Supplementary material

Figure S1. Monthly rainfall (blue bars), average maximum temperatures (continuous lines) and average minimum temperatures (dashed lines) during the experiment in the Yaqui Valley (Sonora, Mexico).

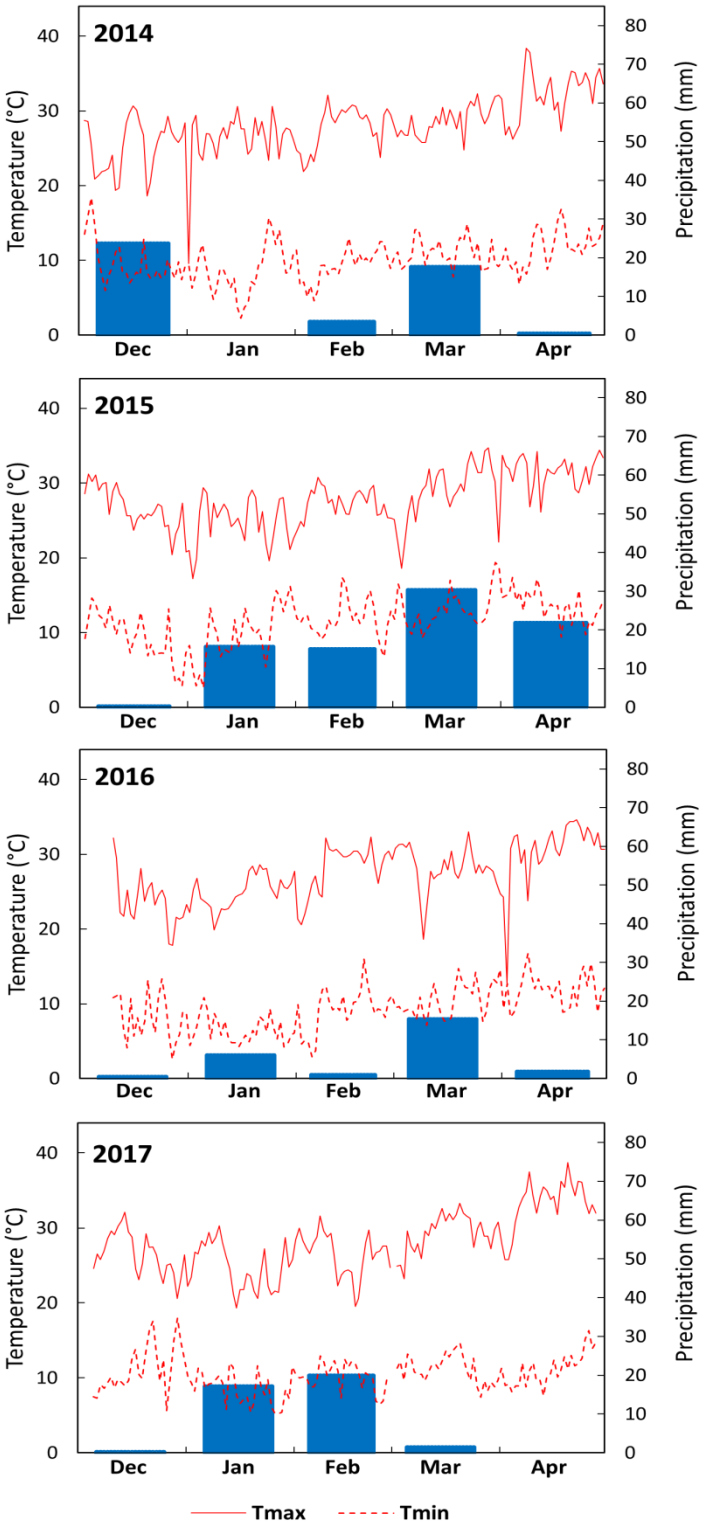

Table S1. Critical dates (sowing, harvest, fertilization, irrigation) for conventional tillage (CT) and conservation tillage (CS) treatments and for the two irrigation blocks during the 4 experimental years.

	2014		2015		2016		2017	
	CT	**CS**	**CT**	**CS**	**CT**	**CS**	**CT**	**CS**
Sowing	27/11/2013	27/11/2013	25/11/2014	27/11/2014	11/12/2015	10/12/2015	06/12/2017	05/12/2016
First fertilization	8/11/2013	27/11/2013	7/11/2014	27/11/2014	23/11/2014	10/12/2015	16/11/2016	05/12/2016
Harvest	29/04/2014		20/04/2015		04/05/2016		29/04/2017	
	Two post-plant irrigations							
Second fertilization	31/01/2014		30/01/2015		13/02/2016		10/02/2017	
First irrigation	31/01/2014		30/01/2015		13/02/2016		10/02/2017	
Second irrigation	01/03/2014		27/02/2015		11/03/2016		11/03/2017	
	Four post-plant irrigations							
Second fertilization	20/01/2014		30/01/2015		05/02/2016		10/02/2017	
First irrigation	03/01/2014		9/01/2015		15/01/2016		12/01/2017	
Second irrigation	20/01/2014		30/01/2015		05/02/2016		10/02/2017	
Third irrigation	20/02/2014		20/02/2015		09/03/2016		14/03/2017	
Fourth irrigation	13/03/2014		12/03/2015		29/03/2016		05/04/2017	

Table S2. Selected dates of image acquisition and the corresponding wheat growth stage (GS) of the two irrigation blocks during the 4 experimental years. Names of the relevant GSs for the analysis are in parentheses in addition to the decimal code.

