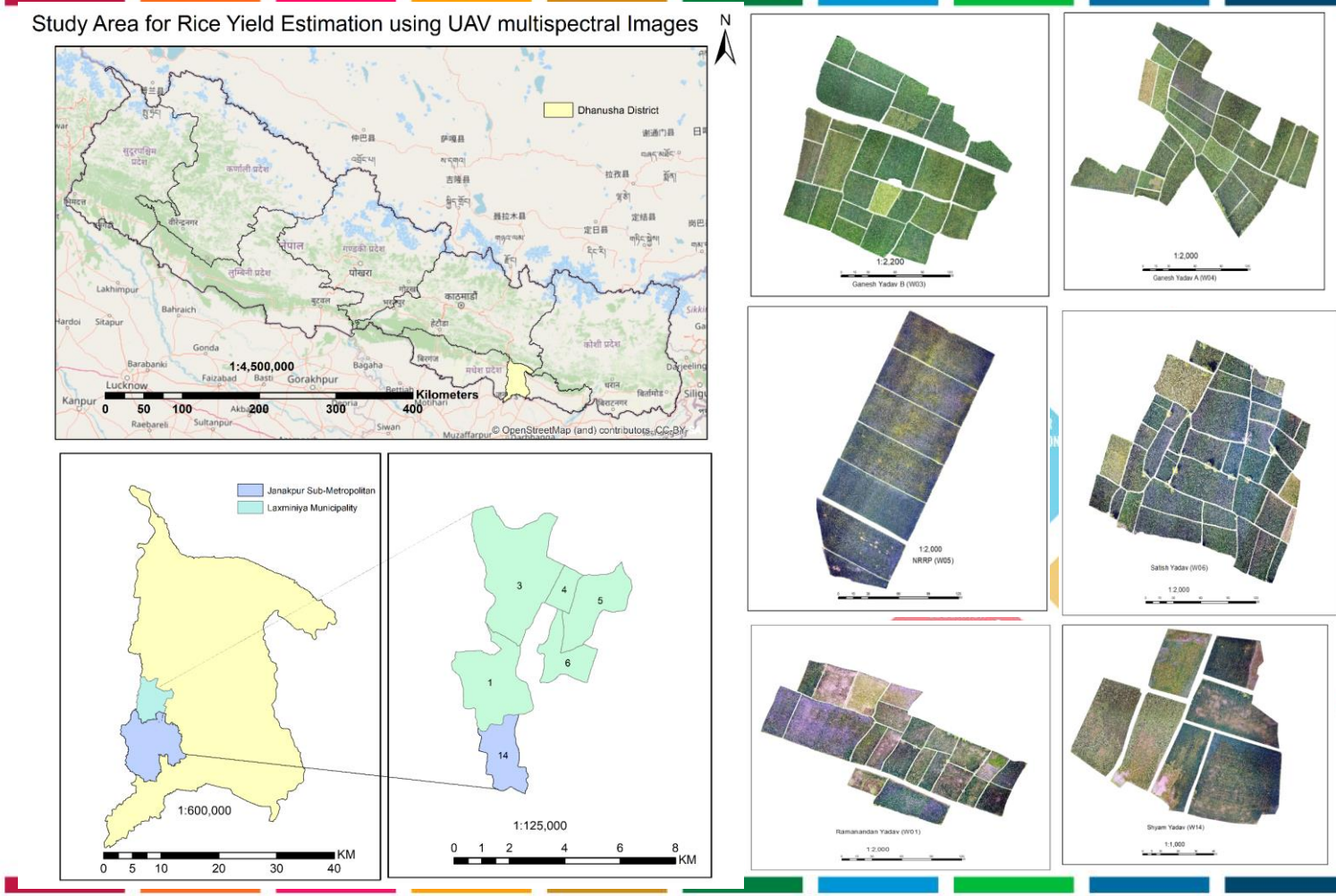


Methodology

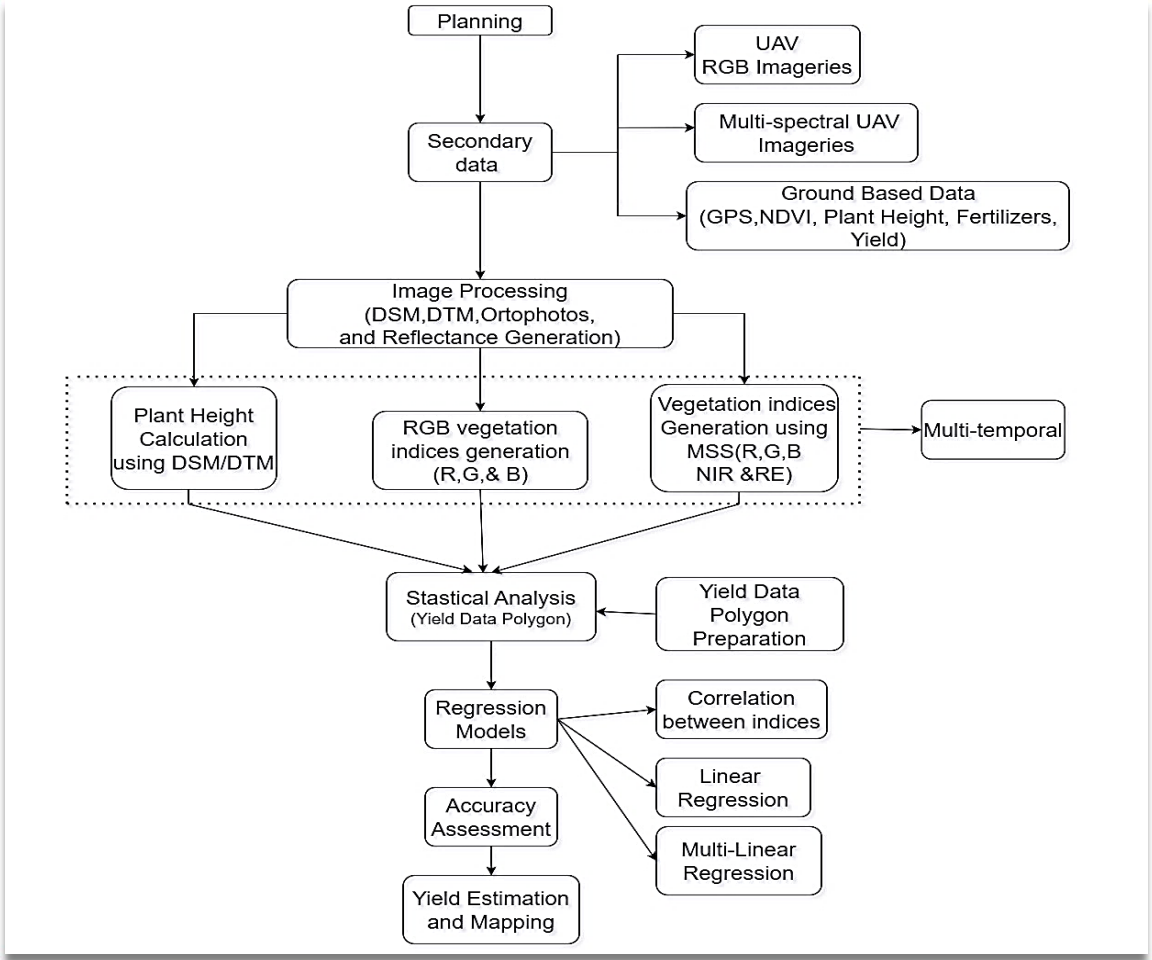
Study Area

- 6 distinct locations within the Laxminiya municipality and Janakpur Sub-metropolitan Madhesh Province ,Dhanusha District of Nepal.

- One on each ward: 01, 03, 04, 05, 06 and 14.

