Estimating crop yield from spectral vegetation indices: a case study from the Po River Plain, Italy

Mustafa Kamal Shahadat

Methodology

(i) **Data collection:** Sentinel-2 satellite images were collected from Copernicus Open Access Hub for a wheat growing region, the Bonifiche Ferraresi farm at Jolanda di Savoi, Italy. The images represent the four growing stages of wheat such as early vegetative phase (4 April 2020), vegetative phase (23 April 2020), reproductive phase (23 May 2020) and Maturity phase (22 June 2020). At harvest, wheat yield data were collected from 40 sites of the region with the geotagged plot dimension of 60 X 60 m^2 for validation.

(ii) **Data preprocessing:** Multispectral image consisting of 8 bands having 20 meter resolution were merged, clipped and composited using QGIS 3.16 Hannover.

(iii) Image and data analysis: Clustered images were composited in 3 ways such as natural color composite (4,3,2 bands), false-color composite (8,4,3) and agricultural false-color composite (11,8,2). Three vegetation indices viz. NDVI, NDre1 and MNDWI1 were calculated according to the formula using respective formula. Simple linear regression and correlation were calculated with the indices values and wheat yield as well as with log transformed yield.

Question and Answer

Q.1. Explore the images with RGB composites. Compare and contrast the colours according to land cover type (buildings, bare soil, crops, etc.) and crop growth stage. What do the colours mean in terms of the spectral response?

In the figure 1, the true color composite (4,3,2 bands), crop fields looking green, while fallow land, roads and built-ups are grey and white.

The false-colour images in the figure 2 showing spectral changes over time. At early vegetative stage, most of the land look bluish and greenish because of green band. The dotted places are wheat fields which are reddish at EVP and VP because of NIR band since green plants reflect most at NIR band. At this stage photosynthesis rate is higher because of high chlorophyll content. Since chlorophyll absorbs green light and reflect red light, hence reflectance at NIR band is higher at this stage. At reproductive phase, wheat fields still reddish but turning brown. At maturity stage, when most of the wheat fields turned brown due to reduced chlorophyll. Buildings are seen bluish at the top of the images at all the stages.

Figure 3 represents the agricultural false-colour image, which is usually suitable for monitoring crop health. At EVP, fallow lands and buildings appear pink and wheat fields looks greenish. The fallow land turned deep pink and wheat fields look dark green because of high chlorophyll content. At RP wheat again turned fade green and brown at MP due to diminishing chlorophyll content. Buildings appear pink all through the stages.