Date of image acquisition	Growth stage of block with two post-plant irrigations	Growth stage of block with four post-plant irrigations
2014		
10/01/2014	GS31* (beginning of stem elongation)	GS23
17/01/2014	GS37 (end of stem elongation)	GS31
30/01/2014	GS41 (early boot stage)	GS37
07/02/2014	GS51 (heading)	GS41
19/02/2014	GS61 (beginning of flowering)	GS51
27/02/2014	GS71 (watery ripe)	GS65
11/03/2014	GS73 (early milk)	GS71
17/03/2014	GS75 (medium milk)	GS73
28/03/2014		GS75
2015		
04/02/2015	GS41	GS37
09/02/2015	GS51	GS41
25/02/2015	GS71	GS61
10/03/2015		GS73
15/03/2015	GS75	
23/03/2015		GS75
2016		
26/02/2016	GS41	GS37
03/03/2016	GS61	GS51
09/03/2016	GS65	GS61
15/03/2016	GS71	
22/03/2016		GS73
2017		
17/01/2017	GS31	GS24
02/02/2017	GS37	GS31
10/02/2017	GS41	GS37
16/02/2017	GS51	GS37
22/02/2017		GS41
15/03/2017	GS71	GS51
05/04/2017	GS75	GS73

*Growth stage reported as in Meier (1997). Growth stages of mono-and dicotyledonous plants. Blackwell Wissenschafts-Verlag.

Table S3. Reflectance used to calculate the airborne indices (Table S5) and the exact bands of the hyperspectral image from which the reflectance was extracted. Where R_i is the reflectance extracted from the *i* band of the hyperspectral image.

Reflectance used to calculate the airborne indices	**Wavelengths (nm) of the bands from which the reflectance was extracted**
R_{400}	398
R_{450}	449
R_{539}	538
R_{550}	550
R_{570}	(567 + 574) / 2*
R_{670}	670
R_{700}	700
R_{704}	707
R_{720}	(714 + 722) / 2*
R_{750}	751
R_{790}	(788 + 795) / 2*
R_{800}	(795 + 803) / 2*
R_{815}	818

*The reflectance was calculated as the average of the reflectance extracted from the two bands.

Table S4. Airborne hyperspectral indices calculated in this study.

Index	Equation	Reference
Greenness or structural indices		
Normalized difference vegetation index (NDVI)	$NDVI = (R_{800} - R_{670})/(R_{800} + R_{670})$	[54]
Reformed difference vegetation index (RDVI)	$RDVI = (R_{800} - R_{670})/(R_{800} + R_{670})^{0.5}$	[55]
Optimized soil-adjusted vegetation index (OSAVI)	$OSAVI = (1 + 0.16) \times (R_{800} - R_{670})/(R_{800} + R_{670} + 0.16)$	[45]
Normalized green	$NG = R_{800}/R_{550}$	[52]
Chlorophyll indices		
Red-edge optical reflectance	R_{750}/R_{710}	[53]
Double peak canopy nitrogen index	$DCNI = (R_{720} - R_{700})/(R_{700} - R_{670})/(R_{720} - R_{670} + 0.03)$	[56]
Modified chlorophyll absorption ratio index (MCARI)	$MCARI = [(R_{700} - R_{670}) - 0.2(R_{700} - R_{550})] (R_{700}/R_{670})$	[52]
Transformed chlorophyll absorption in reflectance index (TCARI)	$TCARI = 3 [(R_{700} - R_{670}) - 0.2 (R_{700} - R_{550}) (R_{700}/R_{670})]$	[46]
Combined TCARI/OSAVI	TCARI/OSAVI	[9]
Normalized difference red-edge (NDRE)	$NDRE = (R_{790} - R_{720})/(R_{790} + R_{720})$	[51]
Red-edge chlorophyll index ($CI_{red\ edge}$)	$CI_{red\ edge} = (R_{800}/R_{720}) - 1$	[47]
Xanthophyll indices		
Photochemical reflectance index (PRI)	$PRI = (R_{570} - R_{539})/(R_{570} + R_{539})$	[48]
Blue/green/NIR ratio indices		
BGI1	$BGI_1 = R_{400}/R_{550}$	[49]
BGI2	$BGI_2 = R_{450}/R_{550}$	[50]
Canopy chloropyhll content		
Canopy chlorophyll content (CCC)	$CCC=0.325(R_{815}/R_{704})-0.358$	[57]
Canopy chlorophyll content index (CCCI)	$CCCI=(NDRE-NDRE_{min})/(NDRE_{max}-NDRE_{min})$	[51]
Nitrogen planar domain index	$NDPI=(CI_{red\ edge}-CI_{red\ edge\ min})/(CI_{red\ edge\ max}-CI_{red\ edge\ min})$	[20]