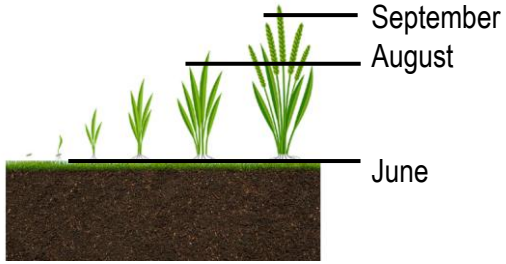


Methodological Diagram

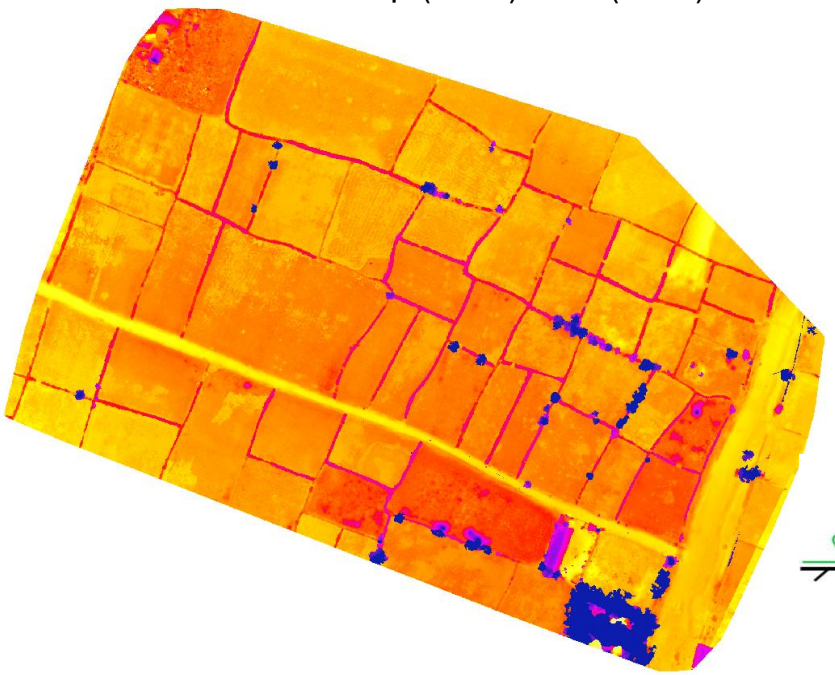


S.N.	Contents
1	Mavic 2 pro Drone
2	Phantom 4 Pro Multispectral
4	Greenseeker Handheld NDVI Measurement
5	Plant Height Data Collection
6	Farm Management Data Collection
7	HandGPS

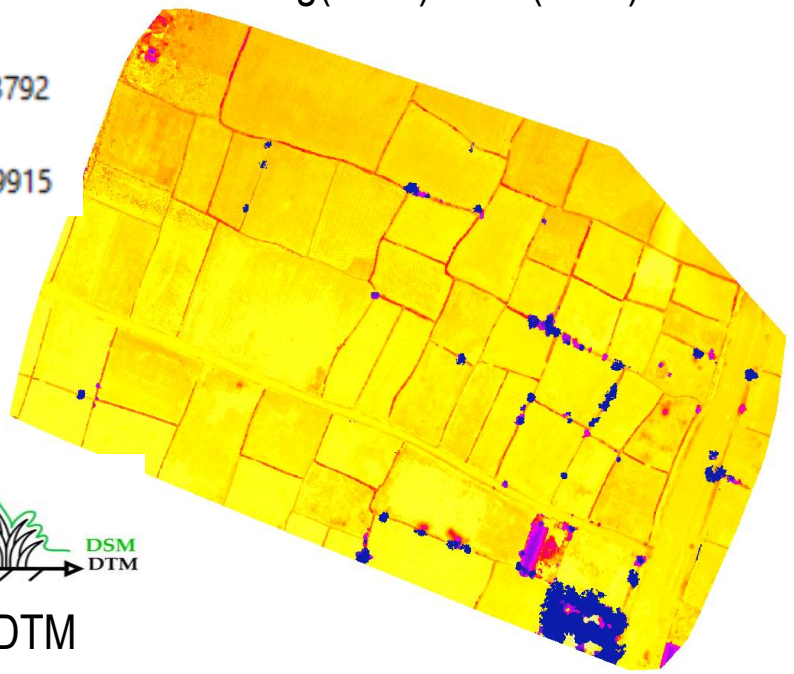
Plant Height Estimation



Ward 01 Sept(DSM)-June(DTM)



Ward 01 Aug(DSM)-June(DTM)

