

## Supplementary Materials

**Table S1.** Year wise soil information of the experimental site.

Level (cm)	Nmin (kg/ha). 2015	Nmin (kg/ha). 2016	Nmin (kg/ha). 2017
0-30	13.6	22.2	27.1
30-60	24.3	10.8	36.1
60-90	27.0	10.1	25.1
Total	<b>64.9</b>	<b>43.1</b>	<b>88.3</b>
<b>Soil (mg)/100 g</b>			
P <sub>2</sub> O <sub>5</sub>	15	20	13
K <sub>2</sub> O	21	17	19
MgO	8	9	9
PH	6.6	6.8	7.0
Org. subs (%)	1.8	1.6	2.4

**Table S2.** Fertilizer application, amount and the developmental stage of crop.

Date of Application	Treatments	N- Fertilizer <sup>a</sup>	BBCH <sup>b</sup>	Amount of Fertilizer(kg/ha)
12/3/2015	HN-NF, HN-WF	KAS	22	50
15/4/2015	HN-NF, HN-WF	KAS	30	45
27/5/2015	HN-NF, HN-WF	KAS	49-65	60
17/3/2016	HN-NF, HN-WF	KAS	25	50
6/4/2016	HN-NF, HN-WF	KAS	30	55
27/5/2016	HN-NF, HN-WF	KAS	51-59	60
24/3/2017	HN-NF, HN-WF	KAS	25	50
19/4/2017	HN-NF, HN-WF	KAS	31-32	25
29/5/2017	HN-NF, HN-WF	KAS	49-69	60

<sup>a</sup> The treatment LN-NF did not receive further nitrogen fertilization; KAS means Kalkammonsalpeter (Calcium ammonium nitrate). It contains 27 kg N/100 kg (dt) KAS fertilizer, including 13.5 kg/dt for each of NH<sub>4</sub> and NO<sub>3</sub>, and 55 kg CaO (calcium oxide) per 100 kg N and 4 kg MgO (magnesium oxide) per 100 kg N.

<sup>b</sup> BBCH means Biologische Bundesanstalt, Bundessortenamt und CHEmische Industrie.

**Table S3.** Application of herbicide, fungicide, and growth regulators on different developmental stages of the wheat.

Year	Treatment	Plant protection/Growth regulator			
		Application round	Date (d.m.Y)	Amount	Spraying agents (ative ingredients <sup>a</sup> )
2015	low nitrogen, no fungicide (LN-NF)	1st herbicide	17.03.2015	150 gr/ha + 0..7 l/ha + 1.5 l/ha	Broadway 68.3 g/kg Pyroxulam + 22.8 g/kg Florasulam + 68.3 g/kg Cloquintocet-Mexyl (Safener) + FHS (mesosulfuron) + Arelon Top (isoproturon)
		2nd herbicide	11.05.2015	1.5 l/ha	MCPA (2-methyl-4-chlorophenoxyacetic acid)
		1st insecticide	12.06.2015	75 ml/ha	Karate Zeon (250 g/L Lambda-Cyhalothrin; Oxiran)
	high nitrogen, no fungicide (HN-NF)	1st herbicide	17.03.2015	150 gr/ha + 0.7 l/ha + 1.5 l/ha	Broadway + FHS + Arelon Top
		2nd herbicide	11.05.2015	1.5 l/ha	MCPA
		1st insecticide	12.06.2015	75 ml/ha	Karate Zeon
		1st growth regulator	07.04.2015	1.0 l/ha	CCC (Chlormequat-chloride)
		2nd growth regulator	16.04.2015	0.5 l/ha + 0.3 l/ha	CCC + Moddus (Trinexapac-ethyl)
	high nitrogen, with fungicide (HN-WF)	1st herbicide	17.03.2015	150 gr/ha + 0.7 l/ha + 1.5 l/ha	Broadway + FHS + Arelon Top
		2nd herbicide	11.05.2015	1.5 l/ha	MCPA
		1st insecticide	12.06.2015	75 ml/ha	Karate Zeon
		1st fungicide	07.04.2015	1.1 l/ha	Diamant (114 g/l Pyraclostrobin (F 500) + 43 g/l Epoxiconazol + 214 g/l Fenpropimorph)
		2nd fungicide	17.04.2015	1.75 l/ha	Capallo (75 g/litre metrafenone+ 62.5 g/litre epoxiconazole + 200 g/litre fenpropimorph)
		3rd fungicide	11.05.2015	1.25 l/ha	Input classic (160 g/l Prothioconazol 300 g/l Spiroxamine)
		4th fungicide	27.05.2015	1.0 l/ha + 1.0 l/ha	Osiris (37.5 g/l Epoxiconazol + 27.5 g/l Metconazol) + SkywayXpro (75 g/L bixafen, + 100 g/L prothioconazole + 100 g/L tebuconazole).
		1st growth regulator	07.04.2015	1.0 l/ha	CCC
		2nd growth regulator	16.04.2015	0.5 l/ha + 0.3 l/ha	CCC + Moddus
2016	low nitrogen, no fungicide (LN-NF)	1st herbicide	16.11.2015	4.0 l/ha	Malibu (300 g/l Pendimethalin + 60 g/l Flufenacet)
		2nd herbicide	08.04.2016	180 g/ha	Hoestar super (125 g/kg Amidosulfuron + 12.5 g/kg Iodosulfuron-methyl-natrium + 125 g/kg Mefenpyr-diethyl)
		1st insecticide	10.06.2016	75 ml/ha	Karate Zeon
	high nitrogen, no fungicide (HN-NF)	1st herbicide	16.11.2015	4.0 l/ha	Malibu
		2nd herbicide	08.04.2016	180 g/ha	Hoestar super
		1st insecticide	10.06.2016	75 ml/ha	Karate Zeon
		1st growth regulator	12.04.2016	0.5 l/ha + 0.3 l/ha	CCC + Moddus

2017	high nitrogen, with fungicide (HN-WF)	1st herbicide	16.11.2015	4.0 l/ha	Malibu
		2nd herbicide	08.04.2016	180 g/ha	Hoestar super
		1st insecticide	10.06.2016	75 ml/ha	Karate Zeon
		1st fungicide	12.04.2016	2.0 l/ha	Capallo
		2nd fungicide	20.04.2016	0.2 l/ha + 1.0 l/ha	Alto (Cyproconazole ) + Bravo (500 g/l chlorothalonil)
		3rd fungicide	02.05.2016	1.2 l/ha + 1.0 l/ha	Adexar (62.5 g/l epoxiconazole+ 62.5 g/litre fluxapyroxad); Credo (100g/l picoxystrobin + 500g/l chlorothalonil)
		4th fungicide	19.05.2016	1.0 l/ha	Input classic
		1st growth regulator	12.04.2016	0.5 l/ha + 0.3 l/ha	CCC + Moddus
	low nitrogen, no fungicide (LN-NF)	1st herbicide	03.11.2016	4.0 l/ha	Malibu
		2nd herbicide	15.05.2017	1.5l/ha	MCPA
		1st insecticide	02.06.2017	75 ml/ha	Karate Zeon
	high nitrogen, no fungicide (HN-NF)	1st herbicide	03.11.2016	4.0 l/ha	Malibu
		2nd herbicide	15.05.2017	1.5 l/ha	MCPA
		1st insecticide	02.06.2017	75 ml/ha	Karate Zeon
		1st growth regulator	23.03.2017	1.0 l/ha	CCC
		2nd growth regulator	21.04.2017	0.5 l/ha + 0.3 l/ha	CCC + Moddus
	high nitrogen, with fungicide (HN-WF)	1st herbicide	03.11.2016	4.0 l/ha	Malibu
		2nd herbicide	15.05.2017	1.5 l/ha	MCPA
		1st insecticide	02.06.2017	75 ml/ha	Karate Zeon
		1st fungicide	24.04.2017	2.0 l/ha	Capallo
		2nd fungicide	15.05.2017	1.75 l/ha +1.0 l/ha	Adexar + Credo
		3rd fungicide	31.05.2017	1.25 l/ha + 1.0 l/ha	Osiris + Skyway Xpro
		1st growth regulator	23.03.2017	1.0 l/ha	CCC
		2nd growth regulator	21.04.2017	0.5 l/ha + 0.3 l/ha	CCC + Moddus

<sup>a</sup> the active ingredient of the chemical is given in bracket the first time it appeared in the Table.

**Table S4.** Description of the measured variable in the experiments.

	Traits	Symbols	Method to measure
Yield related traits	Grain yield	GY (Mg/ha)	Harvesting of central part of each plot was done at the end of the growing season and GY (in Mg. ha <sup>-1</sup> ) was recorded automatically with the help of combine harvester.
			Grain moisture was immediately measured after trashing at the end of maturity phase (BBCH99) and GY was corrected to standard moisture of 14%.
	Spike number per meter square	SNms	Spike numbers were counted for within one meter from all cultivars one by one before harvesting and after flowering.
	Kernels number per spike	KNSp	Kernels per spike, Kernels per m <sup>2</sup> were calculated based on the Thousand kernel weight, Spike numbers per meter square, seed weight per meter square
	Kernels number per meter square	KNms	
	Thousand kernel weight	TKW (g)	TKW was calculated in 2016 and 2017. Three replicates of five hundred seeds were counted with the help of automatic seed counter and weighed. The average of the three replicates was multiplied by two to calculate thousand kernel weight.
	Harvest index	HI, PBWms (g/m <sup>2</sup> )	Plants in one-meter row of every plot were manually harvested after maturity (BBCH 99) used by Voss-Fels et al. (2019) and dried in oven at 65°C for 3 days. After drying, plant biomass weight (shoot dry weight plus grain weight) and seed weight was recorded to estimate the HI as the ratio of seed weight to total biomass weight
	Plant biomass weight,		
Physiological trait	Heading date	HD (Days)	Visually recorded as number of days from 1st of January to the date when the ears from approximately 70 % of total tiller in each plot came out from flag leaf sheath at around BBCH59
	Plant height	PH	The measurement was taken from soil to the top of the spike of the main tiller of the plant between BBCH 65-69 growth stage
	Leaf chlorophyll contents	SPAD	SPAD were measured at BBCH 45-49 using SPAD 502 Plus Chlorophyll Meter (Konica Minolta, Japan) from 3 different plants of each plot. The SPAD values were recorded based on light absorption by chlorophyll between the wave length of 650 nm to 940 nm
Disease incidence	Yellow rust	YR	YR severity (leaf area covered by rust pustules) was visually scored using linear phenotyping scale from 1 to 9 according Pask et al. (2012), where 1 is the most resistant and 9 the most susceptible genotype. Scores for each plot (genotype) were estimated by reflection of the average leaf area covered with disease as well as the plot area covered by the yellow rust and their severity.
Grain quality traits	Grain crude protein content	GPC (%)	The grain quality were analyzed using NIRS instrument (Perten, DA 7250) following the manufacturers guidelines.
	Grain starch content	GSC(%)	
	Sedimentation	Sedimentation (%)	
	Grain N yield	GNY (kg.ha <sup>-1</sup> )	The grain N yield was calculated by dividing the grain crude protein yield by the wheat-specific protein factor of 5.7, and multiply the result by the GY

**Table S5.** Summary of analysis of variance of agronomic and grain quality traits of 220 genotypes tested in 3 different environments.