Figure S6. Correlograms of the vegetation indices calculated as in Table S4. The value inside each square of the grid is the coefficient of correlation (r value) at $P \leq 0.01$ for different years: a) 2014, b) 2015, c) 2016 and d) 2017.

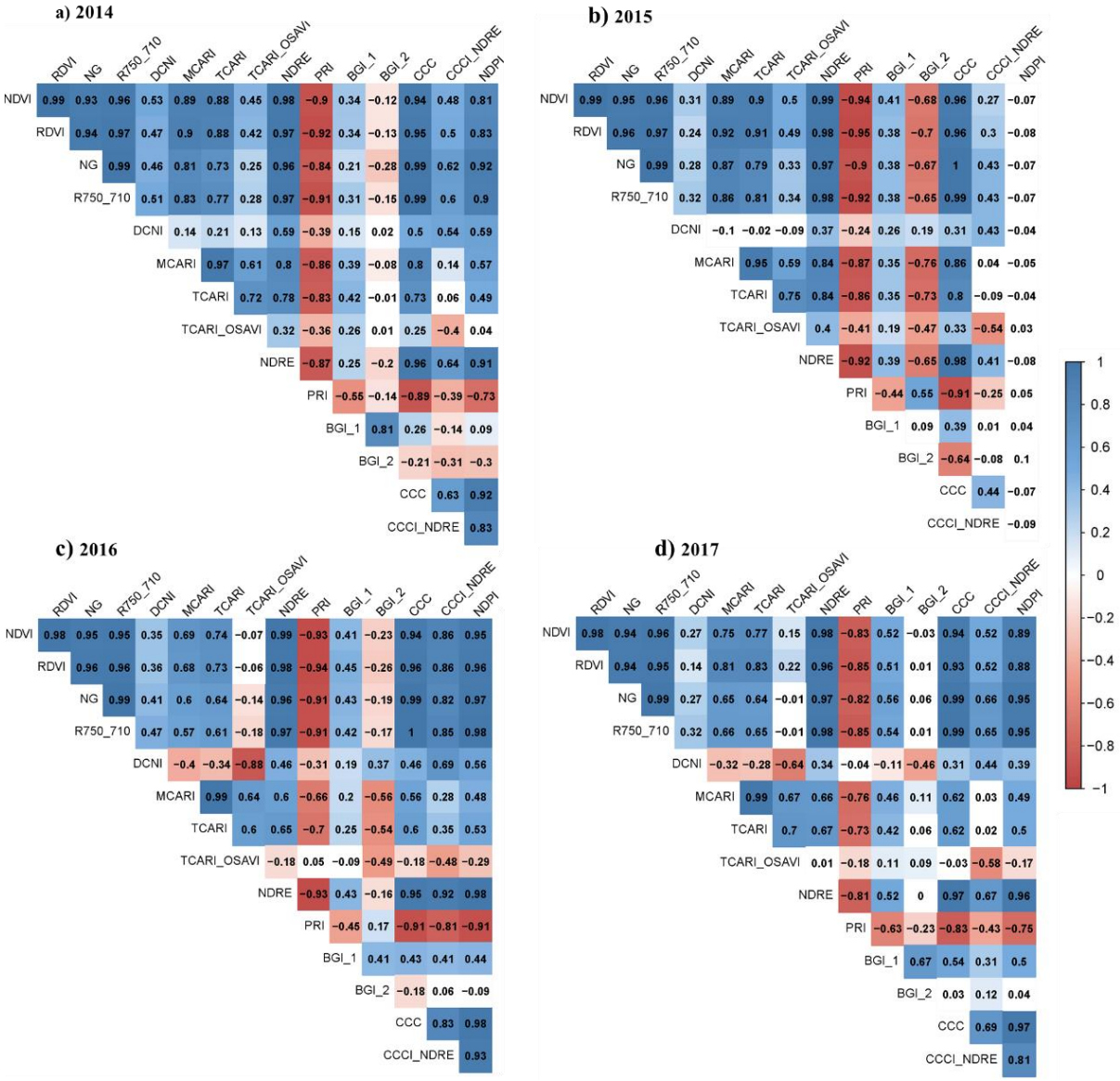

Figure S7. Linear and exponential relationship between spectral indices (NDVI, R_{750}/R_{710} and CCC) and crop variables (yield, biomass and N output) at flowering. The X-axis represents the spectral index values and the Y-axis the crop variable values. Dotted lines are the adjusted linear (black) and exponential (red) model and R^2 its coefficient of determination.