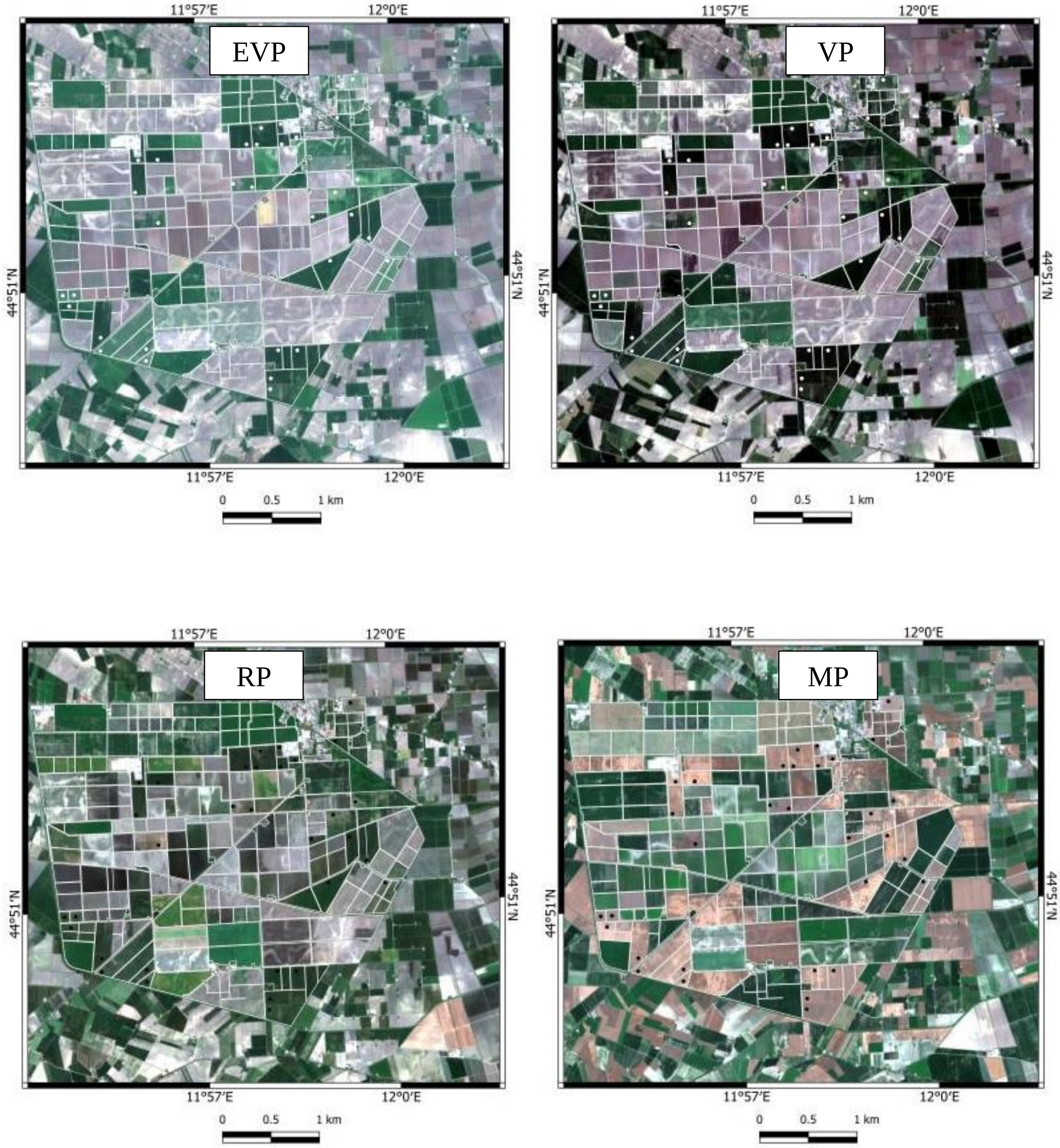


Figure 1. True color composite (band 4, 3, 2) at different growth stages of winter wheat grown at the Bonifiche Ferraresi farm in Emilia-Romagna, Italy during 2020. Where, EVP- early vegetative phase, VP- vegetative phase, RP- reproductive phase, MP- maturity phase. Dots represents sampling points for wheat yield calculation.

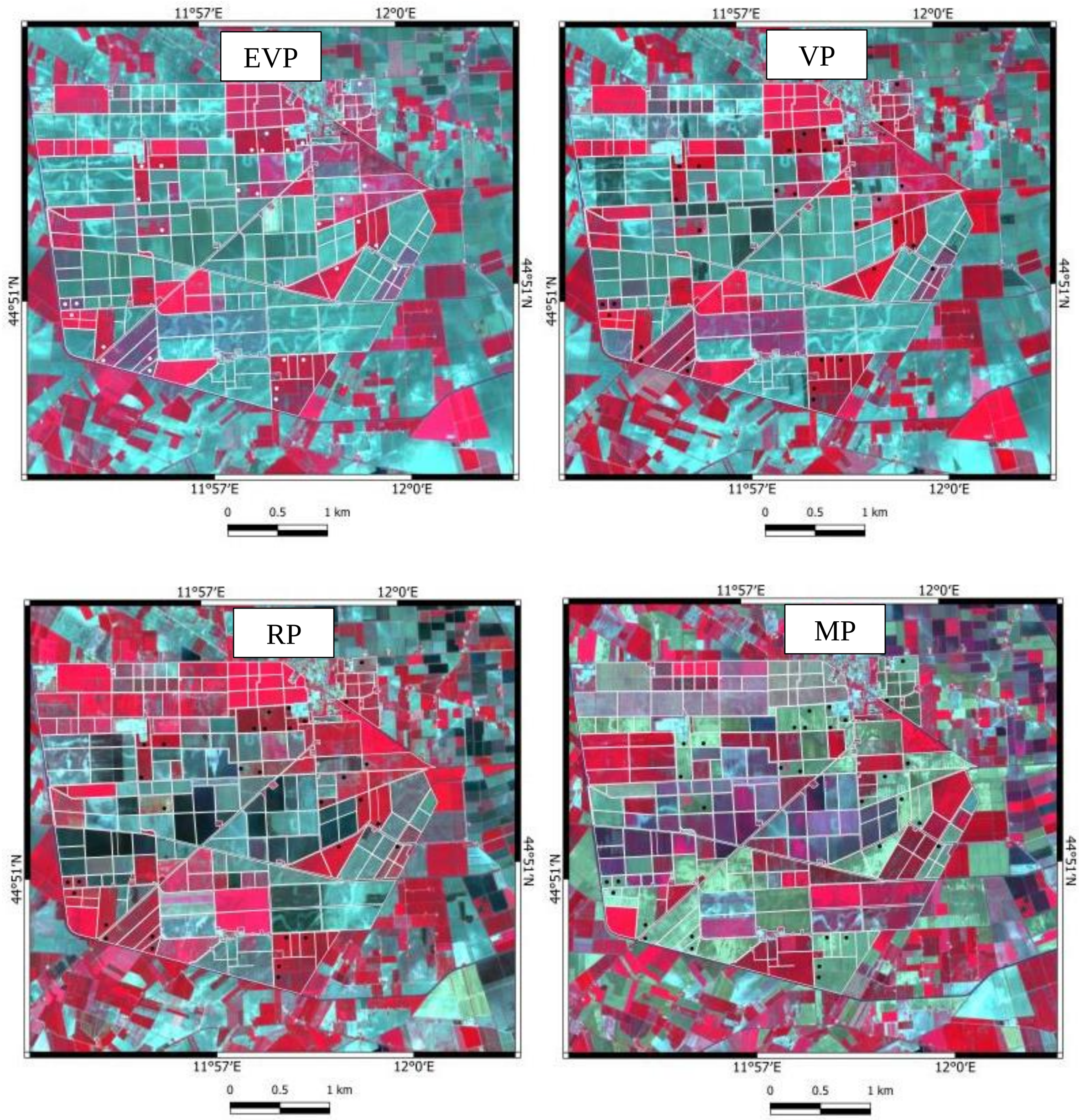


Figure 2. False color composite (band 8, 4, 3) at different growth stages of winter wheat grown at the Bonifiche Ferraresi farm in Emilia-Romagna, Italy during 2020. Where, EVP- early vegetative phase, VP- vegetative phase, RP- reproductive phase, MP- maturity phase. Dots represents sampling points for wheat yield calculation.