Year	Traits	Wald statistic			CV (%)	H <sup>2</sup>
		G	CS	G*CS		
2015	Agronomic traits					
	GY	6891.7***	2396.56***	2290.12***	26.66	0.73
	SNms	619.17**	313.14**	403.97ns	24.59	0.66
	KNSp	-	-	-	-	-
	KNms	-	-	-	-	-
	TKW	-	-	-	-	-
	HD	3875.16**	131.73**	452.34ns	1.88	0.94
	PH	2853.91**	519.06**	393.14ns	10.82	0.96
	HI	5625.89**	143.5**	3065.83**	13.13	0.73
	PBWms	413.41**	365.87**	449.19 ns	29.72	0.44
	Physiological trait					
	SPAD	-	-	-	-	-
	Disease incidence					
	YR	1497.98**	91.29**	466.34ns	50.97	0.84
	Grain quality traits					
	GPC	2083.91**	3655.31**	519.8ns	12.04	0.87
	GSC	899.82**	316.97**	431.9ns	2.12	0.76
	Sedimentation	227.99 ns	408.07**	431.09ns	38.77	0.22
2016	Agronomic traits					
	GY	13408.46***	4810.61***	2557.78***	25.6	0.8
	SNms	395.81**	254.37**	488.64ns	19.13	0.39
	KNSp	32.4E4***	34.4E3***	39.2E4***	0.301	0.38
	KNms	11.3E5***	65.8E4***	98.1E4***	0.32	0.55
	TKW	9751.16**	4636.41**	2154.6**	13.49	0.87
	HD	881.68**	119.44**	504.05ns	0.71	0.69
	PH	5712.85**	369.1**	1099.83**	10.66	0.91
	HI	1619.80**	725.85**	557.05**	12.16	0.69
	PBWms	396.77**	63.09**	389ns	26.62	0.5
	Physiological trait					
	SPAD	216.1**	512.66**	416.66ns	10.3	0.60
	Disease incidence					
	YR	3848.78**	308.45**	579.39**	62.73	0.92
	Grain quality traits					
	GPC	6861.23**	4956.56**	1532.27**	10.7	0.89
	GSC	574.71**	23.74**	399.47ns	1.41	0.66
	Sedimentation	980.55**	195.82**	595**	24.1	0.95
Table S5 (continued)						
Year	Traits	Wald statistic			CV (%)	H <sup>2</sup>
		G	CS	G*CS		
2017	Agronomic traits					
	GY	4001.76***	1413.27***	1103.88** *	17.36	0.75
	SNms	339.53**	99.85**	343.16ns	17.79	0.48
	KNSp	13.1E4***	13651.95***	15.4E4***	0.237	0.43
	KNms	25.7E5***	15.6E4***	28.5E4***	0.24	0.46
	TKW	14852.82**	190.71**	1898.15**	8.04	0.93
	HD	4327.21**	271.57**	412.95ns	1.46	0.95
	PH	10147.78**	362.09**	888.29**	11.71	0.95

HI	1533.21**	575.06**	539.66**	8.44	0.82
PBWms	375.31**	25.44**	467.58ns	20.01	0.38
<i>Physiological trait</i>					
SPAD	901.86**	88.85**	529.39ns	9.46	0.70
<i>Disease incidence</i>					
YR	-	-	-	-	-
<i>Grain quality traits</i>					
GPC	5857.53**	9955.66**	761.25**	11.39	0.93
GSC	2574.5**	665.49**	699.41**	1.26	0.86
Sedimentation	9302.4**	2909.79**	3171.77**	38.91	0.83

\*\* Significant at the 0.01 probability level, \*\*\* Significant at the 0.001 probability level, † ns, nonsignificant at the 0.05 probability level

**Table S6.** Arithmetic mean and treatments effect of agronomic and grain quality traits of 220 genotypes tested in 3 different CS over three growing seasons.

Traits	2015						2016						2017					
	Means			Treatment effect (%)			Means			Treatment effect (%)			Means			Treatment effect (%)		
	HN-NF	HN-WF	LN-NF	N	NF	F <sub>HN</sub>	HN-NF	HN-WF	LN-NF	N	NF	F <sub>HN</sub>	HN-NF	HN-WF	LN-NF	N	NF	F <sub>HN</sub>
GY(Mg/ha)	8.976 <b>b</b> *	11.225 <b>a</b>	6.680 <b>c</b>	34.36	68.03	25.06	6.867 <b>b</b>	9.583 <b>a</b>	6.455 <b>c</b>	6.39	48.46	39.55	9.678 <b>b</b>	10.525 <b>a</b>	7.410 <b>c</b>	30.61	42.03	8.75
SNms	501.69 <b>a</b>	493.90 <b>a</b>	336.88 <b>b</b>	48.92	46.61	-1.55	497.44 <b>b</b>	525.12 <b>a</b>	415.20 <b>c</b>	19.81	26.48	5.57	464.65 <b>a</b>	455.75 <b>a</b>	391.67 <b>b</b>	18.63	16.36	-1.92
KNSp	-	-	-	-	-	-	30.87 <b>b</b>	34.81 <b>a</b>	28.70 <b>c</b>	7.54	21.25	12.76	42.94 <b>b</b>	45.24 <b>a</b>	39.66 <b>c</b>	8.28	14.09	5.36
KNms	-	-	-	-	-	-	15171.13 <b>b</b>	17847.11 <b>a</b>	11648.78 <b>c</b>	30.24	53.21	17.64	19562.48 <b>b</b>	20307.22 <b>a</b>	15290.47 <b>c</b>	27.94	32.81	3.81
TKW (g)	-	-	-	-	-	-	39.83 <b>c</b>	47.57 <b>b</b>	49.14 <b>a</b>	-18.94	-3.18	19.44	46.22 <b>c</b>	47.36 <b>b</b>	48.78 <b>a</b>	-5.25	-2.91	2.46
HD (days)	150.30 <b>a</b>	150.20 <b>a</b>	148.27 <b>b</b>	1.37	1.3	-0.07	154.04 <b>b</b>	154.73 <b>a</b>	153.54 <b>c</b>	0.33	0.77	0.45	148.56 <b>a</b>	148.74 <b>a</b>	147.06 <b>b</b>	1.02	1.15	0.12
PH (cm)	91.61 <b>a</b>	90.01 <b>b</b>	92.50 <b>a</b>	-0.96	-2.69	-1.75	91.12 <b>c</b>	93.66 <b>b</b>	99.43 <b>a</b>	-8.36	-5.8	2.79	87.47 <b>b</b>	87.86 <b>b</b>	94.48 <b>a</b>	-7.43	-7.01	0.45
HI	0.51 <b>b</b>	0.55 <b>a</b>	0.48 <b>c</b>	5.97	15.05	8.57	0.46 <b>b</b>	0.51 <b>a</b>	0.45 <b>c</b>	2.01	13.43	11.19	0.58 <b>b</b>	0.60 <b>a</b>	0.54 <b>c</b>	6.69	10.83	3.89
PBWms (g/m <sup>2</sup> )	1566.62 <b>b</b>	1774.60 <b>a</b>	1031.14 <b>c</b>	51.93	72.1	13.28	1302.53 <b>b</b>	1661.50 <b>a</b>	1266.59 <b>b</b>	2.84	31.18	27.56	1561.35 <b>a</b>	1596.43 <b>a</b>	1382.99 <b>b</b>	12.9	15.43	2.25
SPAD	-	-	-	-	-	-	50.50 <b>b</b>	55.43 <b>a</b>	46.15 <b>c</b>	9.41	20.09	9.77	52.40 <b>a</b>	51.25 <b>b</b>	47.99 <b>c</b>	9.18	6.78	-2.2
YR	2.17 <b>b</b>	1.73 <b>c</b>	2.95 <b>a</b>	-26.59	-41.29	-20.02	1.58 <b>b</b>	1.44 <b>b</b>	2.33 <b>a</b>	-32.3	-38.08	-8.54	-	-	-	-	-	-
GPC (%)	14.42 <b>b</b>	14.63 <b>a</b>	11.61 <b>c</b>	24.22	26.03	1.46	12.35 <b>b</b>	12.61 <b>a</b>	10.41 <b>c</b>	18.71	21.18	2.08	14.20 <b>b</b>	14.60 <b>a</b>	11.51 <b>c</b>	23.39	26.85	2.8
GSC (%)	74.25 <b>a</b>	72.38 <b>b</b>	72.44 <b>b</b>	2.49	-0.08	-2.51	73.67 <b>a</b>	73.32 <b>b</b>	73.27 <b>b</b>	0.55	0.07	-0.47	74.04 <b>b</b>	73.17 <b>c</b>	74.32 <b>a</b>	-0.37	-1.54	-1.18
Sedimentation (%)	34.56 <b>a</b>	34.71 <b>a</b>	16.20 <b>b</b>	113.31	114.24	0.44	34.6 <b>b</b>	35.7 <b>a</b>	25.3 <b>c</b>	36.76	41.11	3.181	39.37 <b>a</b>	38.22 <b>a</b>	19.41 <b>b</b>	102.82	96.87	-2.93

\* Means values within a year in the same row line with different letters indicate a significant difference at  $P < 0.05$

N means nitrogen effect, NF means nitrogen plus fungicide effect, and F<sub>HN</sub> means fungicide effect under low and high nitrogen

**Table S7.** GY (Mg.ha<sup>-1</sup>) statistics for the applied cropping systems and the years of experiments.

Year	CS	Mean	Maximum	Minimum	Range	CV (%)*
2015	HN-NF	8.976	12.511	2.051	10.46	22.47
	HN-WF	11.225	14.073	7.916	6.157	9.54
	LN-NF	6.68	9.62	2.155	7.465	18.79
2016	HN-NF	6.867	9.645	1.239	8.406	23.03
	HN-WF	9.524	12.217	4.127	8.09	13.43
	LN-NF	6.393	8.569	1.751	6.818	19.25
2017	HN-NF	9.678	11.996	5.856	6.14	10.97
	HN-WF	10.525	12.367	7.619	4.748	7.72
	LN-NF	7.41	9.424	4.635	4.989	11.16
Average of three years	HN-NF	8.507	11.384	3.049	8.335	18.82
	HN-WF	10.425	12.886	6.554	6.332	10.23
	LN-NF	6.828	9.204	2.847	6.424	16.4

\*CV stands for coefficient of variation



**Table S8.** Detailed analysis of variance of GY of winter wheat genotypes in cropping systems (CS) by year (Y).

Year		2015			2016			2017		
Source	DF	Anova SS	Mean Square	% Variance Explained	Anova SS	Mean Square	% Variance Explained	Anova SS	Mean Square	% Variance Explained
<b>Cropping systems (CS)</b>	2	454374.824	227187.4121***	70.9	250658.57	125329.2852***	61.36	228223	114111.6963***	77.15
<b>Genotype(G)</b>	219	221449.968	1011.1871***	19.67	208916.91	953.9585***	29.85	83031.4	379.139***	16.36
<b>CS×G</b>	438	66754.6403	152.4079***	9.44	37041.749	84.5702***	8.8	21640.8	49.4083***	6.5
<b>Error</b>	660	9913.6521	15.0207		2135.0851	3.235		3818.17	5.7851	

\*\*\* Significant at the 0.0001 probability level, DF=Degree of freedom

**Table S9.** Three ways ANOVA of GY of winter wheat genotypes (G) in three cropping systems (CS) across three years (Y).

Source	DF	Anova SS	Mean Square	% Variance Explained	F Value
<b>Y</b>	2	198589.9929	99295.00***	10.38	12390.8
<b>CS</b>	2	855052.0568	427526.03***	54.45	53350.1
<b>G</b>	219	439141.9294	2005.21***	16.22	250.23
<b>Y×CS</b>	4	78204.7304	19551.18***	7.89	2439.75
<b>Y×G</b>	438	74256.3878	169.5351***	3.3	21.16
<b>CS×G</b>	438	80519.4934	183.83***	4.03	22.94
<b>Y×CS×G</b>	1314	44917.7155	51.2759 ***	3.74	11.32
<b>Error</b>	1980	15866.908	8.014***		

**Table S10.** N flow related analysis of variance and statistics.

(A) Combined ANOVA of NUE, NAE, and Grain N yield of winter wheat genotypes (G) in three cropping systems (E) across three years (Y).

Anova Factors	Fvalue (NUE)	Fvalue (NAE)	Fvalue (Grain N yield)
<b>Year (Y)</b> ***	156.94***	4.16E+09***	9523.02***
<b>Cropping System (CS)</b>	35649.5***	1.35E+10***	29853.64***
<b>Genotype (G)</b>	28.76***	1.27E+07***	42.78***
<b>Y×G</b>	3	7661408	6.32***
<b>Y×CS</b>	1103.28***	8.13E+08***	1030.96***
<b>CS×G</b>	6.18***	1.67E+07***	7.57***
<b>Y×CS×G</b>	1.32***	2867525***	2.18***

\*\*\* Significant at the 0.001 probability level

(B) Cultivars harvested GY (Mg.ha<sup>-1</sup>) and grain nitrogen yield (GNY in kg.ha<sup>-1</sup>) under the three CS.