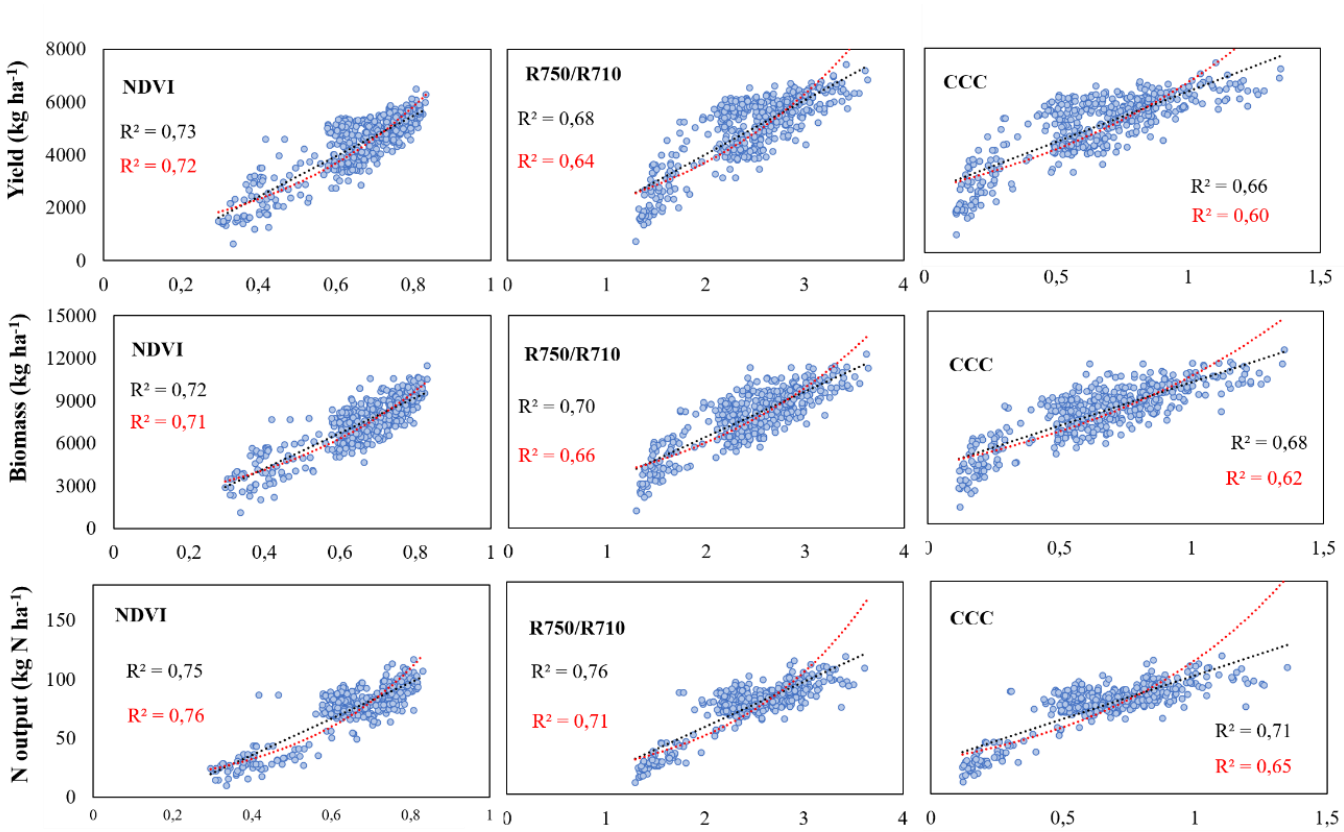

Table S5. Results (P-value) of the analysis of variance between irrigation (irr), tillage (till), N treatment (nlevel) and year, and their combined interactions on the wheat grain yield, total above-ground biomass, grain N concentration (GNC) and N output at harvest.

	Grain yield	**Biomass**	**GNC**	**N output**
irr	**0.000**	**0.000**	**0.000**	**0.000**
till	0.061	**0.007**	**0.004**	**0.020**
nlevel	**< 2.2x10^{-16}**	**< 2.2x10^{-16}**	**< 2.2x10^{-16}**	**< 2.2x10^{-16}**
year	**< 2.2x10^{-16}**	**< 2.2x10^{-16}**	**< 2.2x10^{-16}**	**< 2.2x10^{-16}**
irr:till	**0.003**	**0.002**	**0.000**	**0.001**
irr:nlevel	**< 2.2x10^{-16}**	**0.000**	**< 2.2x10^{-16}**	**< 2.2x10^{-16}**
till:nlevel	0.713	0.556	0.370	0.913
irr:year	**0.000**	**0.002**	**< 2.2x10^{-16}**	**0.000**
till:year	**0.001**	0.065	**0.000**	**0.000**
nlevel:year	0.193	0.096	**< 2.2x10^{-16}**	**0.000**
irr:till:nlevel	**0.018**	0.583	0.068	**0.026**
irr:till:year	**0.018**	**0.000**	**0.000**	0.272
irr:nlevel:year	**0.001**	0.247	**< 2.2x10^{-16}**	**0.041**
till:nlevel:year	**0.000**	**0.022**	0.192	**0.000**
irr:till:nlevel:year	0.951	0.184	**0.001**	0.914

P-values in bold are significant at 5% probability or lower.