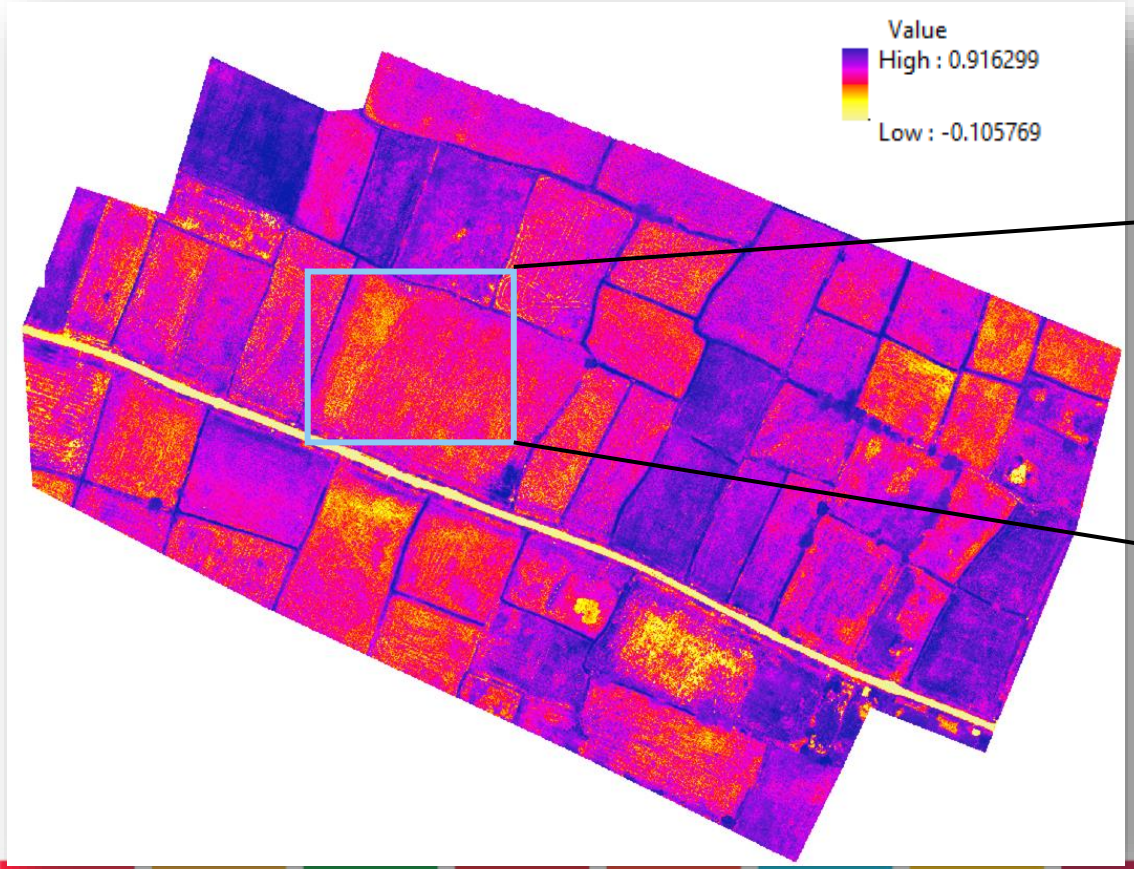


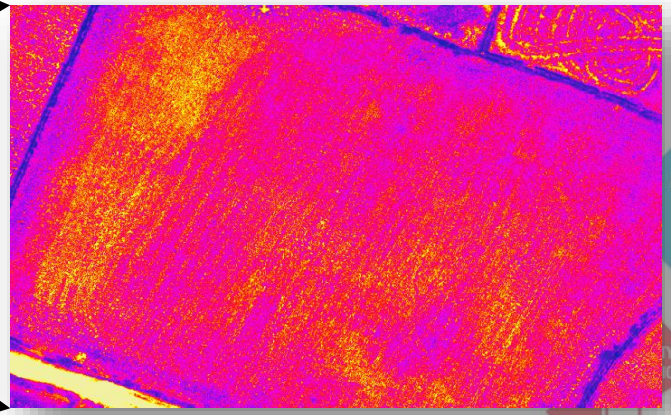
Plant Height= DSM - DTM

Vegetation Indices

S.N.	Name	VI	Formula
1	Red-edge Chlorophyll Index	Clrededge	$\frac{NIR}{REDEDGE} - 1$
2	Difference Vegetation Index	DVI	$2.4 * NIR - RED$
3	Enhanced Vegetation Index	EVI	$2.5 * \frac{NIR - RED}{NIR + 6 * RED - 7.5 * BLUE + 1}$
4	Excess Green Index	ExG	$\frac{2 * GREEN - RED - BLUE}{RED + GREEN + BLUE}$
5	Excess Green minus Excess Red	ExGR	$ExG - ExR$
6	Excess Red	ExR	$\frac{1.4 * RED - GREEN}{RED + GREEN + BLUE}$
7	Green Normalized Difference Vegetation Index	GNDVI	$\frac{NIR - GREEN}{NIR + GREEN}$
8	Green Red Vegetation Index	GRVI	$\frac{GREEN - RED}{GREEN + RED}$
9	Modified Chlorophyll Absorption in Reflectance Index 1	MCARI1	$[1.2 * (2.5 * (NIR - RED) - 1.3 * (NIR - GREEN))$
10	Modified Green Red Vegetation Index	MGRVI	$\frac{GREEN^2 - RED^2}{GREEN^2 + RED^2}$
11	Normalized Difference Red-edge	NDRE	$\frac{NIR - REDEDGE}{NIR + REDEDGE}$
12	Normalized Difference Vegetation Index	NDVI	$\frac{NIR - RED}{NIR + RED}$
13	Optimized Soil Adjusted Vegetation Index	OSAVI	$\frac{NIR - RED}{NIR + RED + 0.16}$
14	Red-edge Difference Vegetation Index	REDVI	$NIR - RE$
15	Red Green Blue Vegetation Index	RGBVI	$\frac{GREEN^2 - BLUE * RED}{GREEN^2 + BLUE * RED}$
16	Soil Adjusted Vegetation Index	SAVI	$\frac{1.5 * (NIR - RED)}{NIR + RED + 0.5}$
17	Simple Ratio	SR	$\frac{NIR}{RED}$
18	Visible Atmospherically Resistant Index	VARI	$\frac{GREEN - RED}{GREEN + RED - BLUE}$
19	Wide Dynamic Range Vegetation Index	WDRVI	$\frac{a * NIR - REDEDGE}{a * NIR + REDEDGE}$ a=[0.1,0.2], generally a=0.2

Vegetation Indices Generation





Mean NDVI: 0.4528

Farm Management Data Preparation

- *Plant Age Determination:*
- precise calculation of the duration between transplantation and the date of imaging.

- *Fertilizers Data:*
- 1 DAP (Diammonium Phosphate)
- 2 Urea
- 3 Potash
- 4 Zinc
- 5 Zyme
- 6 Aluminum Sulphate

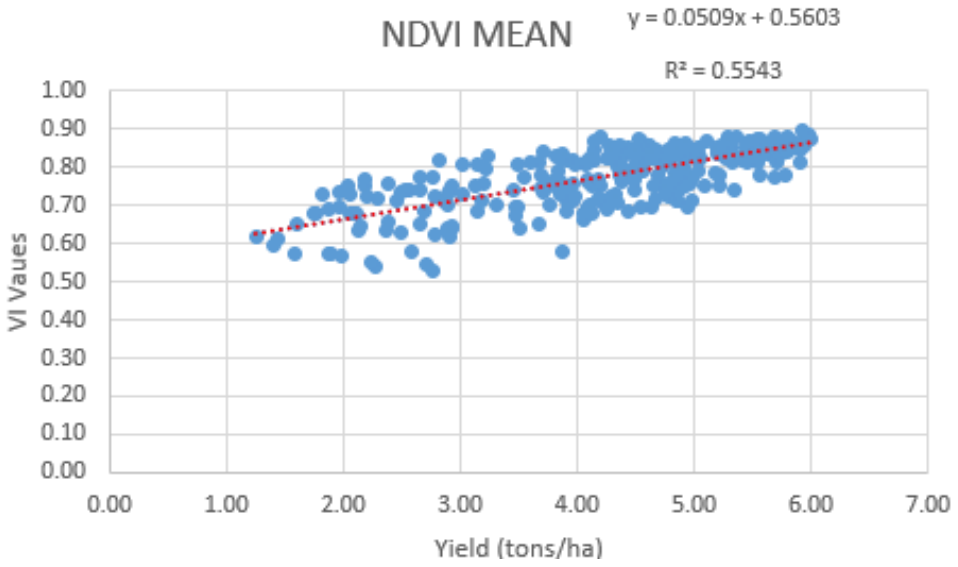
Correlation	NDVI MEAN	NDRE MEAN	GNDVI MEAN	CLRE MEAN	SR MEAN	WDRVI MEAN	VARI MEAN
NDVI MEAN	1.00						
NDRE MEAN	0.89	1.00					
GNDVI MEAN	0.97	0.96	1.00				
CLRE MEAN	0.89	1.00	0.96	1.00			
SR MEAN	0.97	0.89	0.95	0.91	1.00		
WDRVI MEAN	0.89	1.00	0.96	1.00	0.90	1.00	
VARI MEAN	0.94	0.80	0.87	0.81	0.94	0.81	1.00

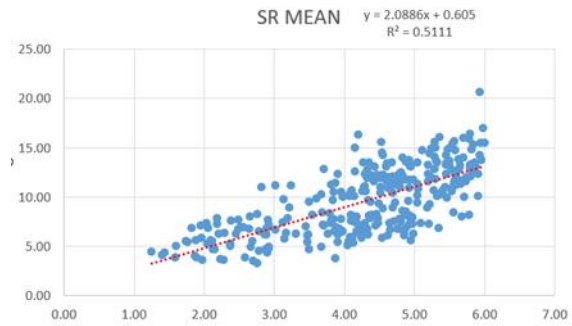
Vegetation Indices data from GaneshYadavB of the month September