Genotypes Name	Briwecs Number	GY <sup>a</sup> (HN-NF)	GY(HN-WF)	GY(LN-NF)	GNY <sup>b</sup> (HN-NF)	GNY (HN-WF)	GNY (LN-NF)
Einstein	1	9.789	11.019	7.455	229.7	264.23	145.05
Oakley	2	6.093	12.2	7.033	133.1	264.43	124.74
Jafet	3	9.973	10.406	7.055	235.14	263.43	138.36
Claire	4	9.771	11.46	8.394	228.36	269.04	150.07
Rebell	5	10.455	10.847	8.031	260.26	266.48	156.5
Memory	6	10.153	10.821	7.826	238.57	245.86	151.55
Kurt	7	9.377	11.743	7.804	221.58	291.37	145.69
Zappa	8	10.836	11.179	7.976	251.64	271.29	155.82
Chevalier	9	9.334	10.335	7.242	228.16	250.84	142.95
Gordian	10	9.785	10.591	7.253	246.12	245.53	135.58
Mentor	11	10.382	11.541	7.276	247.91	279.7	134.75
Meister	12	8.488	11.161	7.511	203.72	282.75	143.09
KWS Santiago	13	9.041	12.11	7.818	205.44	272.84	138.24
Brigand	14	8.453	10.281	7.21	213.16	256.41	141.54
Profilus	15	9.134	10.778	7.418	213.35	259.19	137.59
Durin	16	8.238	9.858	7.197	201.91	248.61	137.96
KWS Pius	17	10.184	11.152	8.101	248.01	277.55	159.21
Paroli	18	8.473	11.259	7.521	199.16	271.37	142.86
Estivus	19	9.227	11.013	7.849	218.13	268.56	148.11
Kronjuwel	20	7.636	9.34	6.022	184.56	242.31	125.79
Desamo	21	9.559	10.521	7.283	232.69	258.41	141.05
Carenius	22	9.242	11.057	7.252	216.88	259.18	141.7
Mulan	23	9.751	11.286	7.922	232.07	267.58	144.09
Kredo	24	9.435	11.364	7.495	232.72	264.91	143.86
Nelson	25	9.63	10.287	6.396	239.39	263.93	127.06
Patras	26	10.03	10.789	7.355	243.5	267.27	145.41
Götz	27	8.211	10.083	6.024	200.6	256.67	120.72
Robigus	28	5.874	11.276	6.216	137.01	267.76	118.96
Anapolis	29	10.438	11.478	7.705	255.14	275.73	144.51
Solstice	30	8.194	10.76	7.256	199.13	253.68	139.82
Biscay	31	9.448	11.566	7.612	223.04	271.69	141.37
Capone	32	10.092	10.652	7.994	246.89	254.56	153.39
Tabasco	33	10.862	12.019	8.315	242.94	280.31	156.22
Kometus	34	7.485	11.117	6.699	184.25	266.67	126.81
Cubus	35	9.76	10.812	7.204	231.55	255.77	137.04
Edward	36	9.397	11.603	8.134	226.86	284.69	158.91
Famulus	37	9.155	9.979	6.749	223.1	252.75	132.06
Dekan	38	8.715	10.781	7.864	203.62	259.88	154.86
SW Topper	39	9.39	10.126	6.446	233.44	265.69	129.11
Matrix	40	8.061	11.093	7.036	194.89	271.6	136.76
Jenga	41	8.977	11.156	7.933	208.69	263.64	148.17
Linus	42	10.432	11.566	7.823	253.39	271.97	152.52
TJB 990-15	43	9.382	10.264	7.009	227.1	250.95	141.3
Forum	44	9.869	11.085	7.426	232.37	272.2	146.54
Colonia	45	9.983	11.062	7.486	240.34	268.37	148.08
Transit	46	8.76	10.684	7.533	213.66	271.93	147.13
Potenzial	47	9.463	10.85	7.337	223.98	256.72	145.92
Gacho	48	9.878	11.623	8.034	234.99	275.68	148.99
Tarso	49	8.976	10.332	6.649	215.78	266.14	133.3
Hermann	50	8.224	10.637	7.091	195.11	266.72	137.79

Glaucus	51	9.646	10.959	7.575	245.09	269.1	147.89
Tuareg	52	9.538	11.3	7.419	225.92	278.18	134.91
Atomic	53	10.285	11.314	7.739	247.33	270.89	151.74
Tobak	54	9.937	12.288	8.571	225.36	293.89	156.24
Pionier	55	9.464	10.932	7.248	228.62	259.93	139.9
Manager	56	8.847	10.883	7.709	218.08	256.15	142.14
Gourmet	57	8.933	10.047	6.311	226.29	255.11	123.66
Limes	58	9.702	10.984	7.399	238.72	281.05	146.55
Ritmo	59	8.741	10.701	6.942	209.23	264.24	135.74
Kalahari	60	10.057	11.121	7.56	232.07	267.23	147.95
Intro	61	10.263	11.064	7.925	242.29	261.65	151.59
Oxal	62	9.868	10.893	7.632	239.2	263.68	142.6
Zobel	63	8.289	10.866	6.525	197.78	268.29	126.51
Event	64	9.46	10.615	6.469	225.46	257.36	133.76
Joker	65	9.453	10.663	7.403	222	249.04	147.51
Global	66	9.513	11.666	7.498	222.8	273.48	141.29
Elixer	67	10.566	11.706	7.759	251.89	280.35	151.9
Fedor	68	9.946	10.76	7.899	227.1	254.94	152.88
Türkis	69	9.108	11.1	7.337	210.74	255.32	140.76
Skagen	70	9.327	10.79	7.66	223.77	262.48	147.69
Greif	71	9.364	10.46	7.56	225.3	249.83	144.55
Esket	72	10.023	10.661	7.013	236.46	254.33	138.05
Primus	73	8.796	11.116	7.257	201.9	261.34	139.16
Skalmeje	74	9.672	11.343	7.368	222.88	266.47	139.98
Genius	75	9.59	10.49	6.776	237.83	263.78	135.68
Enorm	76	8.867	10.011	6.621	216.54	250.14	131.7
Florian	77	9.257	10.192	7.118	223.88	255.29	151.14
Skater	78	7.447	10.984	6.846	169.58	257.52	133.21
Brilliant	79	9.025	10.824	7.346	210.54	266.26	140.78
Inspiration	80	9.421	11.143	7.448	216.82	270.71	146.08
Apertus	81	10.026	11.025	7.634	239.07	269.44	149.45
Ellvis	82	9.231	10.698	8.053	226.04	267.53	158.47
Edgar	83	10.04	11.296	7.829	234.89	274.87	148.85
Maris Huntsman	84	8.671	10.713	6.627	208.79	265.4	130.73
SY Ferry	85	10.082	11.147	8.167	245.13	275.58	155.86
Landsknecht	86	8.204	11.698	7.317	189.48	264	136.09
Sponsor	87	8.39	10.462	7.49	200.37	245.85	144.36
Impression	88	9.792	11.123	7.707	236.81	267.68	148.76
Winnetou	89	8.59	11.504	6.932	207.06	271.48	131.56
Toronto	90	8.7	10.227	6.973	222.66	256.68	140.21
Torrild	91	9.621	10.74	7.342	230.47	265.91	141.41
Contra	92	8.81	11.107	7.797	209.69	274.9	152.94
Schamane	93	8.676	10.475	6.63	206.3	261.38	129.56
Granada	94	4.274	10.113	4.711	101.69	240.93	93.44
KWS Cobalt	95	10.259	11.057	8.461	236.1	250.43	162.71
Tommi	96	9.611	10.71	7.468	233.35	270.77	147.95
Saturn	97	8.225	10.47	6.797	194.34	246.99	131.59
Severin	98	6.576	9.556	5.862	162.41	242.07	121.32
JB Asano	99	7.571	10.881	6.558	174.03	266.89	126.96
Kerubino	100	8.77	11.145	6.879	206.99	265.84	137.03
Arktis	101	8.789	10.543	6.914	211.02	247.81	129.18
Urban	102	7.942	9.809	6.547	192.17	243.56	125.74
Orestis	103	8.687	10.718	7.355	204.72	254.26	137.71

Flair	104	7.594	10.532	6.727	177.16	252.72	122.55
Anthus	105	9.527	11.304	8.027	222	266.13	146.97
Bombus	106	9.416	11.398	7.728	224.85	272.9	143.67
Lucius	107	9.047	10.399	6.722	216.4	254.47	132.55
Herzog	108	8.263	10.673	7.014	193.2	254.6	128.94
Sorbas	109	8.278	9.903	6.471	205.3	253.02	131.41
Tabor	110	8.307	9.112	6.35	207.74	227.11	124.89
Terrier	111	8.199	10.854	7.405	189.91	255.85	137.29
Magister	112	8.007	9.959	6.11	199.81	255.2	117.74
Altos	113	9.195	9.993	6.507	219.15	254.08	130.17
Progress	114	8.558	9.796	6.667	206.3	238.67	126.72
Xanthippe	115	8.968	11.44	7.062	212.42	269.51	132.87
Avenir	116	9.64	10.631	7.35	231.44	252.47	146.83
Pantus	117	7.415	10.573	6.47	176.38	256.57	128.06
Drifter	118	8.822	11.031	8.027	212.61	263.52	151.36
Joss	119	8.555	9.596	6.305	207.68	244.45	126.49
Kranich	120	7.429	9.666	6.223	178.63	233.57	117.72
Sperber	121	9.274	10.279	6.404	227	260.71	124.43
Discus	122	8.09	10.601	7.096	195.28	263.67	138.94
Helios	123	3.709	9.675	4.265	92.02	239.49	84.71
Obelisk	124	8.588	10.956	6.872	213.13	265.53	129.52
Magnus	125	8.315	10.856	6.977	192.3	259.04	141.31
Disponent	126	8.447	10.49	6.81	203.15	269.15	135.97
Tambor	127	8.801	10.051	6.555	215.76	252.24	133.37
Boxer	128	8.936	11.161	7.215	203.03	264.25	136.74
Sokrates	129	9.194	11.199	7.042	222.95	267.57	135.82
Carisuper	130	7.854	9.295	6.231	192.03	235.43	127.07
Rektor	131	7.112	9.906	6.086	168.08	248.37	122.81
Alves	132	9.876	10.923	8.01	231.5	257.97	151.65
NaturaStar	133	7.431	9.694	6.176	176.75	243.22	124.53
Alidos	134	8.819	9.906	6.313	217.37	251.09	130.26
Monopol	135	7.485	9.272	6.189	176.5	233.55	128.64
Akratos	136	9.051	11.191	7.445	208.53	272.46	149.84
Knirps	137	7.319	9.729	6.453	180.21	241.65	126.5
Bussard	138	8.143	9.74	6.336	199.58	249.85	127.95
Oberst	139	7.541	10.419	6.251	183.5	256.65	125.91
Cappelle Desprez	140	7.73	8.66	6.209	197.59	234.27	127.77
Tiger	141	9.248	10.632	7.186	222.05	267.44	148.16
Ibis	142	9.308	10.127	7.185	231.05	244.22	147.42
Batis	143	8.74	10.593	7.29	202.28	257.78	140.55
Topfit	144	8.013	9.722	6.695	191.95	245.72	132.79
Akteur	145	8.055	10.292	6.432	196.54	268.13	131.7
Ludwig	146	8.973	10.625	7.058	218.75	260.98	140.41
Asketis	147	8.222	10.826	6.721	192.14	256.14	131.04
Aristos	148	7.983	10.524	7.077	192.5	257.09	138.42
Zentos	149	8.529	10.107	6.914	202.26	253.21	133.17
Diplomat	150	7.499	9.344	6.39	182.22	231.56	127.35
Astron	151	8.365	9.867	6.907	204.17	256.91	142.09
Basalt	152	7.318	9.462	6.465	175.01	233.51	124.87
Kormoran	153	7.815	9.845	6.477	192.28	247.67	131.09
Aron	154	8.264	10.067	6.696	203.71	255.35	137.4
KWS Milaneco	155	8.062	9.926	6.507	197.99	242.28	133.13