Figure S9. Biomass for combined tillage and irrigation factors, for each N treatment, over the 4 years. Small bars indicate SE.

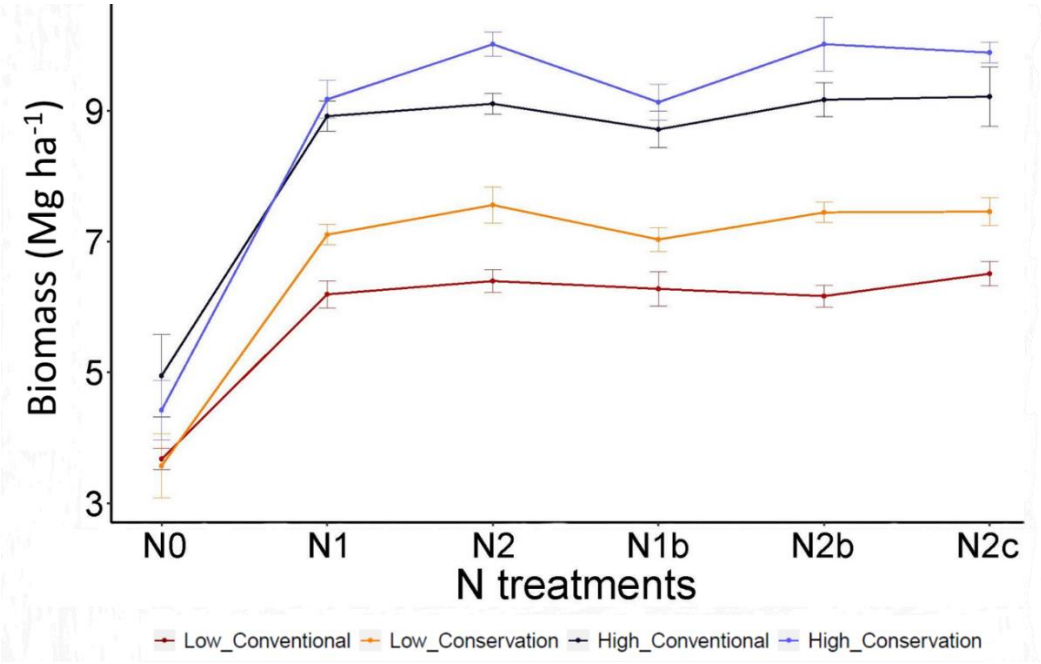

Figure S10. Spectral reflectance (%) from 400 nm to 850 nm, for the different N treatments (N0, N1, N1b, N2, N2b, N2c) with conventional tillage, either with two post-plant irrigations (top row), or with four post-plant irrigations (bottom row), at five growth stages, in 2014.