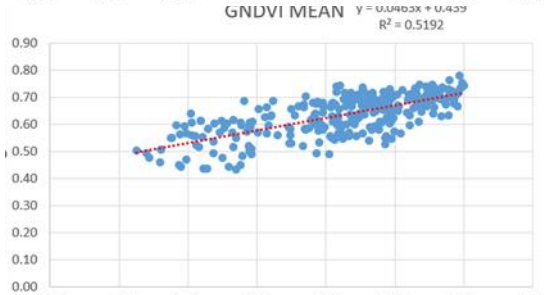
	NDVI MEAN	NDRE MEAN	GNDVI MEAN	GRVI MEAN	CLRE MEAN	DVI MEAN	EVI MEAN	EXG MEAN	EXGR MEAN	EXR MEAN	MCARI1 MEAN	MGRVI MEAN	OSAVI MEAN	REDVI MEAN	RGBVI MEAN	SAVI MEAN	SR MEAN	WDRVI MEAN	VARI MEAN
NDVI MEAN	1																		
NDRE MEAN	0.887668356	1																	
GNDVI MEAN	0.97014795	0.961640949	1																
GRVI MEAN	0.826105626	0.520637742	0.673143699	1															
CLRE MEAN	0.892932348	0.997180893	0.960128279	0.547216358	1														
DVI MEAN	0.1155248	-0.120864163	-0.007867369	0.390916479	-0.07541854	1													
EVI MEAN	0.237713541	-0.004782374	0.114733359	0.483956132	0.04042506	0.992099636	1												
EXG MEAN	0.020994307	-0.409907906	-0.193729617	0.510746633	-0.375291908	0.642352232	0.626610295	1											
EXGR MEAN	0.30521078	-0.136264788	0.084430181	0.746459892	-0.100403544	0.632702296	0.653074407	0.953260495	1										
EXR MEAN	-0.753817626	-0.407009458	-0.578952376	-0.990787175	-0.435898091	-0.450984311	-0.533124937	-0.619697757	-0.827872711	1									
MCARI1 MEAN	0.119904998	-0.135807337	-0.015936194	0.420566882	-0.089785927	0.998099073	0.990451182	0.677740683	0.67087856	-0.484452265	1								
MGRVI MEAN	0.822839929	0.511695173	0.666526056	0.999119484	0.53835682	0.402604238	0.494525553	0.51848862	0.752282605	-0.991539441	0.432718842	1							
OSAVI MEAN	0.254014514	0.010488961	0.13120989	0.496302576	0.055702414	0.989801121	0.999824946	0.625157984	0.656244657	-0.544055828	0.988169414	0.50663627	1						
REDVI MEAN	0.87860075	0.873260417	0.898003991	0.658047422	0.891353698	0.356162422	0.462385223	-0.077641727	0.16782474	-0.580063992	0.338195861	0.652171362	0.476110493	1					
RGBVI MEAN	-0.037212358	-0.455698286	-0.242088008	0.4467669	-0.420485849	0.647692914	0.624386177	0.994706713	0.925890668	-0.558430573	0.679482649	0.454777171	0.622088959	-0.113922889	1				
SAVI MEAN	0.24367886	0.000696706	0.120714076	0.488589895	0.045910637	0.991299628	0.999977819	0.626362193	0.654494585	-0.537274463	0.989670965	0.499072468	0.999926339	0.467328573	0.62382727	1			
SR MEAN	0.970483549	0.889579766	0.951998307	0.822134066	0.906695097	0.165900527	0.285472255	0.022081235	0.303124783	-0.746381408	0.165901176	0.81288013	0.301742733	0.915865564	-0.028891737	0.291421882	1		
WDRVI MEAN	0.891555119	0.998916561	0.961299362	0.53760743	0.999590634	-0.092565791	0.023432857	-0.388683914	-0.114039548	-0.425339422	-0.107143468	0.528725434	0.038715757	0.885029111	-0.434167279	0.028918403	0.900733476	1	
VARI MEAN	0.942180736	0.797059147	0.868043411	0.913731171	0.814067527	0.171381229	0.285463794	0.120212276	0.413553443	-0.85105012	0.187812221	0.909176701	0.300279045	0.808895796	0.051417347	0.290884594	0.944298621	0.808290443	1

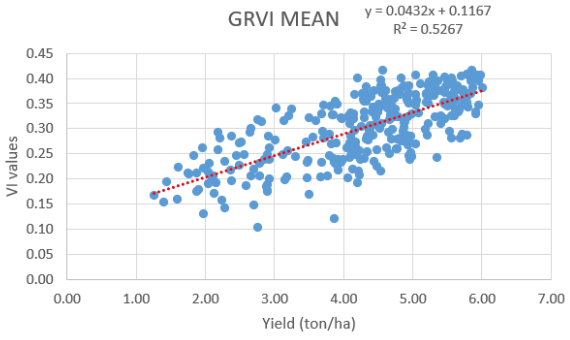
Single Linear Regression

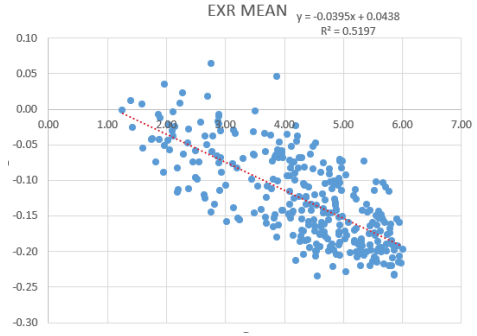
AUGUST			SEPTEMBER	
S.N.	Index	R-squared values	Index	R-squared values
1	DAP	0.02	CLRE	0.00001
2	PLANT HEIGHT	0.05	NDRE	0.02
3	POTASH	0.07	DAP	0.02
4	ZINC	0.10	REDVI	0.04
5	WDRVI	0.17	PLANT HEIGHT	0.06
6	UREA	0.27	POTASH	0.07
7	CLRE	0.28	ZINC	0.10
8	NDRE	0.29	EVI	0.24
9	RGBVI	0.30	UREA	0.25
10	EXG	0.30	WDRVI	0.27
11	REDVI	0.30	RGBVI	0.35
12	SR	0.31	EXG	0.38
13	EXGR	0.32	SAVI	0.40
14	DVI	0.32	DVI	0.40
15	GNDVI	0.33	OSAVI	0.40
16	EXR	0.33	EXGR	0.47
17	EVI	0.33	MCARI1	0.50
18	SAVI	0.34	MGRVI	0.51
19	OSAVI	0.34	SR	0.51
20	NDVI	0.34	GNDVI	0.52
21	GRVI	0.34	EXR	0.52
22	MGRVI	0.34	VARI	0.52
23	MCARI1	0.34	GRVI	0.53
24	VARI	0.40	NDVI	0.55