Aszita	156	7.499	8.503	5.72	193.23	234.97	122.42
Kobold	157	8.136	9.408	6.309	196.08	245.23	122.94
Carimulti	158	8.313	9.116	6.395	206.32	246.06	127.47
Admiral	159	7.955	9.489	6.31	188.95	237.45	124.86
Vuka	160	7.056	9.903	6.08	167.89	248.4	121.45
Benno	161	7.345	9.693	6.526	181.22	247.04	135.78
Apollo	162	8.33	10.387	6.795	198.63	250.95	132
Aquila	163	6.79	10.095	5.942	159.86	245.36	115.4
Kanzler	164	7.279	10.337	6.269	168.75	259.29	126.58
Kraka	165	7.401	10.178	6.433	178.02	245.45	125.86
Caribo	166	7.377	9.835	6.258	182.64	250.12	126.14
Butaro	167	7.674	8.671	5.637	199.24	238.01	119.78
Konsul	168	7.203	8.435	5.822	186.78	225.28	122.55
Ares	169	7.319	10.339	6.238	170.8	256.13	125.47
Centurk	170	4.704	8.449	4.75	122.13	219.48	96.95
NS 22/92	171	7.844	8.621	6.783	202.24	223.01	137.98
Benni multifloret	172	4.837	7.77	4.37	121.17	202.76	90.54
Hope	173	5.18	8.176	4.201	127.71	213.32	90.24
Vel	174	5.795	7.504	4.646	157.25	205.81	102.71
Phoenix	175	4.395	8.4	3.926	110.69	226.47	83.93
Mironovska 808	176	6.081	8.51	4.455	158.22	224.71	92.92
Caphorn	177	9.759	10.607	7.375	244.79	264.01	147.6
Cordiale	178	9.041	10.782	7.581	211.57	251.57	152.62
Apache	179	9.883	11.452	7.248	239.75	271.63	138.2
Premio	180	10.124	11.167	6.926	249.21	275.08	131.76
Isengrain	181	9.511	10.766	7.035	235.19	253.93	139.45
Alixan	182	8.099	11.274	6.667	188.09	275.59	130.8
Boregar	183	9.424	11.271	7.712	226.11	268.61	148.52
Renesansa	184	6.04	8.861	5.444	154.53	230.71	113.57
Tremie	185	8.933	11.082	7.201	214.43	264.09	140.42
KWS Ferrum	186	8.916	11.654	7.549	216.93	264.79	141.17
Triple Dirk "S"	187	6.807	8.951	5.305	170.99	223.34	106.49
Cardos	188	7.424	10.217	6.24	183.44	253.63	127.19
Soissons	189	8.858	9.973	6.384	223.88	244.81	126.82
BCD 1302/83	190	5.377	9.47	5.019	136.92	248.82	104.38
Arlequin	191	10.018	11.435	8.054	230.96	259.5	150.34
Sonalika	192	6.703	9.554	5.983	160.06	226.35	116.87
Camp Remy	193	8.608	10.06	6.379	217.92	250.74	130.42
Cajeme 71	194	3.308	8.943	3.714	83.32	239.35	76.34
Avalon	195	8.147	9.11	6.318	203.67	227.38	133.77
Ivanka	196	3.694	9.577	3.768	87.57	236.34	76.6
Pobeda	197	6.686	9.038	5.337	175.02	244.23	114.35
NS 66/92	198	7.683	8.908	5.682	199.15	230.21	118.14
Mexico 3	199	7.482	9.315	5.804	187.43	235.55	118.41
Orcas	200	7.966	10.869	7.239	189.29	269.99	143.3
Nimbus	201	6.016	9.96	5.415	147.12	241.5	113.91
Muskat	202	10.449	10.994	7.592	265.96	262.59	143.71
Florida	203	6.939	9.063	5.549	177.29	230.96	113.86
Rumor	204	9.129	11.713	7.404	219.85	267.09	143.45
Highbury	205	7.139	8.341	5.637	184.61	221.44	119.2
Siete Cerros 66	206	4.03	9.378	4.632	104.28	245.57	95.12
Kontrast	207	8.883	9.973	6.409	220.64	256.69	133.28

WW 4180	208	8.904	10.454	6.808	218.88	253.84	132.37
INTRO 615	209	7.077	8.521	6.017	182.59	215.37	124.93
NS 46/90	210	4.592	9.434	3.926	122.7	257.33	84.52
Mex. 17 bb	211	7.003	8.35	5.504	181.65	218.75	113.11
Labriego-Inia	212	6.627	9.401	4.731	163.5	237.98	96.92
Pegassos	213	8.172	10.589	6.818	195.51	254.66	135.27
Hybred	214	9.655	11.119	7.221	226.74	261.38	140.75
Hyland	215	9.89	11.721	7.866	231.32	266	154.36
Hybery	216	10.741	12.043	8.268	253.75	272.97	154.85
Hystar	217	10.314	11.729	7.691	248.35	269.3	143.87
Hylux	218	10.18	11.803	8.711	234.84	263.24	155.86
Piko	219	8.949	9.734	6.626	221.59	233.09	127.76
SUR 99820	220	9.074	11.329	7.748	207.38	261.31	144.05

(C) Summary of three years averages of grain nitrogen yield (GNY in kg.ha<sup>-1</sup>) under the three CS.

Yielding Status	GNY (HN-NF)	GNY(HN-WF)	GNY(LN-NF)
High Yielding	234.16	269.45	148.89
Low Yielding	197.56	252.10	130.04
Mean	215.86	260.775	139.465
Difference (High-Low)	36.60	17.36	18.84

(D) Summary of three years averages nitrogen flow under the three CS and correlations coefficient between GY and GNY under each CS.

Treatment	GY (Mg/ha)	GNY (kg/ha)	Nitrogen available (kg/ha)	Applied N fertilizer	<sup>a</sup> Utilized N from fertilizer (kg/ha)	Lost N from N fertilizer (kg/ha)	<sup>b</sup> N utilized for 1 Mg grain	Corr
HN-NF	8.51	205.21	220.00	151.67	72.8	78.87	25.86	0.98
HN-WF	10.44	255.72	220.00	151.67	72.8	78.87	21.07	0.90
LN-NF	6.84	133.98	65.43	0.00	0.00	0.00	9.56	0.97

<sup>a</sup> Utilized N from fertilizer (kg/ha) to grain N yield is equal to 48% of the applied n fertilizer according to Ladha et al. [43]; <sup>b</sup> N utilized for 1t grain calculated according to Angus [44], Corr: Correlation coefficient between GY and GNY.

**Table S11.** Pairwise comparison of GYs and its components correlation coefficients among cropping systems.

P-values	HN-NF	HN-WF
	<i>PBWms</i>	
HN-WF	0.001***	1
LN-NF	0.001***	0.001***

	<i>HI</i>	
HN-WF	0.06	1
LN-NF	0.01**	0.56
	<i>TKW</i>	
HN-WF	0.001***	1
LN-NF	0.8	0.001***
	<i>KN<sub>ms</sub></i>	
HN-WF	0.01**	1
LN-NF	0.36	0.01**
	<i>KNS<sub>ps</sub></i>	
HN-WF	0.01**	1
LN-NF	0.45	0.08
	<i>SN<sub>ms</sub></i>	
HN-WF	0.14	1
LN-NF	0.67	0.06

The table displays p-values and significance levels.



**Table S12.** Pairwise comparison of coefficients (intercepts and slopes) of regressions model GY vs traits of interest under three CS.

Regresssion Equation		Rsquare ; Pvalue	HN-NF		HN-WF	
Chlorophyll content (GY vs SPAD in 2016)						
HN-NF	y = 0.1518x – 0.7986	R <sup>2</sup> = 0.3042; p***	intercepts	Slopes	intercepts	Slopes
HN-WF	y = 0.0717x + 5.5511	R <sup>2</sup> = 0.0369; p***	2.03e-05a***	0.00341 **		
LN-NF	y = 0.1332x + 0.2681	R <sup>2</sup> = 0.4196; p***	0.25763	0.336	0.0001 ***	0.0154*
Chlorophyll content (GY vs SPAD in 2017)						
HN-NF	y = 0.0375x + 7.4074	R <sup>2</sup> = 0.0079	intercepts	Slopes	intercepts	Slopes
HN-WF	y= 0.0319x + 8.6046	R <sup>2</sup> = 0.0112	0.514	0.866		
LN-NF	y = 0.0795x + 0.31376	R <sup>2</sup> = 0.059; p***	0.020*	0.218	0.001 ***	0.108
YR (Yellow rust)						
HN-NF	y = -0.966x + 10.317	R <sup>2</sup> = 0.317, p***	intercepts	Slopes	intercepts	Slopes
HN-WF	y = -0.451x + 11.142	R <sup>2</sup> = 0.1114, p***	0.001***	2.93e-05 ***	2.93e-05 ***	
LN-NF	y = -0.533x + 8.2365	R <sup>2</sup> = 0.364, pns	< 2e-16 ***	1.20e-05 ***	< 2e-16 ***	0.396
HD (Heading Date)						
HN-NF	y = 0.257x – 30.389	R <sup>2</sup> = 0.1293, p***	intercepts	Slopes	intercepts	Slopes
HN-WF	y = 0.150x – 12.247	R <sup>2</sup> = 0.0669, p*	0.035 *	0.058		
LN-NF	y = 0.260x – 32.151	R <sup>2</sup> = 0.229, p***	0.826	0.959	0.008 **	0.027 *
PH (plant height)						
HN-NF	y = -0.059x + 13.826	R <sup>2</sup> = 0.113, p***	intercepts	Slopes	intercepts	Slopes
HN-WF	y = -0.067x + 16.489	R <sup>2</sup> = 0.376, p***	0.012 *	0.495		
LN-NF	y = -0.043x + 10.918	R <sup>2</sup> = 0.222, p***	0.003**	0.129	8.39e-13 ***	0.003 **
GPC (grain protein content)						
HN-NF	y = -1.085x + 23.33	R <sup>2</sup> = 0.127***	intercepts	Slopes	intercepts	Slopes
HN-WF	y = -1.253x + 27.91	R <sup>2</sup> = 0.631***	0.419	0.615		
LN-NF	y = -1.550x + 24.16	R <sup>2</sup> = 0.491***	0.626	0.545	0.723	0.846
GSC (grain starch content)						
HN-NF	y = 0.857x – 54.91	R <sup>2</sup> = 0.1775***	intercepts	Slopes	intercepts	Slopes
HN-WF	y = 0.7953x – 47.6	R <sup>2</sup> = 0.481***	0.052	0.326		
LN-NF	y = 0.776x – 50.12	R <sup>2</sup> = 0.295***	0.733	0.017 *	0.012*	0.015*

<sup>a</sup> Pvalue of the comparison between both intercepts and slopes, \* Significant at the 0.05 probability level,

\*\* Significant at the 0.01 probability level, \*\*\* Significant at the 0.001 probability level, ns, nonsignificant at the 0.05 probability level

**Table S13.** Full regression (A) and path models (B) with direct and indirect effects of 13 independent variables on GY of 220 cultivars tested in 3 different CS over three growing seasons.**A**