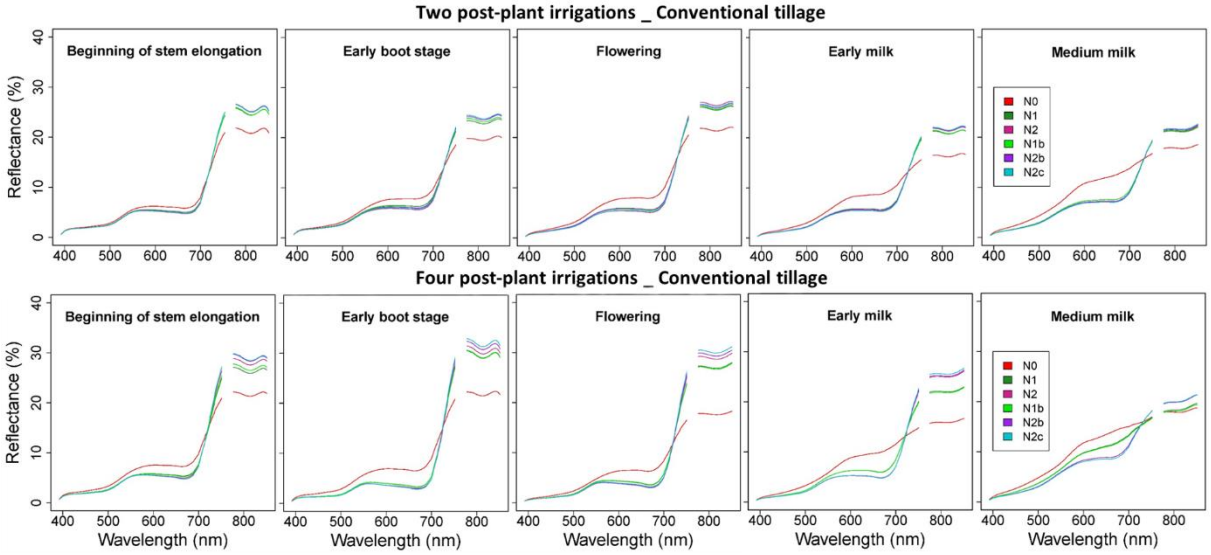

Figure S11. Contour maps of the coefficient of determination (R^2) between the NDSI (R_i, R_j) and grain yield using the complete combinations of two wavelengths at *i* and *j* nm within the range 400–850 nm. At each growth stage, data from the different years were merged to build the figure (4 years for all the GSs, and 2 for the end of stem elongation and early milk stages).

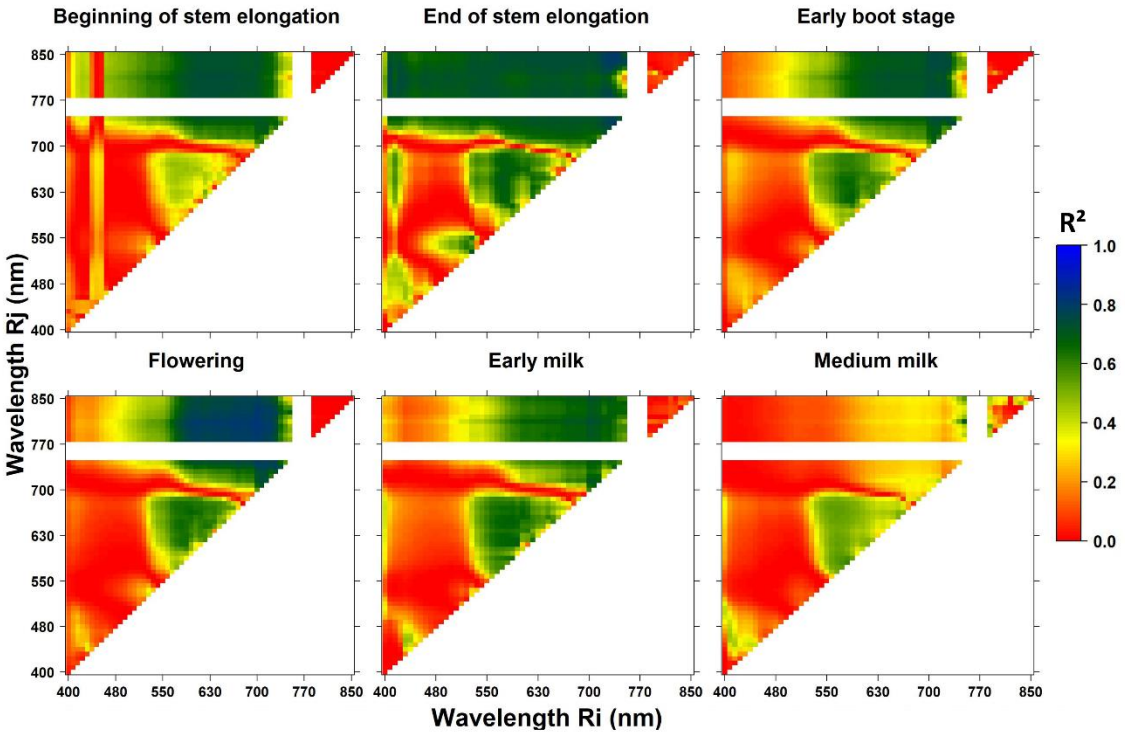

Figure S12. Contour maps of the root mean square error (RMSE, kg ha^{-1}) between the NDSI (R_i, R_j) and biomass using the complete combinations of two wavelengths at *i* and *j* nm within the range 400–850 nm. At each growth stage, data from the different years were merged to build the figure (4 years for all the GSs and 2 for the end of stem elongation and medium milk stages).