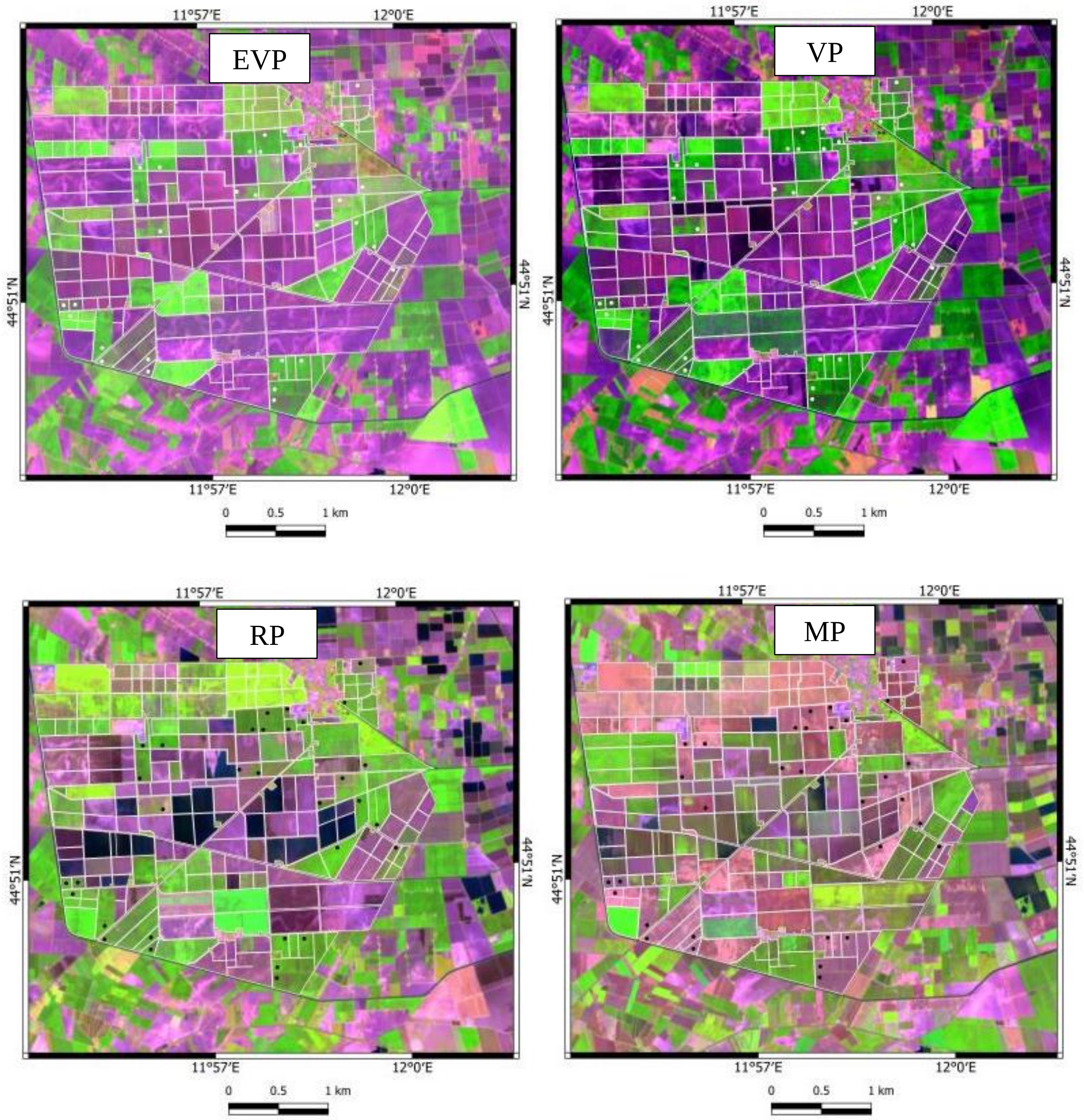


Figure 3. Agriculture False color composite (band 11, 8, 2) at different growth stages of winter wheat grown at the Bonifiche Ferraresi farm in Emilia-Romagna, Italy during 2020. Where, EVP- early vegetative phase, VP- vegetative phase, RP- reproductive phase, MP- maturity phase. Dots represents sampling points for wheat yield calculation.

Q. 2. Which spectral vegetation index produces the highest correlation with crop yield? What image date and crop stage (early vegetative, vegetative, reproductive, ripening/maturity) produces the highest correlation with crop yield? Is the relationship linear or non-linear? Why do you think the given index and crop stage are the best performing?