Full regression model									
Variable	HN-NF			HN-WF			LN-NF		
	b <sup>α</sup>	± std Error	Prob <sup>sig</sup>	b	± std Error	Prob <sup>sig</sup>	b	± std Error	Prob <sup>sig</sup>
Constant	−232.20	69.76	0.001 **	−95.24	56.63	0.094	−209.5	51.92	0 ***
HD	0.82	0.24	0.001 ***	0.81	0.22	0 ***	0.7	0.19	0 ***
SPAD	0.28	0.14	0.04 *	0.04	0.13	0.738	0.36	0.1	0 ***
YR	−2.71	0.58	0 ***	−1.66	0.42	0 ***	−2.08	0.28	0 ***
PH	−0.06	0.06	0.382	−0.07	0.05	0.176	0.04	0.04	0.332
SNms	0.00	0.01	0.837	−0.01	0.01	0.134	0.03	0.01	0.032 *
KNSp	−0.21	0.14	0.128	−0.12	0.09	0.201	0.11	0.12	0.347
KNms	0.00	0.00	0.206	0	0	0.747	0	0	0.312
TKW	0.16	0.15	0.294	0.24	0.11	0.034 *	0.13	0.11	0.206
HI	161.30	14.70	0 ***	86.37	13.16	0 ***	94.32	13.49	0 ***
PBWms	0.03	0.00	0 ***	0.01	0	0.026 *	0.01	0	0.001 ***
GPC	−1.06	1.20	0.379	−5.75	0.88	0 ***	−3.69	0.93	0 ***
GSC	1.26	0.63	0.047 *	1.51	0.53	0.004 **	1.69	0.51	0.001 **
Sedimentation	−0.13	0.08	0.137	−0.13	0.06	0.03 *	0	0.1	0.986
R square (%)	86.2			81.6			84.7		

α regression slope; \* Significant of the slope at the 0.05 probability level; \*\* Significant of the slope at the 0.01 probability level; \*\*\* Significant of the slope at the 0.001 probability level; ns, nonsignificant of the slope at the 0.05 probability level

**B**

Path Analysis model												
Variable	HN-NF				HN-WF				LN-NF			
	Direct effect	Indirect effect	ri/j	Prob <sup>sig</sup>	Direct effect	Indirect effect	ri/j	Prob <sup>sig</sup>	Direct effect	Indirect effect	ri/j	Prob <sup>sig</sup>
HD	0.11	0.175	0.285	0***	0.127	−0.014	0.113	0***	0.132	0.330	0.462	0***
SPAD	0.064	0.426	0.490	0.032*	0.012	0.198	0.210	0.729	0.13	0.433	0.563	0***
YR	−0.158	−0.405	−0.563	0***	−0.128	−0.179	−0.307	0***	−0.243	−0.359	−0.602	0***
PH	−0.031	−0.304	−0.335	0.365	−0.067	−0.541	−0.608	0.16	0.042	−0.522	−0.480	0.314
SNms	0.009	0.153	0.162	0.831	−0.079	0.102	0.023	0.12	0.131	0.065	0.196	0.026*
KNSp	−0.115	0.556	0.441	0.114	−0.101	0.334	0.233	0.185	0.077	0.307	0.384	0.33
KNms	−0.112	0.666	0.554	0.19	0.029	0.329	0.358	0.738	−0.093	0.649	0.556	0.295
TKW	0.047	0.375	0.422	0.277	0.092	0.006	0.098	0.027	0.056	0.345	0.401	0.19
HI	0.51	0.275	0.785	0***	0.354	0.346	0.700	0***	0.389	0.278	0.667	0***
PBWms	0.447	0.298	0.745	0***	0.118	0.090	0.208	0.02*	0.214	0.314	0.528	0***
GPC	−0.035	−0.321	−0.356	0.362	−0.38	−0.414	−0.794	0***	−0.172	−0.532	−0.704	0***
GSC	0.062	0.359	0.421	0.039*	0.137	0.546	0.683	0.003**	0.122	0.426	0.548	0.001**
Sedimentation	−0.056	−0.287	−0.343	0.123	−0.098	−0.480	−0.578	0.024*	0.001	−0.430	−0.429	0.985
R square	86.2				81.6				84.7			

\* Significant of the slope at the 0.05 probability level; \*\* Significant of the slope at the 0.01 probability level; \*\*\* Significant of the slope at the 0.001 probability level; ns, nonsignificant of the slope at the 0.05 probability level

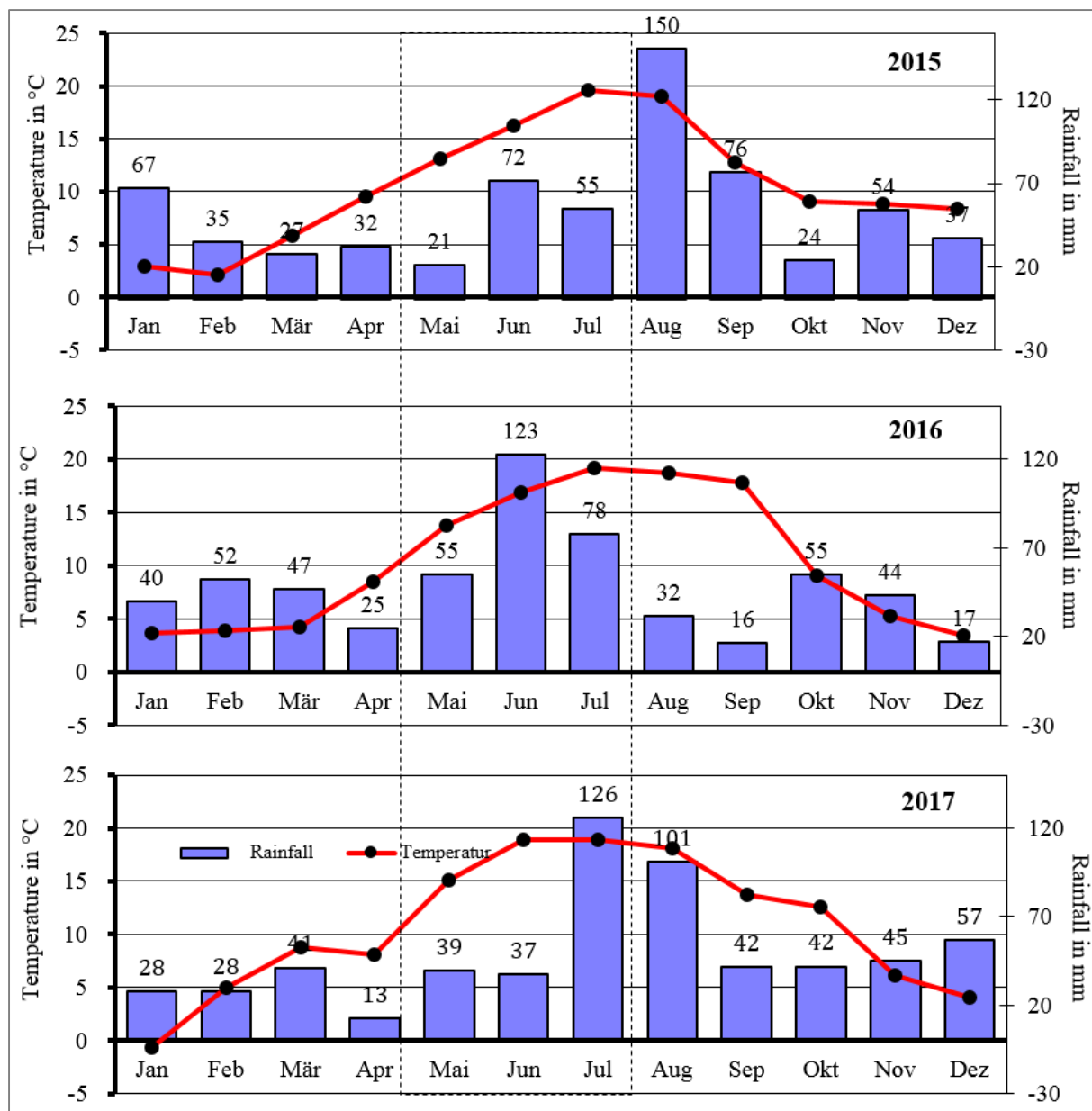
**Table S14.** Summary of winning genotypes in the three environments and their year of release.

Genotypes (Name)	Briwecs Number	Release Year	Selected_HN-NF	Selected_HN-WF	Selected_LN-NF	all 3 CS	Score Summary
Memory	6	2013	1	0	0	0	1
KWS Santiago	13	2011	0	1	0	0	1
Mulan	23	2006	0	0	1	0	1
Patras	26	2012	1	0	0	0	1
Biscay	31	2000	0	1	0	0	1
Colonia	45	2011	1	0	0	0	1
Gaicho	48	1993	0	0	1	0	1
Tobak	54	2011	0	1	0	0	1
Fedor	68	2007	1	0	0	0	1
Bombus	106	2012	0	1	0	0	1
Alves	132	2010	0	0	1	0	1
Rumor	204	2013	0	1	0	0	1
Hybery	216	2010	0	1	0	0	1
Hystar	217	2007	0	1	0	0	1
Hylux	218	2012	0	0	0	1	1
Claire	4	1999	0	0	1	1	2
Mentor	11	2012	1	1	0	0	2
KWS Pius	17	2010	1	0	0	1	2
Capone	32	2012	1	0	1	0	2
Edward	36	2013	0	1	0	1	2
Atomic	53	2012	1	0	0	1	2
Elixer	67	2012	1	1	0	0	2
Edgar	83	2010	1	0	0	1	2
KWS Cobalt	95	2013	1	0	0	1	2
Rebell	5	2013	1	0	1	1	3
Zappa	8	2009	1	0	1	1	3
Anapolis	29	2013	1	1	0	1	3
Tabasco	33	2008	1	1	0	1	3
Linus	42	2010	1	1	0	1	3
Intro	61	2011	1	0	1	1	3
SY Ferry	85	2012	1	0	1	1	3
Hyland	215	2009	1	1	1	0	3

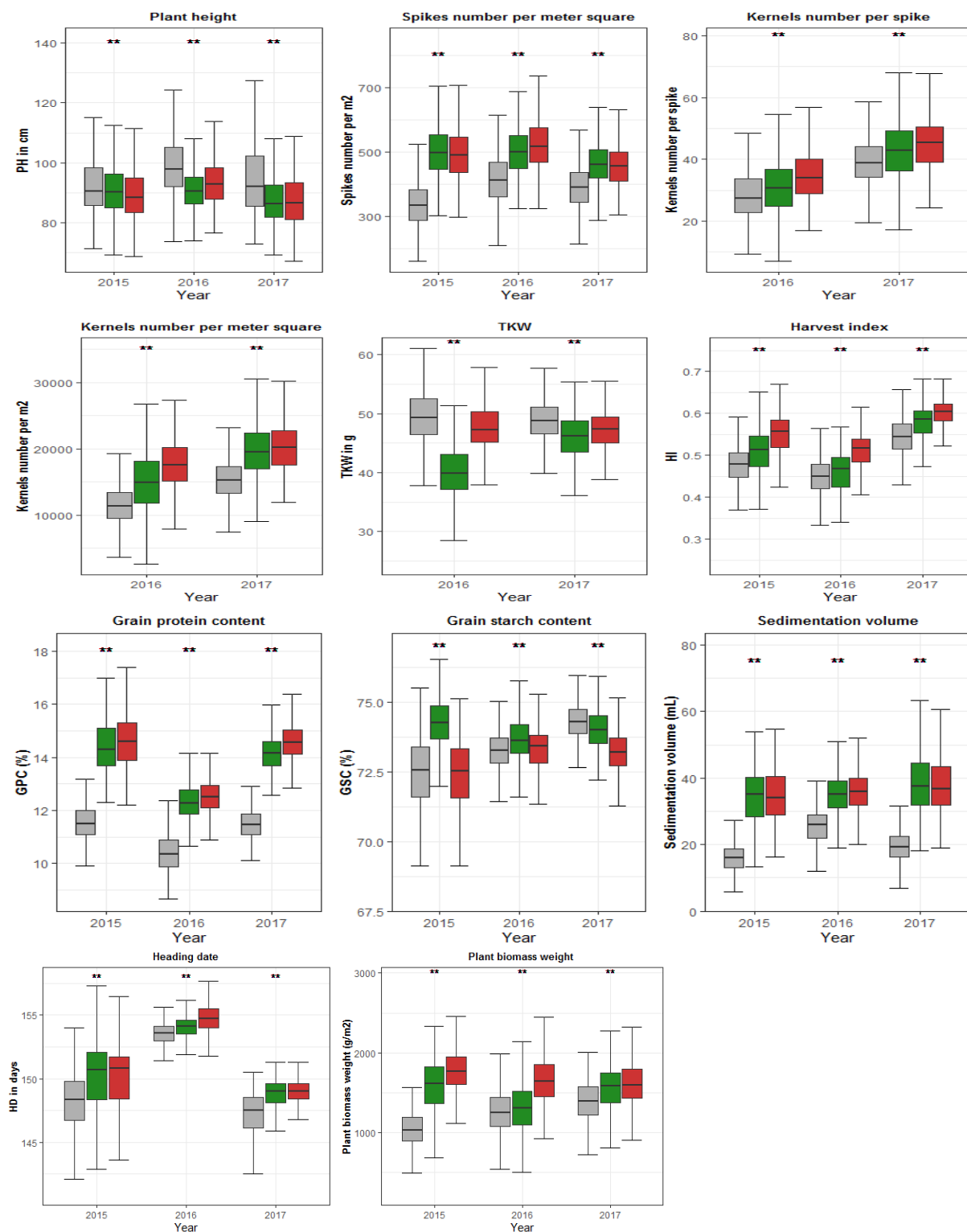
The digits 0, 1, 2, 3 indicate the number of selection times of a high yielding genotype under the defined CS

**Table S15.** Pairwise comparison of coefficients (intercepts and slopes) of regressions model traits of interest vs years of release under three CS.