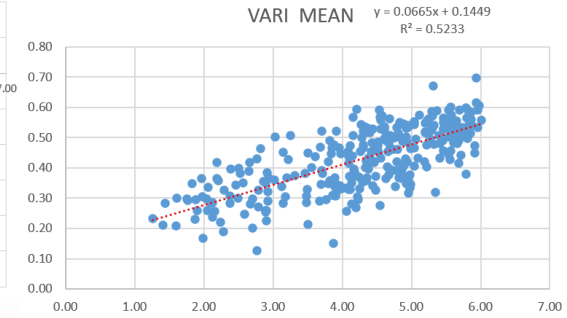












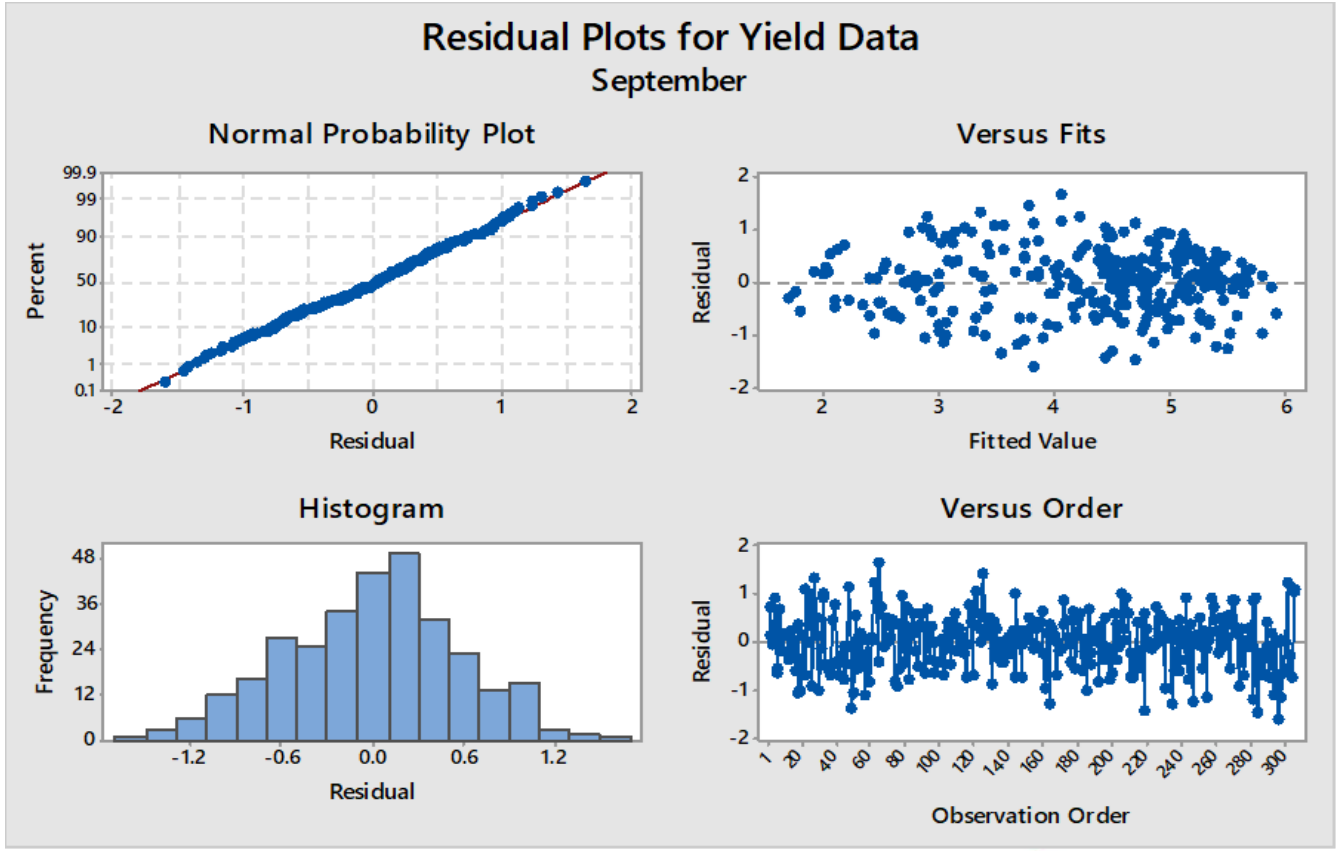
Multi-Linear Regression

S	R-sq	R-sq(adj)	R-sq(pred)
0.605426	74.26%	72.46%	69.72%

Model Summary

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	20	301.450	15.0725	41.12	0.000
EXR MEAN	1	5.629	5.6291	15.36	0.000
GNDVI MEAN	1	1.631	1.6313	4.45	0.036
MCARI1 MEAN	1	0.661	0.6607	1.80	0.180
MGRVI MEAN	1	1.493	1.4926	4.07	0.045
NDVI MEAN	1	1.651	1.6506	4.50	0.035
SR MEAN	1	0.502	0.5022	1.37	0.243
VARI MEAN	1	5.831	5.8312	15.91	0.000
GRVI MEAN	1	5.237	5.2368	14.29	0.000
EXGR MEAN	1	2.430	2.4296	6.63	0.011
OSAVI MEAN	1	6.079	6.0787	16.58	0.000
DVI MEAN	1	4.000	3.9995	10.91	0.001
SAVI MEAN	1	6.448	6.4481	17.59	0.000
PH_sept_MEAN	1	0.411	0.4111	1.12	0.290
PlantAge	1	14.102	14.1021	38.47	0.000
UREA_TOTAL	1	0.002	0.0016	0.00	0.947
PaddyVariety	3	8.291	2.7636	7.54	0.000