Normalized Difference Vegetation Index (NDVI) produced significantly highest positive correlation (0.85) with yield at reproductive stage (23 May 2020) followed by Normalized Difference Red-edge 1 (0.84) at this stage (Figure 3, 4, 5, 6). According to many scientists, at this stage photosynthesis reach at pick and all the organs are well developed for grain filling. NDVI can efficiently detect the chlorophyll absorption in green band and reflectance in NIR region because of maximum canopy coverage as a result of increased biomass.

Positive and significant correlation between spectral bands and grain yield were also observed from NDre1 (0.74) and NDVI (0.72) at vegetative phase, NDre1 (0.56) and NDVI (0.51) at early vegetative stage.

At maturity stage (22 June 2020), the correlation between yield and the indices are poor because the lack of chlorophyll and no photosynthesis occur as a result crop canopy becomes brown.

The relationship appears linear from scatter plots. The coefficient of determination (R^2) did not increased in the simple linear regression of the log transformed yield than without transformation. For example, at reproductive phase functional relationship between NDVI and grain yield shows higher R^2 (0.72) value than log transformed yield (0.65), which indicates the relationship is linear (Fig. 4).

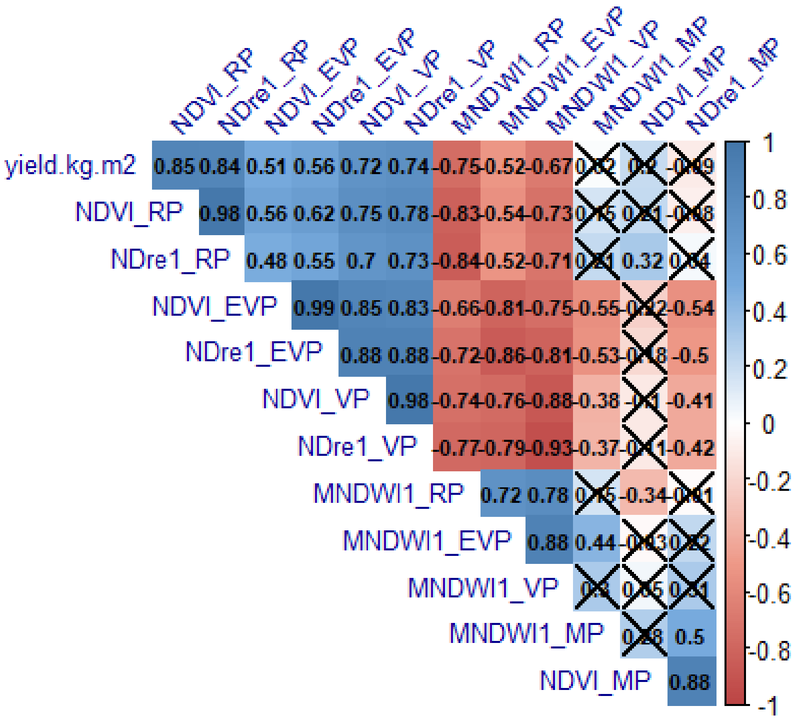


Fig. 3. Correlation matrix among the vegetation indices and grain yield of wheat.