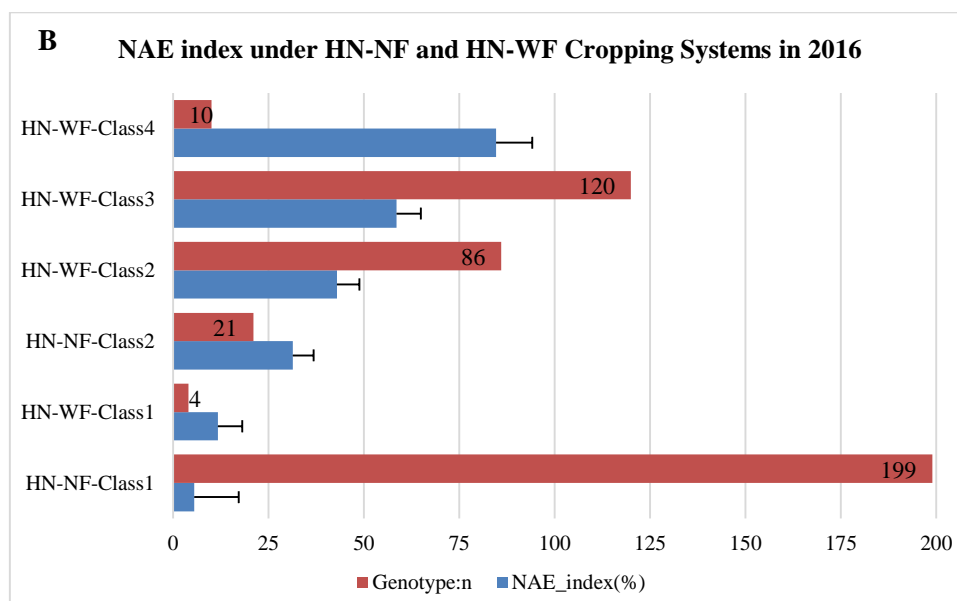
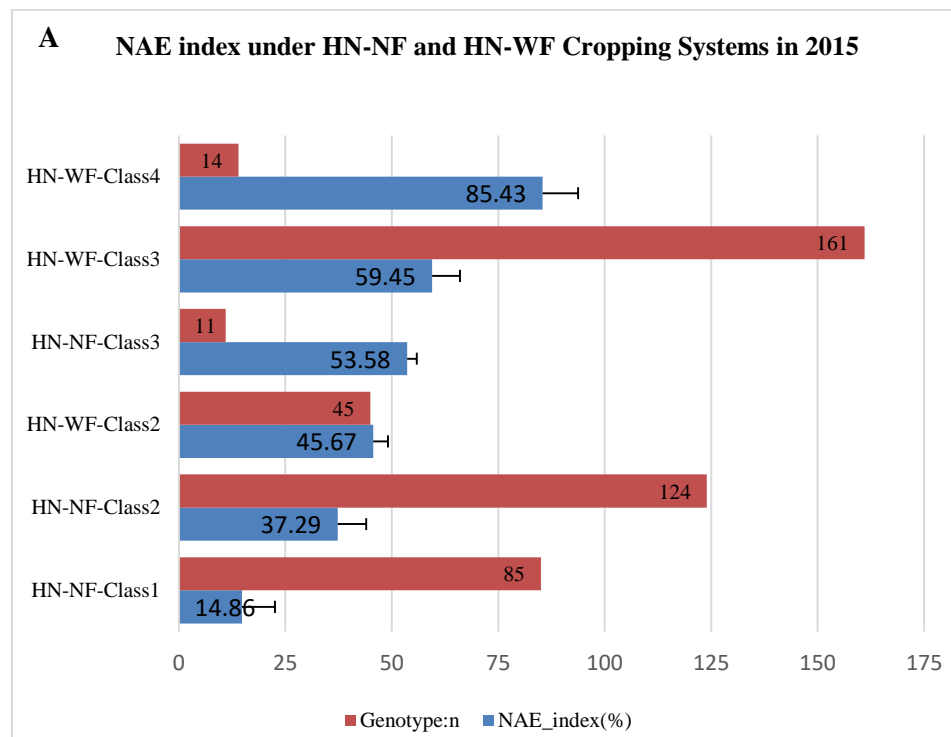
Traits	Treatment	HN-NF		HN-WF	
		<i>intercepts</i>	<i>Slopes</i>	<i>intercepts</i>	<i>Slopes</i>
HD	HN-WF	0.352	0.359		
	LN-NF	0.482	0.523	0.0865	0.103
SPAD	HN-WF	0.32005	0.34407		
	LN-NF	0.00763 **	0.01061 *	0.000188 ***	0.000354 ***
YR	HN-WF	0.38921	0.4043		
	LN-NF	0.00173 **	0.00218 **	9.33e-05 ***	0.000136 ***
PH	HN-WF	0.43362	0.43585		
	LN-NF	0.00488 **	0.00573 **	0.0532	0.0591
SNms	HN-WF	0.402	0.406		
	LN-NF	0.627	0.517	0.727	0.8558
KNSp	HN-WF	0.0694	0.0755		
	LN-NF	0.7736	0.7488	0.12285	0.14113
KNms	HN-WF	0.0574	0.0640		
	LN-NF	0.0609	0.0475 *	0.978	0.889
TKW	HN-WF	0.1817	0.21242		
	LN-NF	0.78471	0.69281	0.0926	0.0861
HI	HN-WF	0.0568	0.0701		
	LN-NF	0.3039	0.2786	0.356	0.443
PBWms	HN-WF	4.99e-05 ***	6.97e-05 ***		
	LN-NF	0.00795 **	0.00584 **	0.1164	0.1715
GY	HN-WF	0.000247 ***	0.000486 ***		
	LN-NF	0.000609 ***	0.000340 ***	0.761	0.904
GPC	HN-WF	0.00181 **	0.00215 **		
	LN-NF	0.32759	0.1585	0.0384 *	0.108
GSC	HN-WF	0.0587	0.0759		
	LN-NF	0.7434	0.8002	0.126	0.137
Sedimentation	HN-WF	0.5219	0.4838		
	LN-NF	0.0072 **	0.0103 *	0.0332 *	0.0522

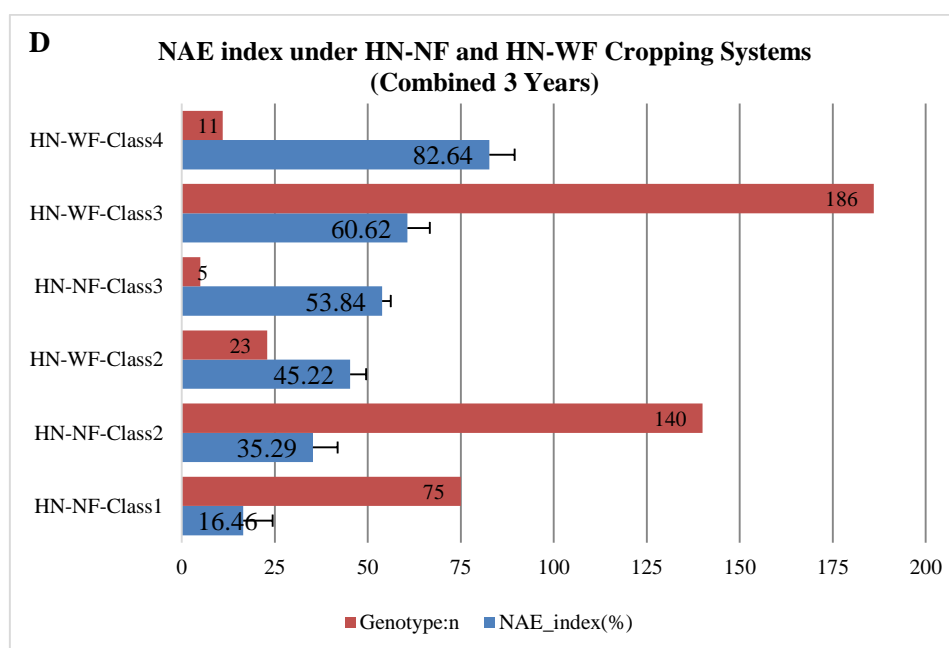
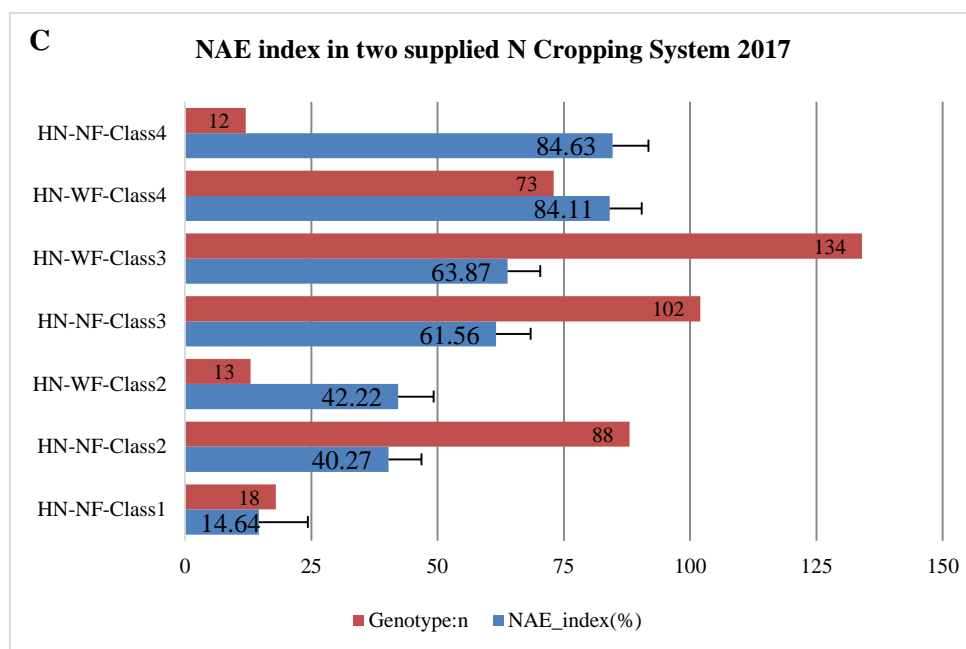


**Figure S1.** Weather conditions data from the experimental site illustrating significant differences in rainfall (pink bars) and temperature (red curves) among growing seasons 2015, 2016, and 2017 at reproductive stage (dotted rectangle).