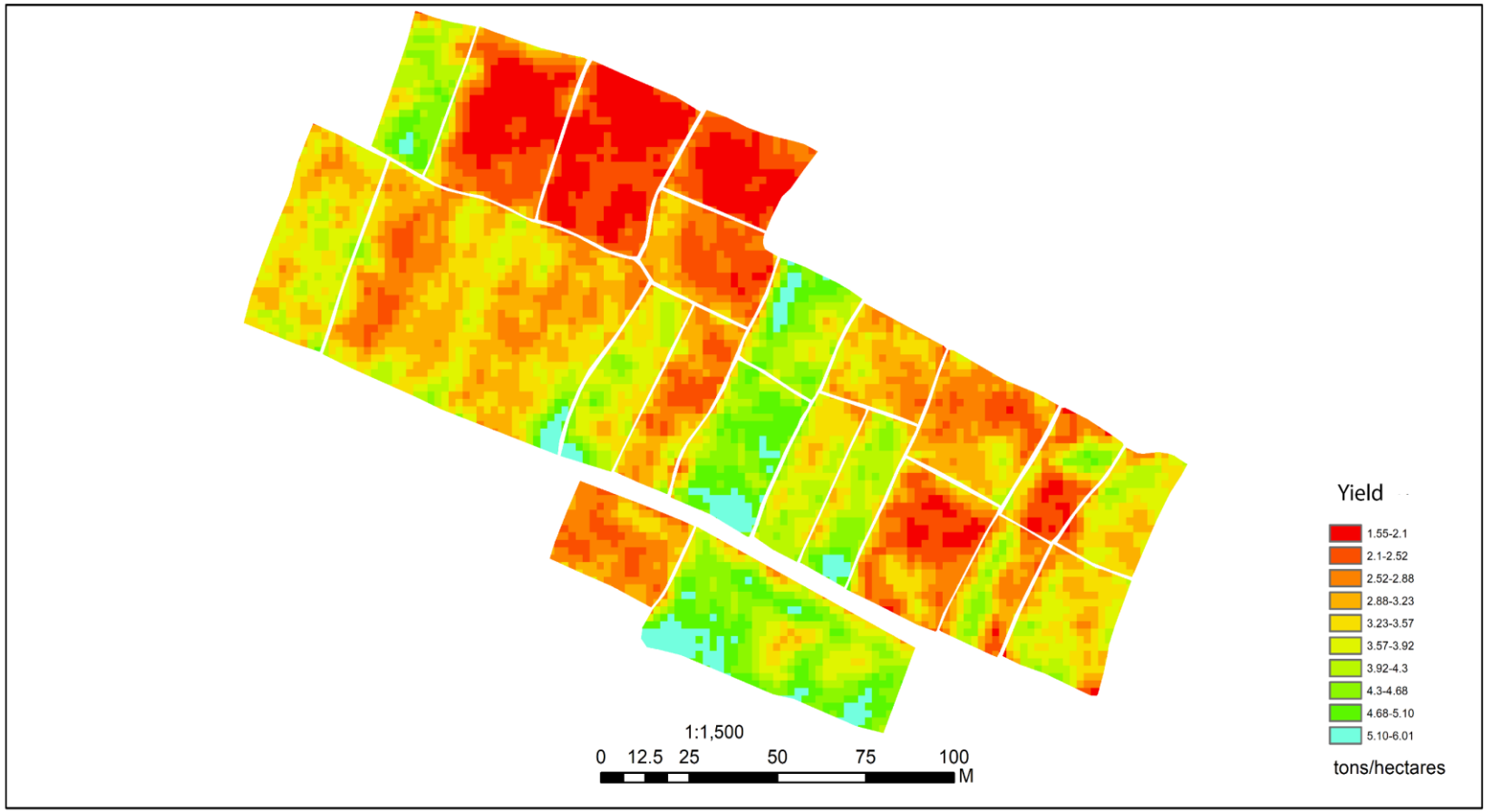


Regression Formula to calculate Yield

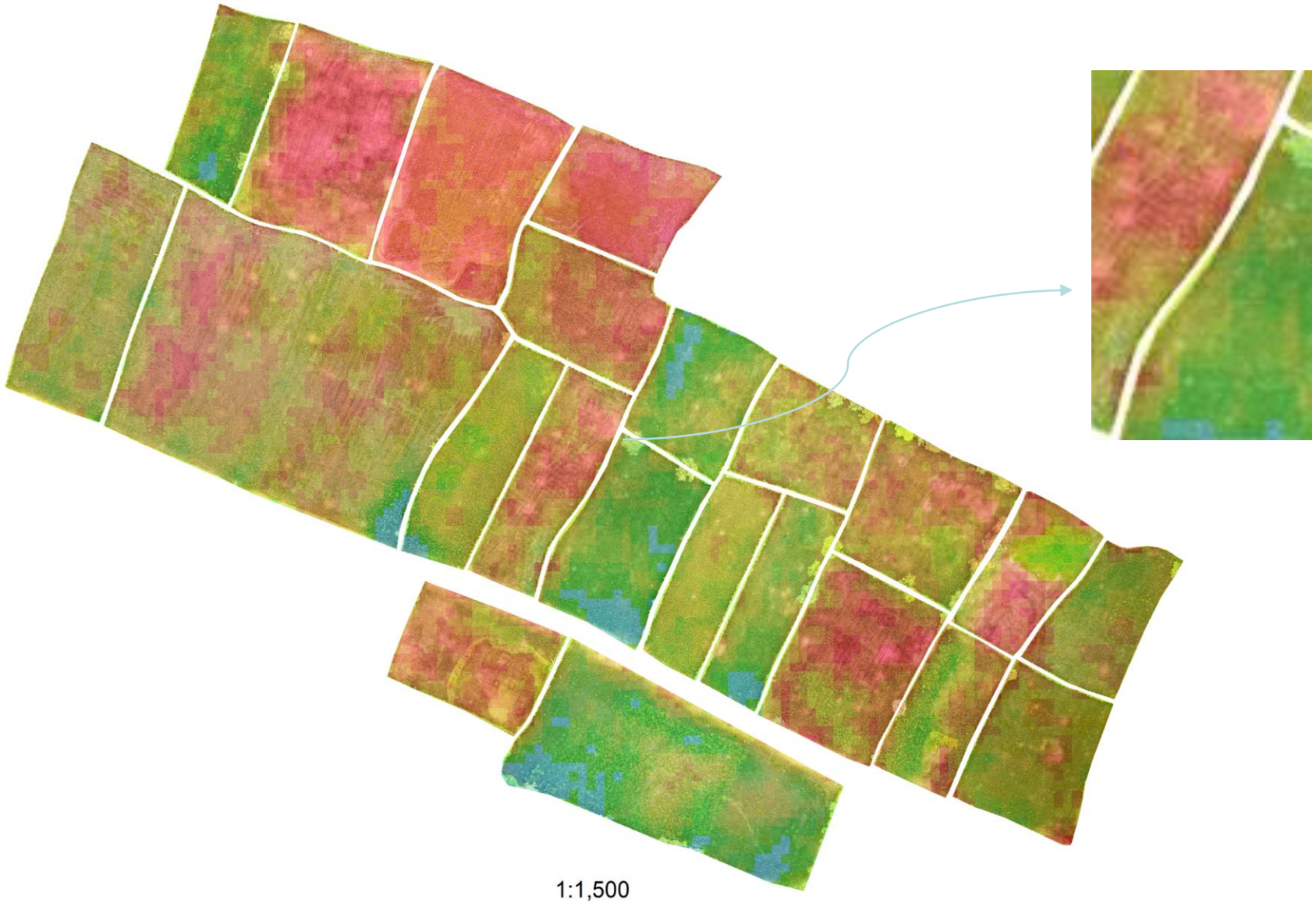
PaddyVariety
▪ Katarni Correct yield equation = 47.5 - 300.0 EXR + 34.8 GNDVI + 115.2 MCARI1 - 7.54 MGRVI - 38.7 NDVI - 0.174 SR + 80.5 VARI - 391 GRVI + 13.96 EXGR + 12340 OSAVI + 819 DVI - 25402 SAVI + 0.0669 Plant height+ 0.02784 Plant Age - 0.0024 UREA- 0.387 POTASH + 0.0231 DAP
▪ Sambha Correct yield equation = 47.0 - 300.0 EXR + 34.8 GNDVI + 115.2 MCARI1 - 7.54 MGRVI - 38.7 NDVI - 0.174 SR + 80.5 VARI - 391 GRVI + 13.96 EXGR + 12340 OSAVI + 819 DVI - 25402 SAVI + 0.0669 Plant height+ 0.02784 Plant Age - 0.0024 UREA- 0.387 POTASH + 0.0231 DAP
▪ Sona Correct yield equation = 46.9 - 300.0 EXR + 34.8 GNDVI + 115.2 MCARI1 - 7.54 MGRVI - 38.7 NDVI - 0.174 SR + 80.5 VARI - 391 GRVI + 13.96 EXGR + 12340 OSAVI + 819 DVI - 25402 SAVI + 0.0669 Plant height+ 0.02784 PlantAge - 0.0024 UREA- 0.387 POTASH + 0.0231 DAP
▪ OV Correct yield equation = 47.1 - 300.0 EXR + 34.8 GNDVI + 115.2 MCARI1 - 7.54 MGRVI - 38.7 NDVI - 0.174 SR + 80.5 VARI - 391 GRVI + 13.96 EXGR + 12340 OSAVI + 819 DVI - 25402 SAVI + 0.0669 plant height0.02784 PlantAge - 0.0024 UREA - 0.387 POTASH + 0.0231 DAP

Results

Yield Prediction Map of Ward 01



Overlay of predicted yield data over RGB orthophoto of Ward 01



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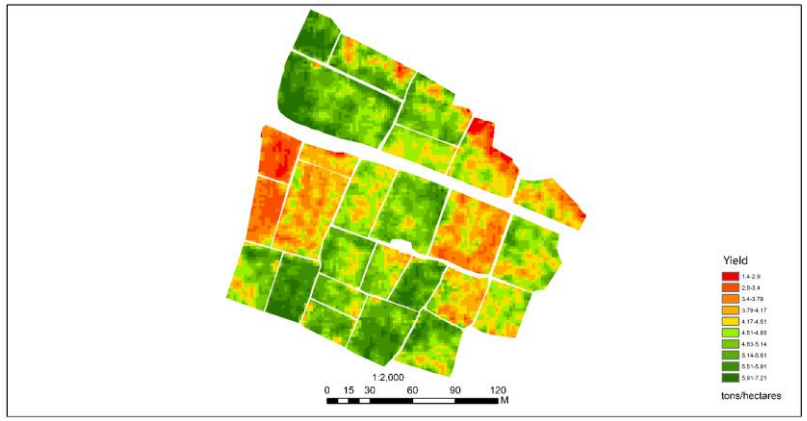
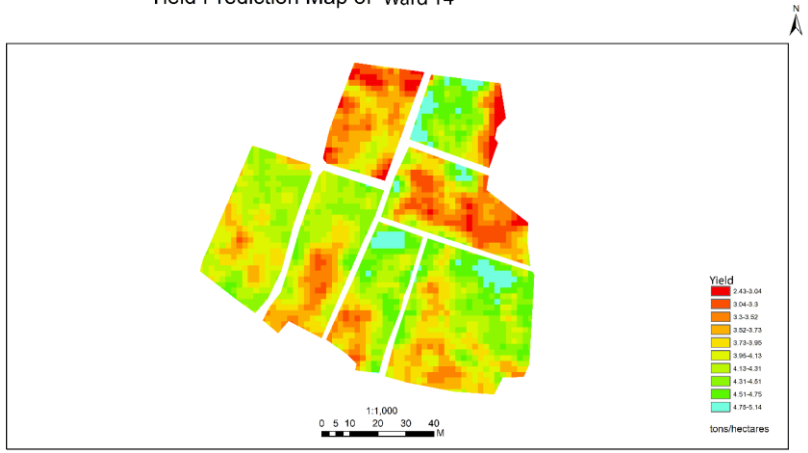
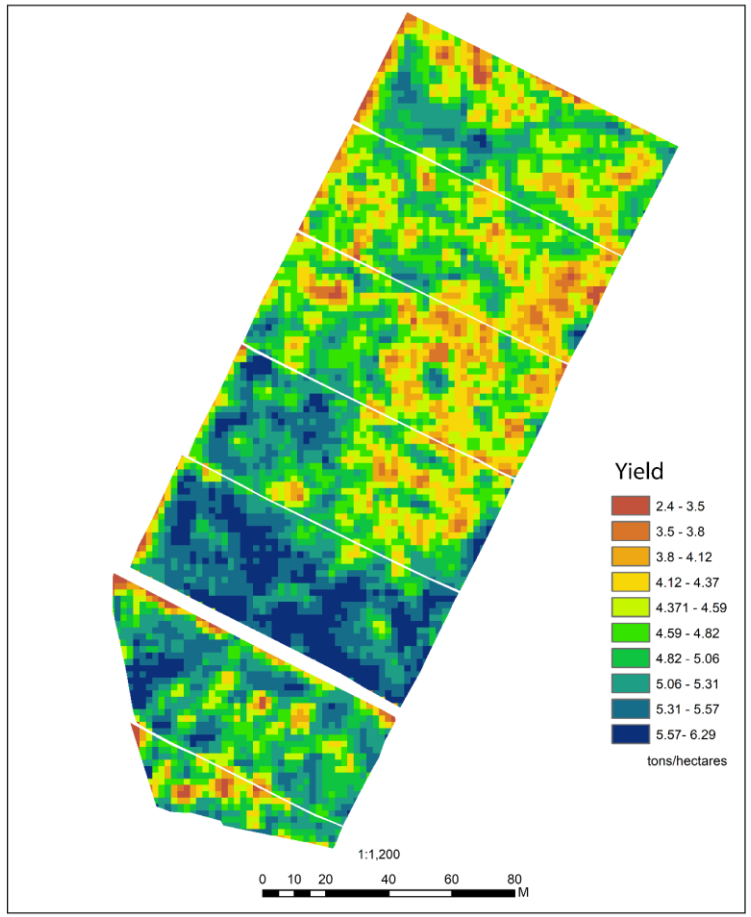
Yield Prediction Map of Ward 03