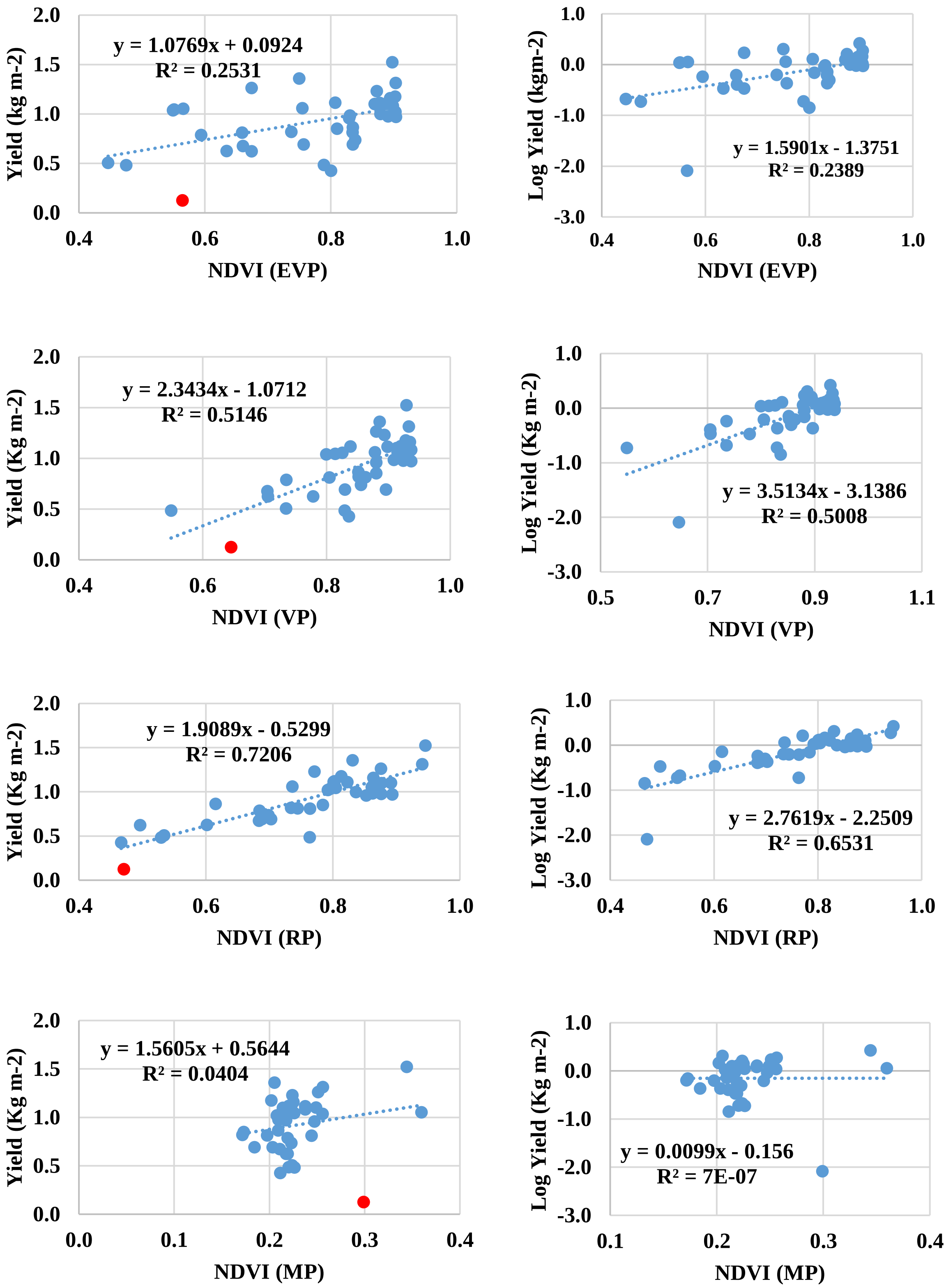


Fig. 4. Functional relationships between grain yield and its log transformation with NDVI at different growth stages of wheat

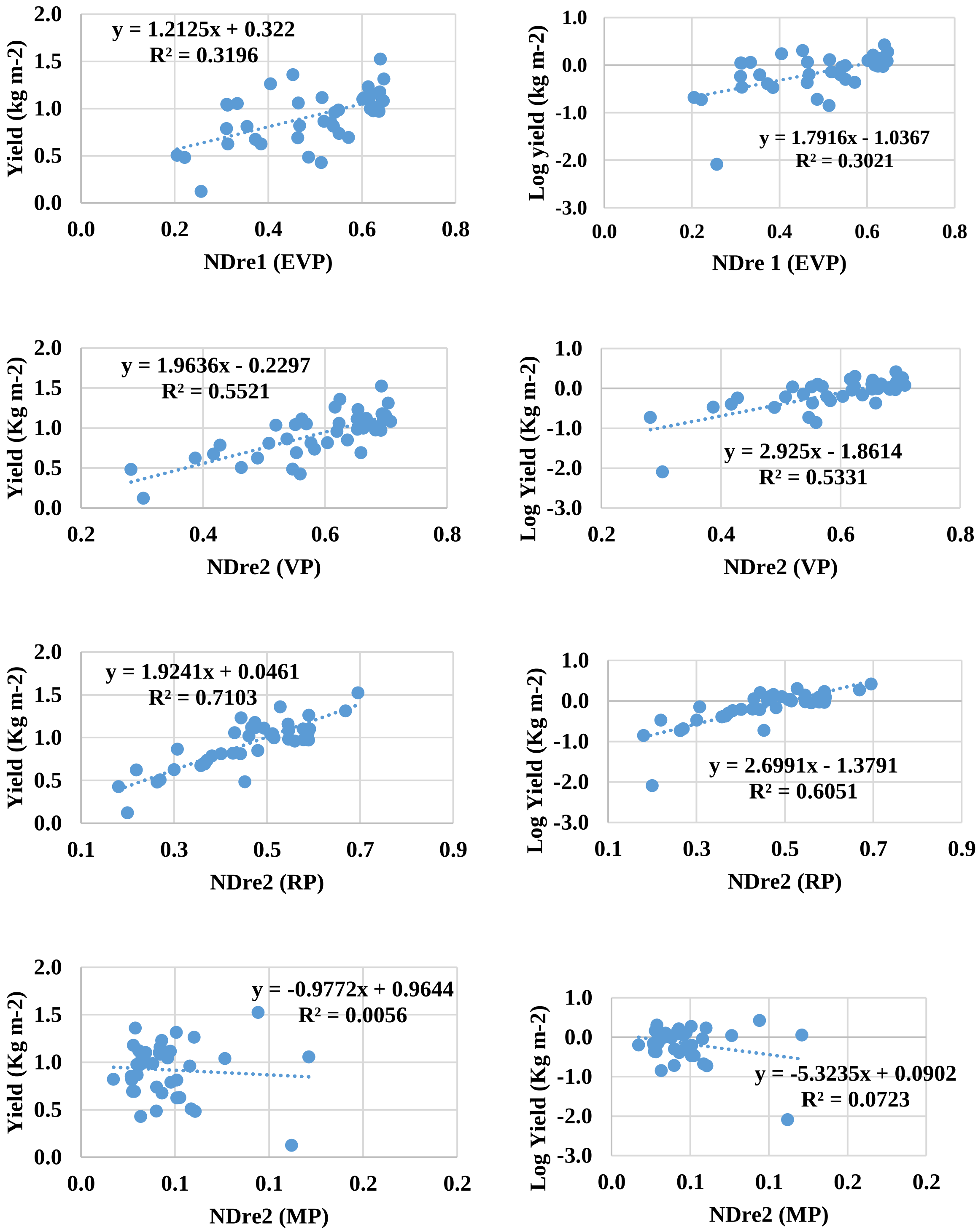


Fig. 5. Functional relationships between grain yield and its log transformation with NDre2 at different growth stages of wheat