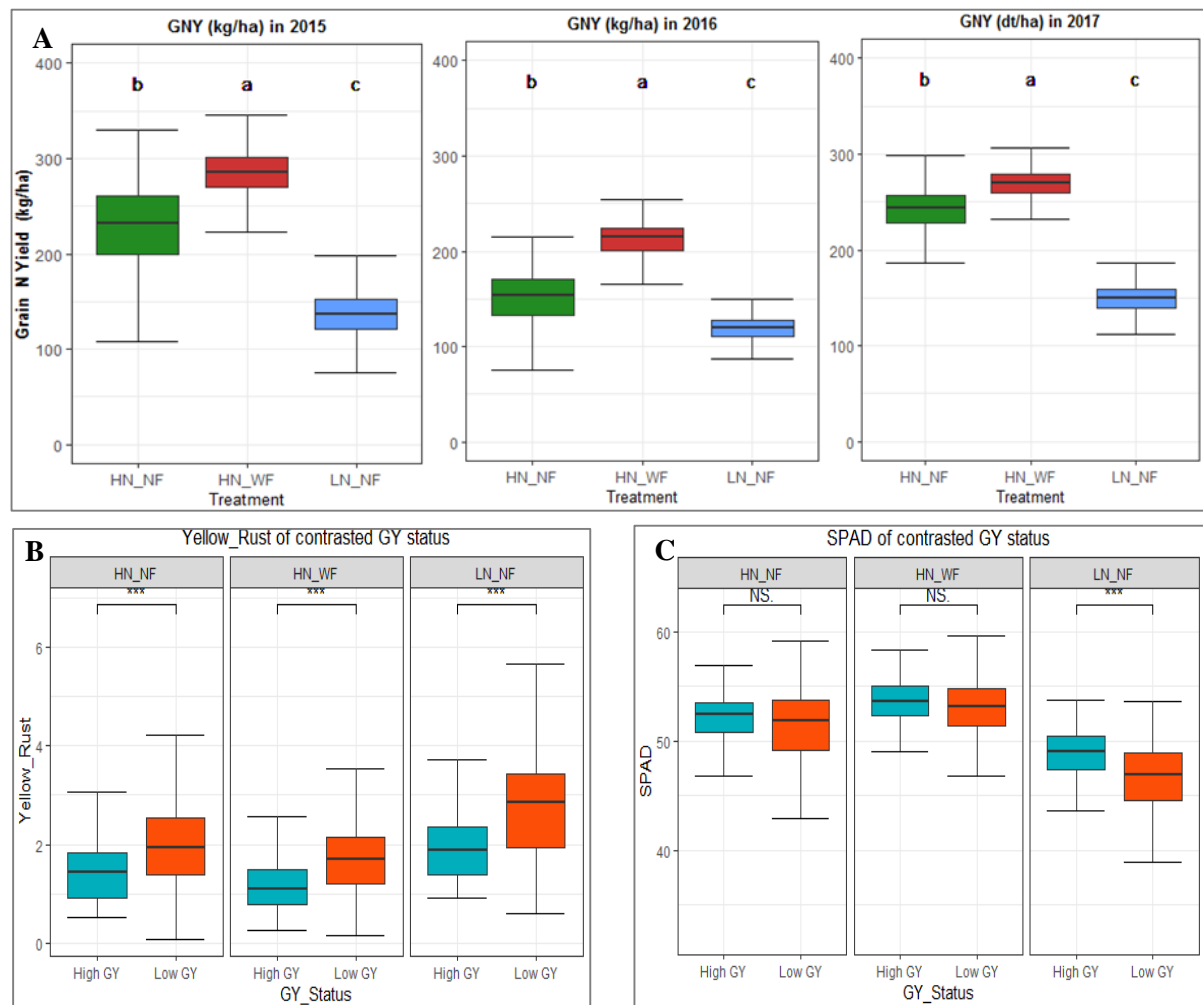
**Figure S2.** Significant differences among the three cropping systems (CS) for evaluated traits with LN-NF in gray, HN-NF in green, and HN-WF in red color. NS means not significant at  $p=0.05$ , \*\* significant at  $p=0.01$ , and \*\*\* significant at  $p=0.001$ .



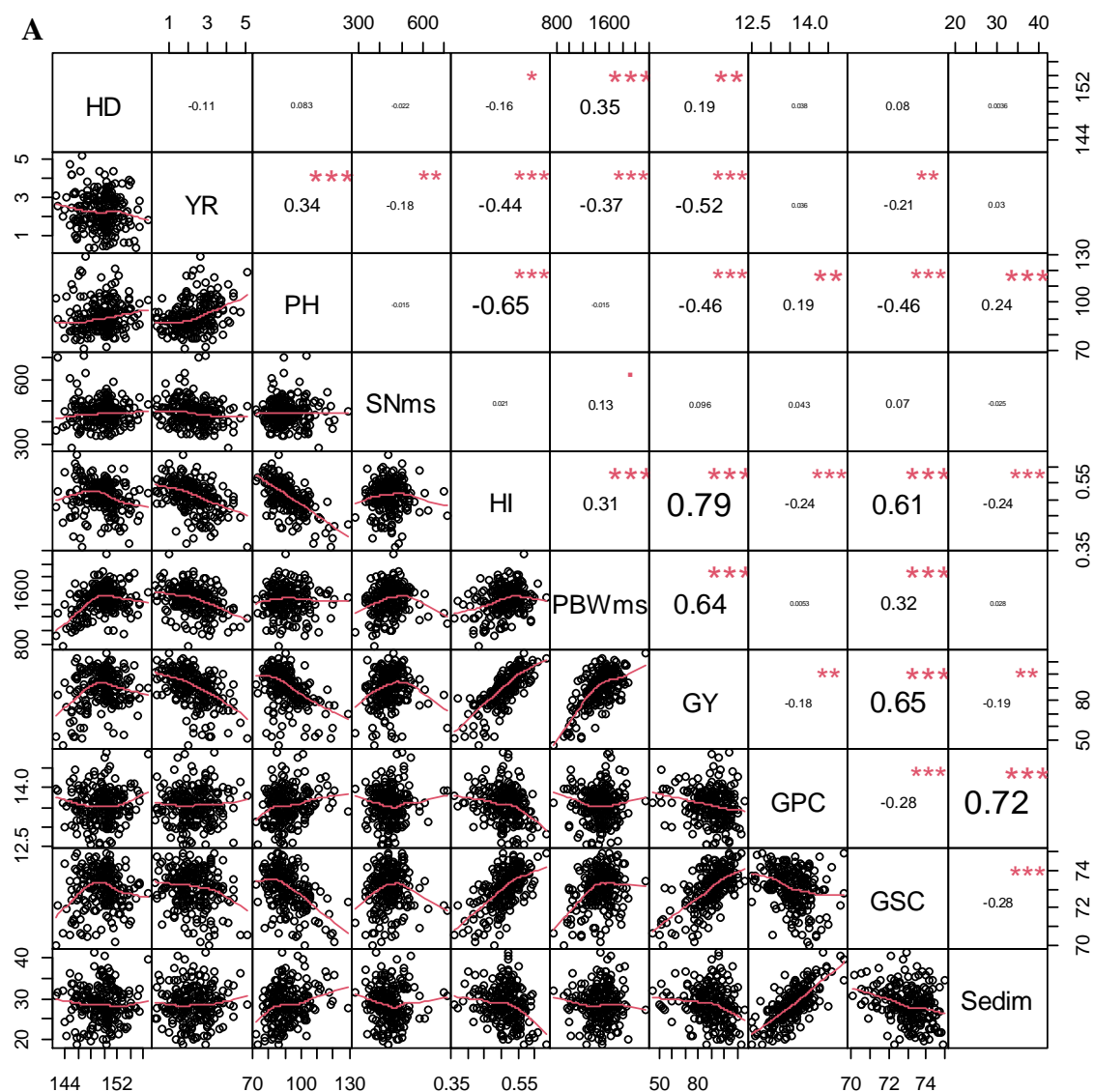


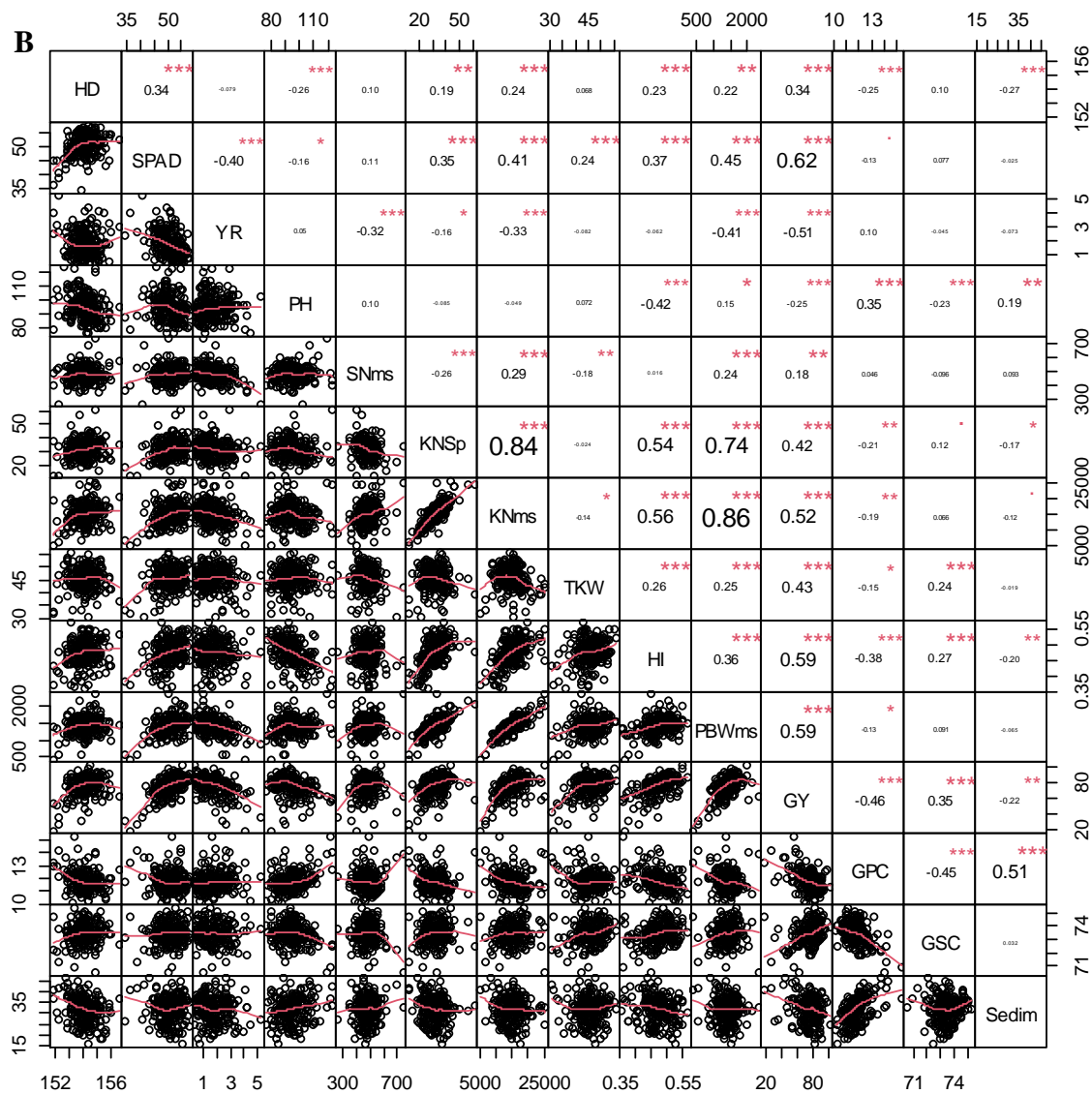
**Figure S3.** Agronomy efficiency use of Nitrogen supplied. The red bar charts are the number of cultivars belonging to the defined class of NAE index. The blue bar charts are showing the average percentage of NAE.