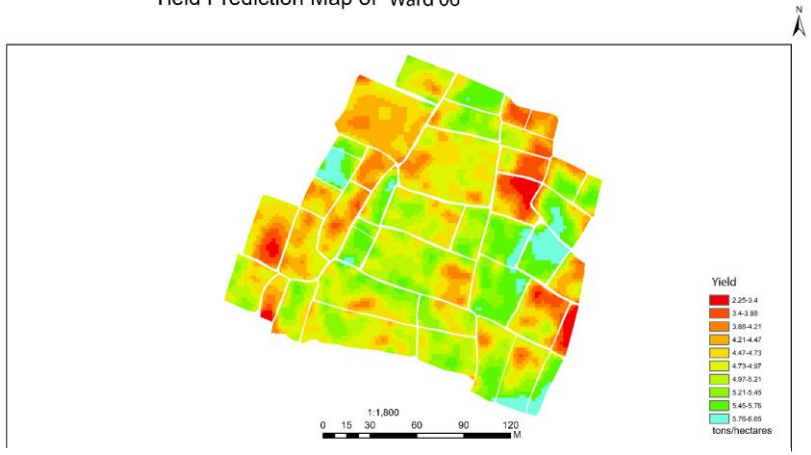
Yield Prediction Map of Ward 14



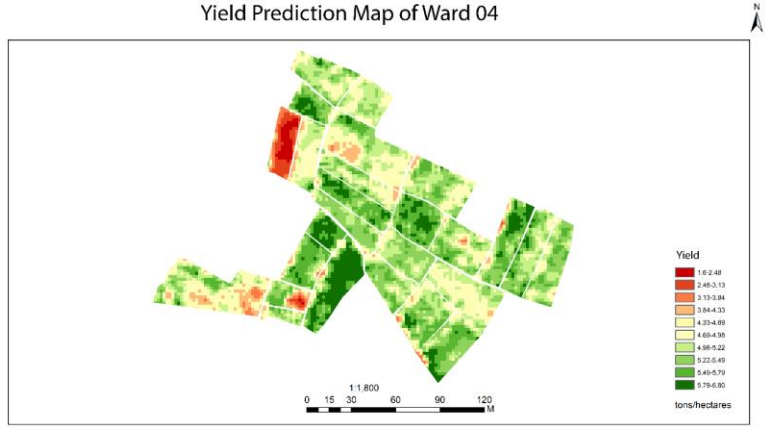
Yield Prediction Map of Ward 05



Yield Prediction Map of Ward 06



Yield Prediction Map of Ward 04



Conclusion

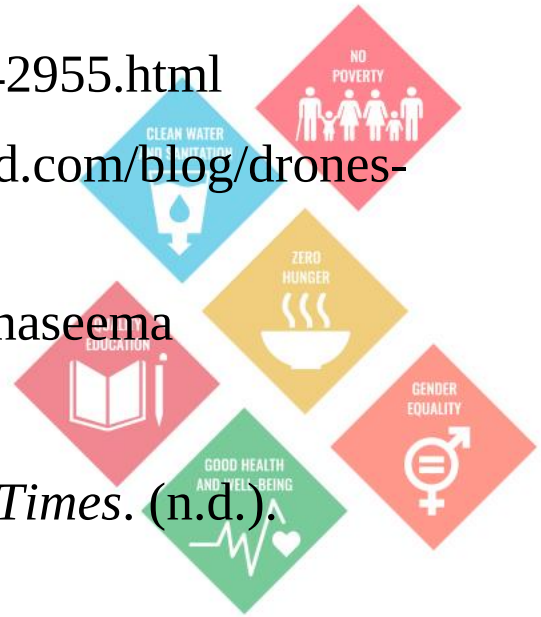
- Yield estimation mapping can done using multi-linear regression model.
- UAV technology valuable for rice yield estimation.
- Multi-parameter models yield better accuracy.
- Models vary for different rice varieties.

RGB imagery showed potential for yield estimation when multispectral is unavailable.

References

THE 17 GOALS | Sustainable Development. (n.d.). https://sdgs.un.org/goals

- *Artificial intelligence in Asian agriculture: Its time has come - APO*. (n.d.). https://www.apo-tokyo.org/articles/artificial-intelligence-in-asian-agriculture-its-time-has-come/
- *In same serie with 39742955 Rice seedlings*. (n.d.). https://depositphotos.com/serie/39742955.html
- *Internet of Fields: Drones & variable rate application | Pix4D*. (n.d.). https://www.pix4d.com/blog/drones-variable-rate-application/
- *Konaseema - Alchetron, The Free Social Encyclopedia*. (n.d.). https://alchetron.com/Konaseema
- *Next Farmer*. (n.d.). https://nextfarmer.org/
- *Rice plants in UP dwarfed by disease, output likely to be hit, fear scientists - Hindustan Times*. (n.d.).



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PLATINUM SPONSOR Trimble

Annex

- R-squared values of RGB and MSS.