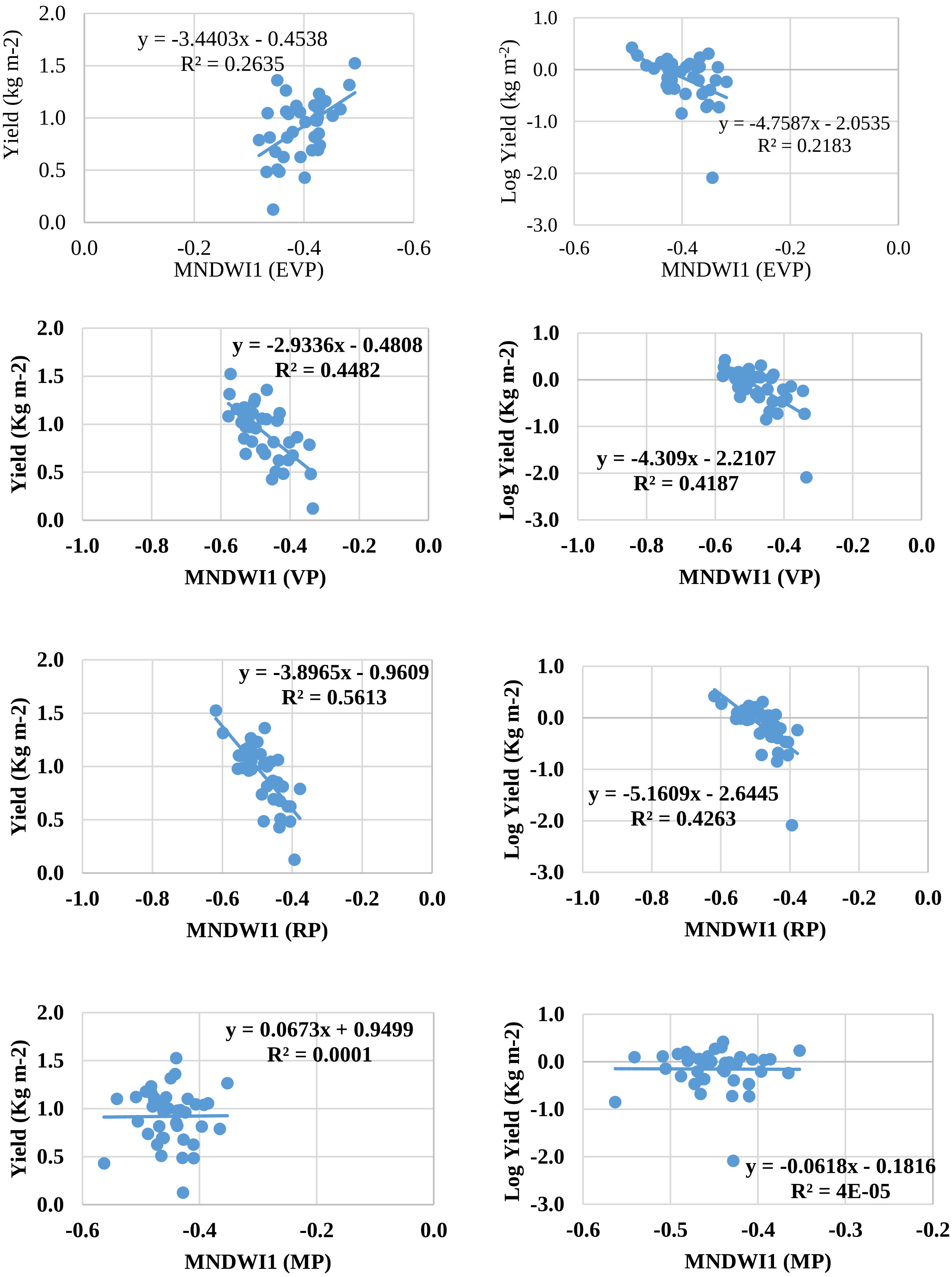
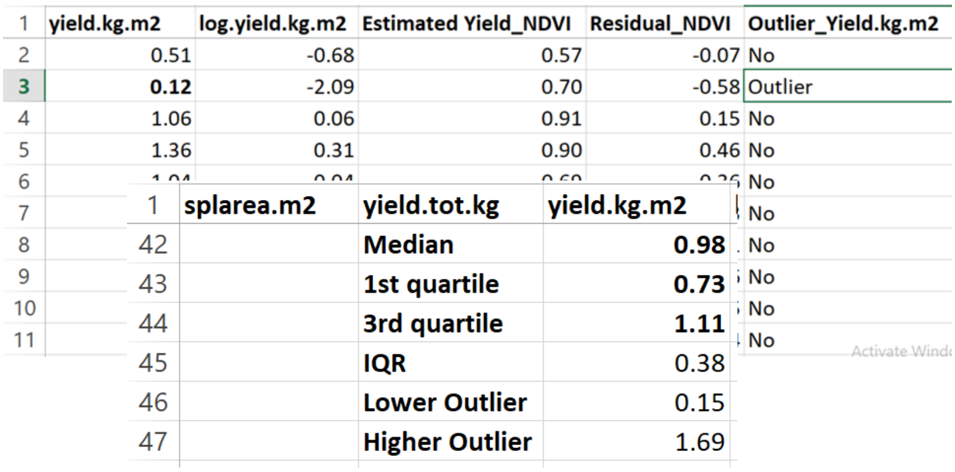