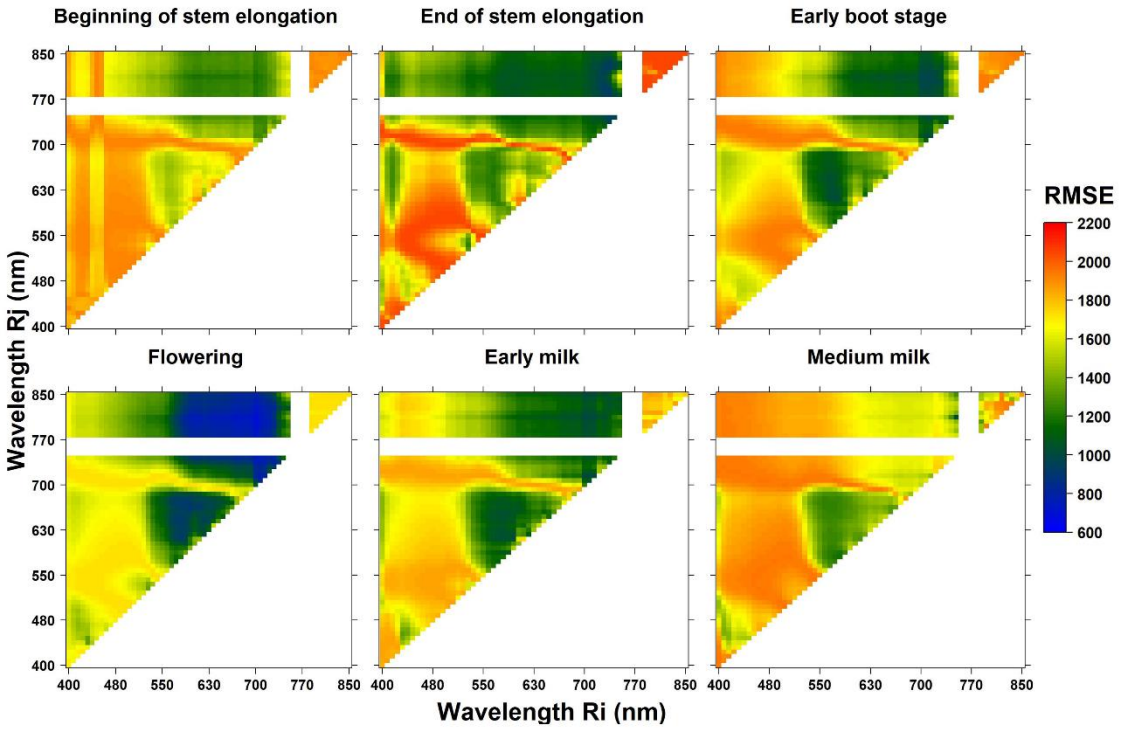

Figure S13. Contour maps of the coefficient of determination (R^2) between the NDSI (R_i, R_j) and biomass using the complete combinations of two wavelengths at *i* and *j* nm within the range 400–850 nm. At each growth stage, data from the different years were merged to build the figure (4 years for all the GSs and 2 for the end of stem elongation and medium milk stages).

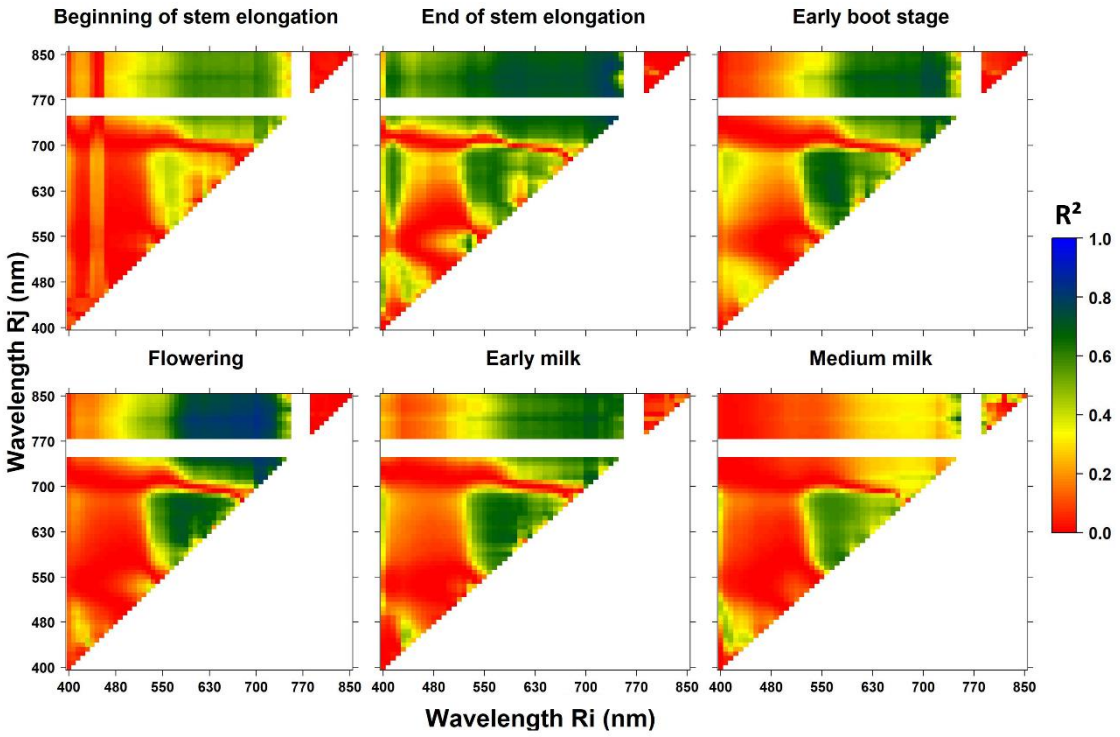

Figure S14. Contour maps of the coefficient of determination (R^2) between the NDSI (R_i, R_j) and Grain N concentration using the complete combinations of two wavelengths at *i* and *j* nm within the range 400–850 nm, at different growth stages for different years: a) 2014, b) 2015, c) 2016 and d) 2017.