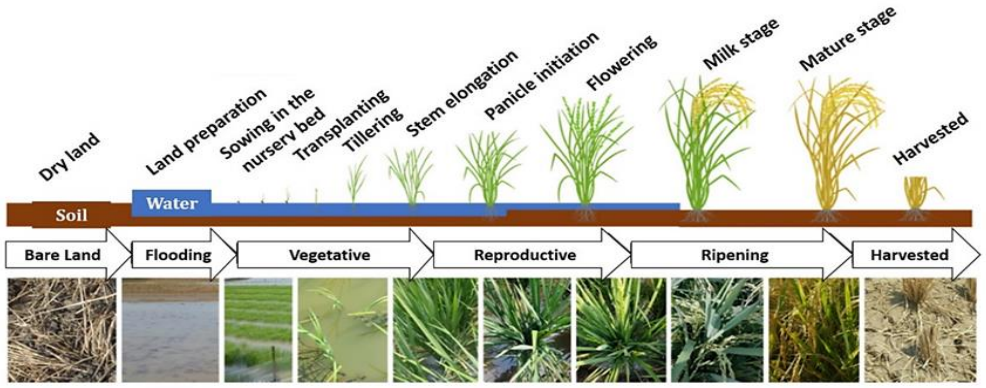
Bands in Multispectral UAV (DJI Phantom 4 Multispectral):

Blue: 450nm ± 16nm

Green: 560 ± 16nm

Red: 650nm ± 16nm

Red Edge: 730nm ±16nm
Near Infra red: 840nm ±26nm



Life Cycle of Rice Plant (Sheng et al., 2022)

SEPTEMBER		
Index	**R-squared values**	**Sensor**
CLRE	0.00001	MSS
NDRE	0.02	MSS
REDVI	0.04	MSS
EVI	0.24	MSS
WDRVI	0.27	MSS
RGBVI	0.35	RGB
EXG	0.38	RGB
SAVI	0.40	MSS
DVI	0.40	MSS
OSAVI	0.40	MSS
EXGR	0.47	RGB
MCARI1	0.50	MSS
MGRVI	0.51	RGB
SR	0.51	MSS
GNDVI	0.52	MSS
EXR	0.52	RGB
VARI	0.52	RGB
GRVI	0.53	RGB
NDVI	0.55	MSS

Multilinear Regression:

Regression based on Plant-Varieties

Plant Variety	Sample Size	R^2 Value
Katarni	83	63.66%
Sona	128	79.58%
Sambha	57	67.24%
Other Variety	37	67.07%

Regression Based on wards

Ward No	Sample Size	R^2 value
1	87	55.87%
3	44	55.32%
4	39	72.31%
5	65	59.87%
6	31	74.18%
14	40	79.65%

For regression based on rice-plant type: Sona

Yield = 341 - 0.0098 CLRE - 3074 DVI - 2353 EVI - 2873 EXG + 2314 EXGR + 110.3 GNDVI - 1644 GRVI + 210 MCARI1 - 257 MGRVI + 3.8 NDRE - 138.5 NDVI + 17262 OSAVI - 1976 REDVI + 463 RGBVI - 29628 SAVI - 0.810 SR + 121.0 VARI + 3.79 WDRVI - 0.0609 Age of Seedling + 0.098 Plant Height - 1.43 POTASH + 1.819 ZYME - 0.152 ALUMINIUM SULPHATE - 0.075 DAP + 0.436 UREA + 0.098 ZINC

1.Regression based on Plant-Type:

Plant Type	Sample Size	R^2 Value	Regression Equation
Katarni	83	63.66 %	Yield= -266+ 0.1095 CLRE + 51572 EVI + 2402 EXG -1826 EXGR + 1063 GRVI + 1040* MCARI1 + 216 MGRVI + 8.26 NDRE + 7.1 NDVI + 19157 OSAVI - 449 RGBVI -82306 SAVI + 0.018 SR + 30.8 VARI - 21.6 WDRVI + 0.0305 Age of Seedling +0.449 Plant Height_- 0.51 POTASH + 0.458 ZYME + 4.00 ALUMINIUM SULPHATE - 0.2109 DAP + 0.0856 UREA + 0.548 ZINC
Sona	128	79.58 %	Yield = 341 - 0.0098 CLRE - 3074 DVI - 2353 EVI - 2873 EXG + 2314 EXGR + 110.3 GNDVI - 1644 GRVI + 210 MCARI1 - 257 MGRVI + 3.8 NDRE - 138.5 NDVI + 17262 OSAVI - 1976 REDVI + 463 RGBVI - 29628 SAVI - 0.810 SR + 121.0 VARI + 3.79 WDRVI - 0.0609 Age of Seedling + 0.098 Plant Height - 1.43 POTASH + 1.819 ZYME - 0.152 ALUMINIUM SULPHATE - 0.075 DAP + 0.436 UREA + 0.098 ZINC
Samba	57	67.24 %	Yield = 36+ 73.0 CLRE - 23882 DVI + 14831 EVI + 1094 EXG - 836 EXGR + 653 GRVI - 16620 MCARI1 - 182 MGRVI - 246 NDRE + 8554 OSAVI + 0.0114 REDVI - 2.14 SR + 26 VARI+ 4.2 WDRVI - 0.0151 Age Of Seedling- 0.039 PH_sept_+ 7.8 POTASH+ 1.06 ZYME+ 8.1 ALUMINIUM SULPHATE2+ 0.192 DAP- 39 UREA
Other Variety	37	67.07 %	Yield= -401+ 0.501 CLRE + 703 DVI - 11091 EVI + 2806 EXG - 2355 EXGR - 724 GNDVI + 1785 GRVI - 5274 MCARI1 + 23.7 MGRVI - 16.8 NDRE + 818 NDVI + 115 OSAVI + 0.000229 REDVI - 390 RGBVI + 11472 SAVI + 4.17 SR - 131 VARI + 12.5 WDRVI + 0.49 Plant height + 4.01 POTASH + 0.619 DAP_ - 0.782 UREA

2. Regression Based on Wards

Ward No	Sample Size	R^2 value	Regression Equation
1	87	55.87%	38.7 - 187 EXR + 79.6 GNDVI - 257 GRVI + 320 MCARI1 + 43.6 MGRVI - 91.3 NDVI - 0.358 SR + 42.2 VARI + 0.034 Plant height
3	44	55.32%	-34.9 + 104 EXR + 39 GRVI + 13.4 VARI + 392 MCARI1 - 25.1 MGRVI + 0.731 SR - 137 GNDVI + 163 NDVI - 0.373 Plant height t+ 0.570 ZINC + 0.0024 UREA
4	39	72.31%	-510 - 91283 DVI + 109303 EVI + 4604 EXG - 3656 EXGR - 168 GNDVI + 2667 GRVI - 19890 MCARI1 + 357 MGRVI + 177 NDVI - 3415 OSAVI - 0.000185 REDVI - 789 RGBVI + 0.76 SR - 176 VARI - 0.610 Plant height+ 0.307 DAP - 0.175 UREA - 1.26 ZINC + 0.0200 PlantAge
5	65	59.87%	-96 + 42.7 CLRE - 18906 DVI - 505644 EVI + 1177 EXG - 892 EXGR + 51 GNDVI + 685 GRVI - 2834 MCARI1 - 226 MGRVI - 176 NDRE - 40 NDVI - 45204 OSAVI + 7960 REDVI + 533190 SAVI - 2.12 SR + 58 VARI + 1.8 WDRVI + 0.118 plant height
6	31	74.18%	-5682 + 1190 CLRE - 55789 DVI - 1209887 EVI - 876 EXG + 770 EXGR + 409 GNDVI - 295 GRVI + 50743 MCARI1 - 319 MGRVI + 2620 NDRE - 357 NDVI - 114093 OSAVI + 30211 REDVI + 97 RGBVI + 1263646 SAVI - 4.22 SR + 156 VARI - 8739 WDRVI - 0.165 UREA+ 0.150 PlantAge
14	40	79.65%	682 - 2.79 CLRE - 24656 DVI - 762293 EVI - 3593 EXG + 2634 EXGR + 369 GNDVI - 1325 GRVI + 25335 MCARI1 - 201 MGRVI - 146 NDRE - 484 NDVI - 49537 OSAVI - 12632 REDVI + 669 RGBVI + 750174 SAVI MEAN - 119 VARI + 334 WDRVI + 2.45 Plant height+ 0.0442 DAP - 0.042 Plant Age