Fig. 6. Functional relationships between grain yield and its log transformation with MNDWI1 at different growth stages of wheat



1	yield.kg.m2	log.yield.kg.m2	Estimated Yield_NDVI	Residual_NDVI	Outlier_Yield.kg.m2
2	0.51	-0.68	0.57	-0.07	No
3	0.12	-2.09	0.70	-0.58	Outlier
4	1.06	0.06	0.91	0.15	No
5	1.36	0.31	0.90	0.46	No
6	[illegible]	[illegible]	[illegible]	[illegible]	No
7					No
8					No
9					No
10					No
11					No

1	splarea.m2	yield.tot.kg	yield.kg.m2
42		Median	0.98
43		1st quartile	0.73
44		3rd quartile	1.11
45		IQR	0.38
46		Lower Outlier	0.15
47		Higher Outlier	1.69

Fig. 7. Outlier detection using interquartile range using spreadsheet function.

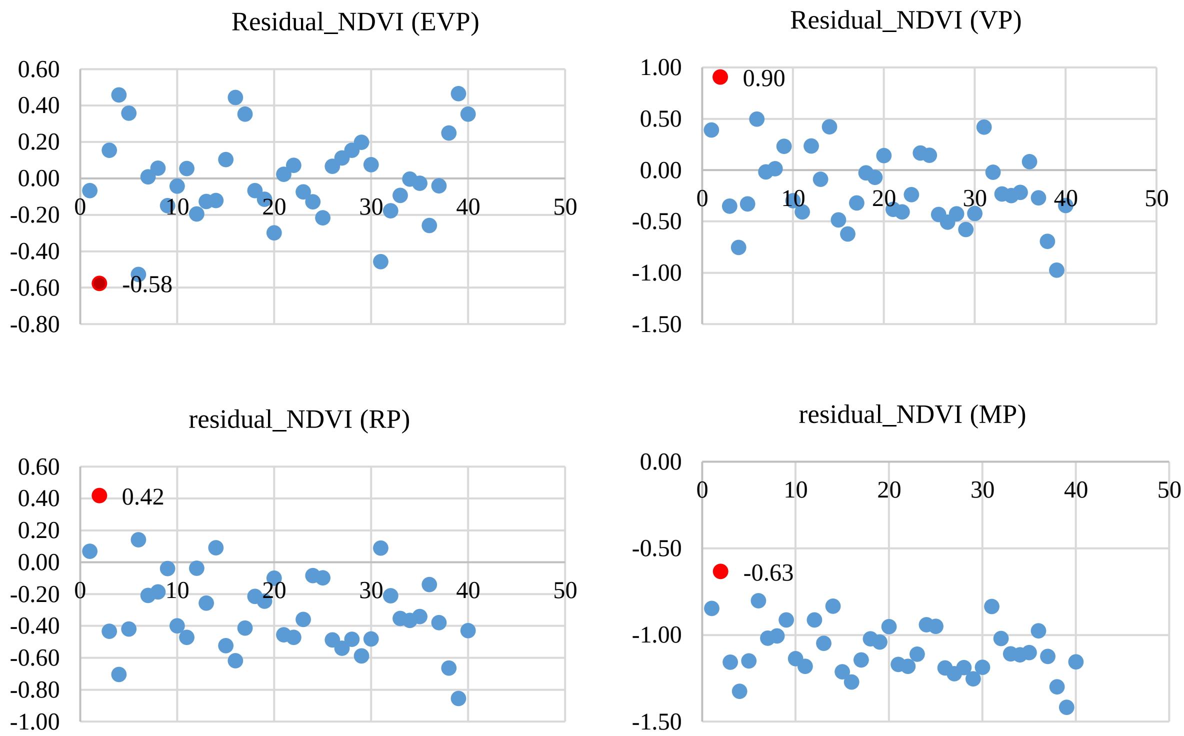


Fig. 8. Residual plots of NDVI at different growth stages of wheat

Q.3. Examine the scatter and residual plots. Do you see any potential outliers? Would you remove these values? Why or why not?

Scatter plots (Fig.4) and residual plots (Fig. 8) shows the potential outliers represented in red dot. Which is again demonstrated by the outlier detection through interquartile range formula in the spreadsheet (Fig. 7). The DWBNF0202 has far lower yield (0.12 kg m^{-2}) compared to other sampling points, which is detected as outlier. However, after removing this outlier the functional relationship did not increase R^2 value. This plot would have disease infested or some experimental error might have happened.