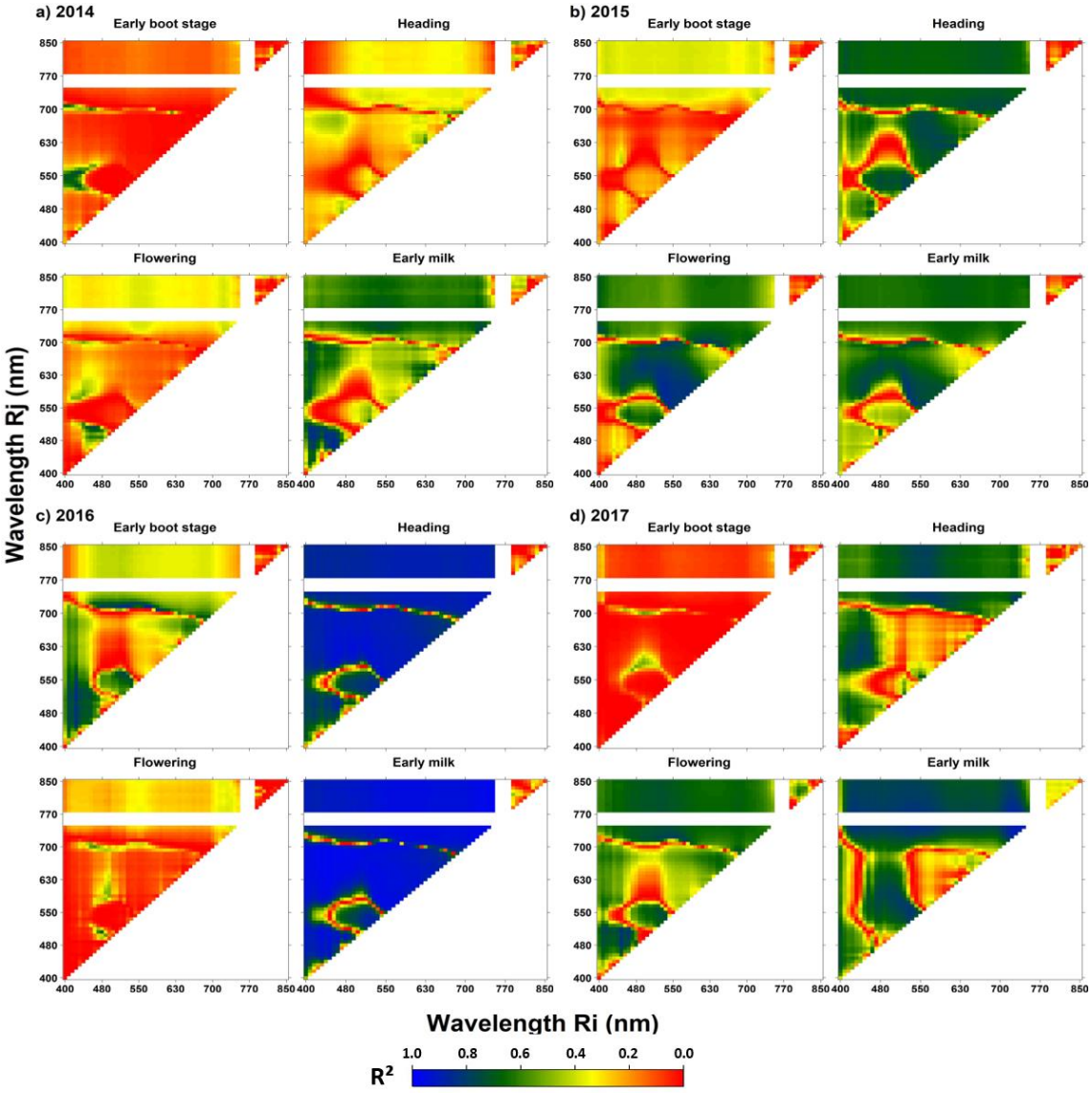

Figure S15. Contour maps of the coefficient of determination (R^2) between the NDSI (R_i, R_j) and N output using the complete combinations of two wavelengths at *i* and *j* nm within the range 400–850 nm. At each growth stage, data from the different years were merged to build the figure (4 years for all the GSs and 2 for the end of stem elongation and medium milk stages).