Q.4. Sometimes the data is non-linear. Transform the yield data using the natural log. Does the transformation improve the regression? Why or why not?

Log transformation of yield data did not improve the regression performance because the relationship is linear, which have been demonstrated in the question 2.

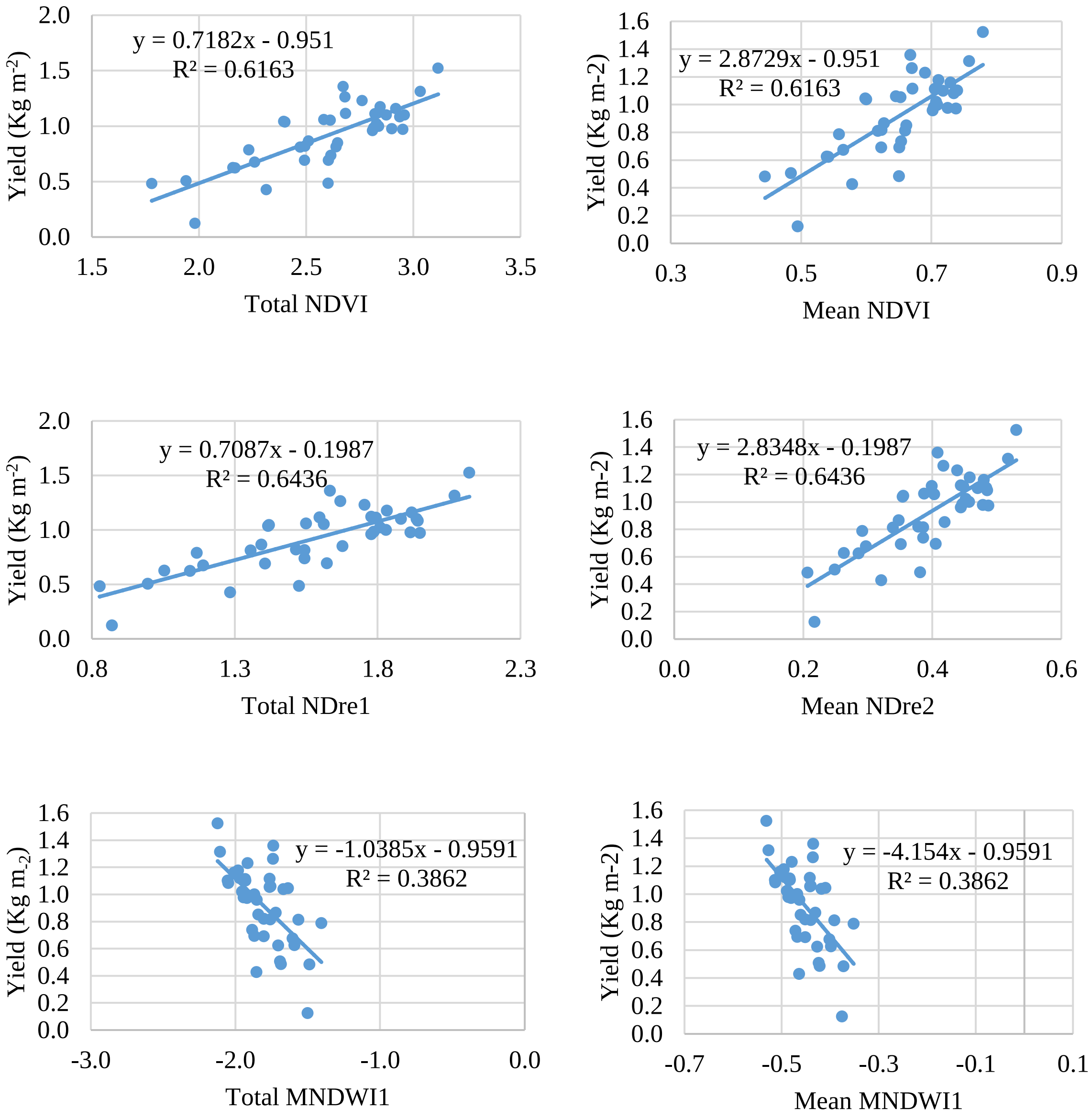


Fig. 9. Linear regression and scatterplots between grain yield and using seasonal total and mean values of different indices

Q.5. Single date images usually produce the regression poorer estimates than multitude image composites. Now sum the indices (e.g., NDVI) and take the average (e.g., meanNDVI) over the growing season. Repeat your regression analysis. Do seasonal composites improve estimation of crop yield?

The summation and average of indices did not improve regression performance. Highest R^2 (0.64) was observed from NDre1 both from total and average (Fig. 9). However, the total and average indices did not predict yield better than single observation at reproductive stage. Because only four images were summed and averaged. Better prediction could be achieved if more number of images were used in this calculations.

Conclusion

Overall, wheat growth stages were better visualized with false-colour image composites (band 8, 4, 3). Among the three vegetation indices, NDVI from reproductive phase better predicted wheat yield and the relationship was found linear. However, total and average indices values did not improved the prediction performance. If more number of images are used in the calculation the prediction performance could be improved.