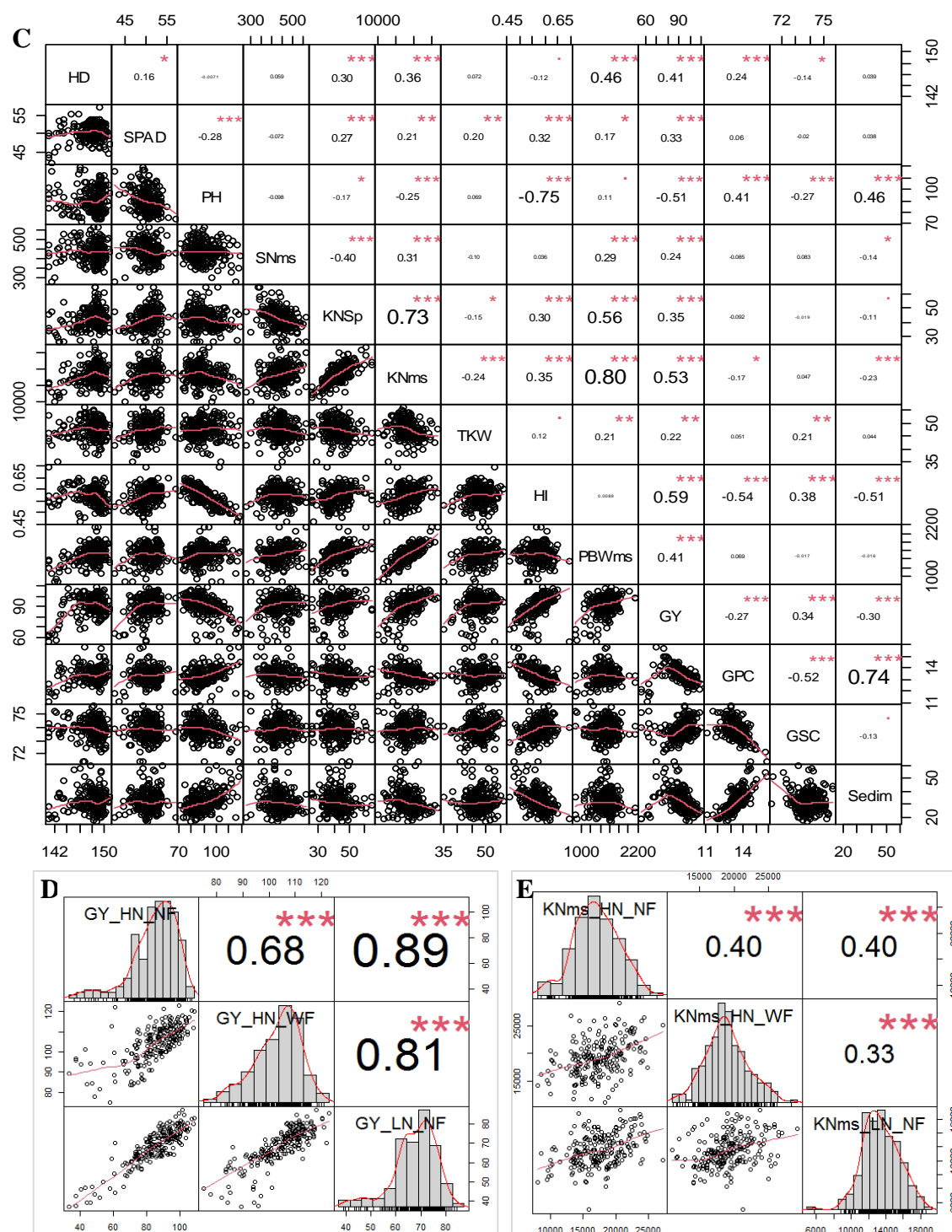




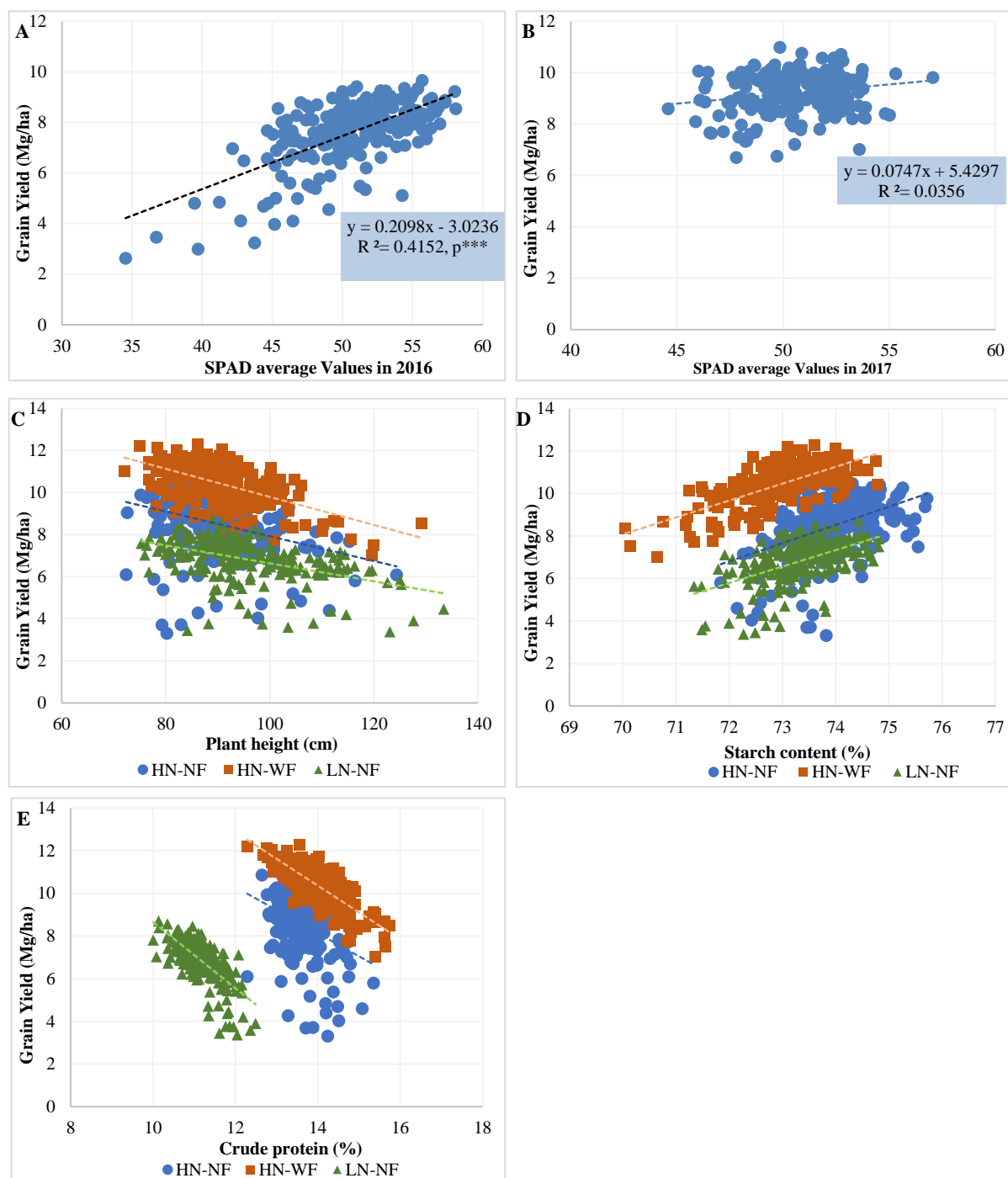
**Figure S4.** (A) Grain N yield (GNV) under three CS (HN–NF in green color, HN–WF in red color, LN–NF in blue color) across the three years (abc) above the boxplots denotes the groups means with a the highest and c the lowest means GNV; (B) Resilience to YR infestation of GY contrasting cultivars; (C) Chlorophyll content (SPAD) of GY contrasting cultivars. NS means not significant at  $p=0.05$  and \*\*\* significant at  $p=0.001$ .



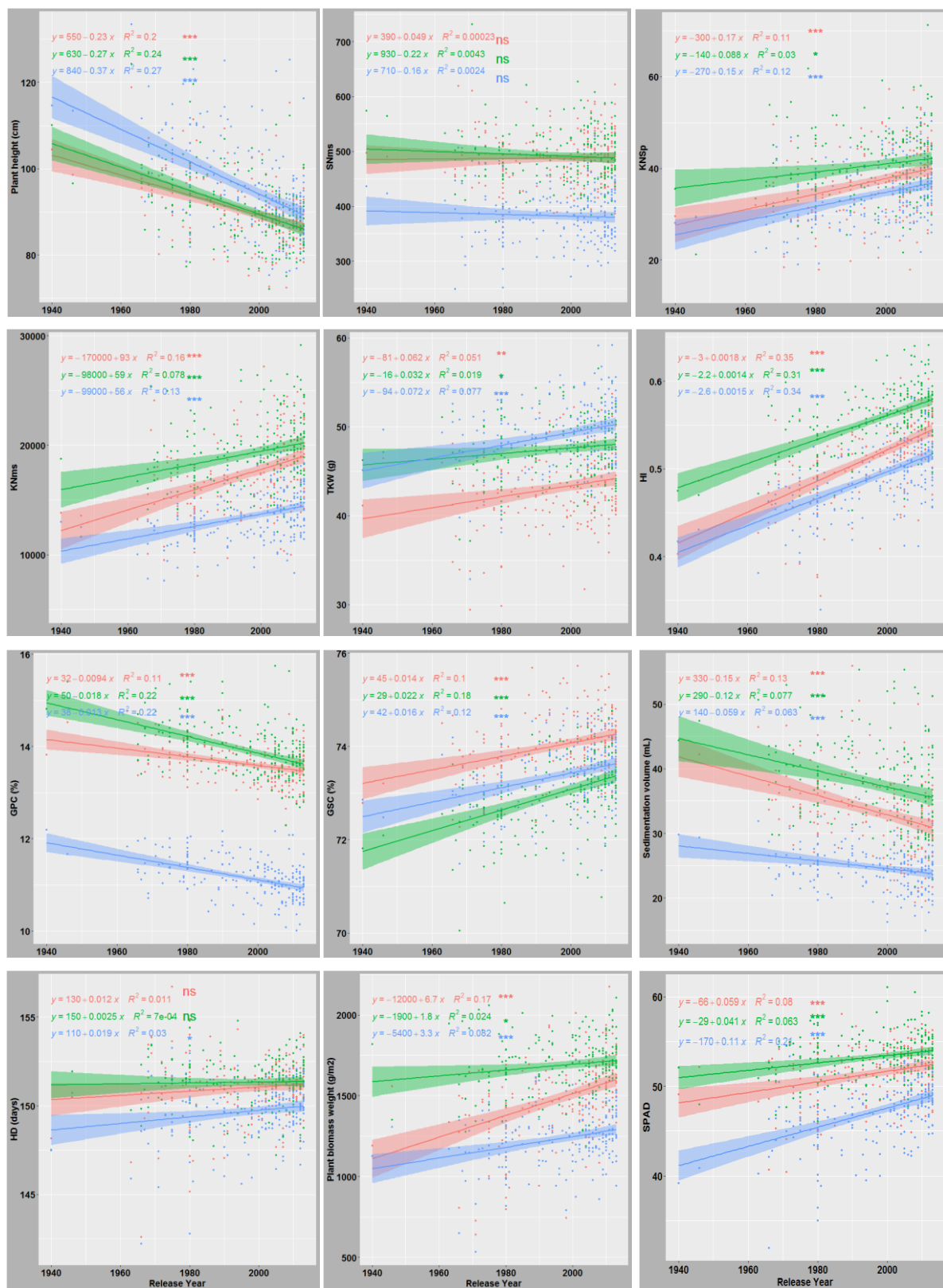


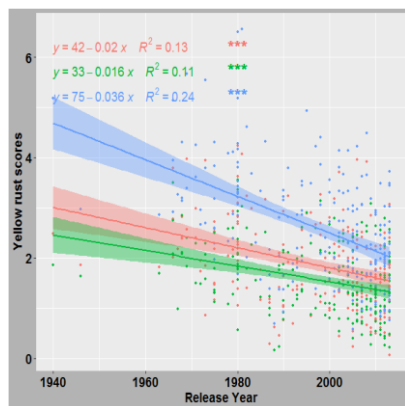


**Figure S5.** Pearson correlation coefficients and associated probability among evaluated traits based on of the genotype mean from the three tested cropping systems in three years of trials (A)=2015; (B)=2016; (C)=2017. (DE) Correlation among the three CS for GY and KNms. All traits were measured in a wheat population containing 220 breeding lines grown in three cropping systems between 2015 and 2017. The number of stars indicates the significance level, \* $P < 0.05$ ; \*\* $P < 0.01$  and \*\*\*  $P < 0.001$ .

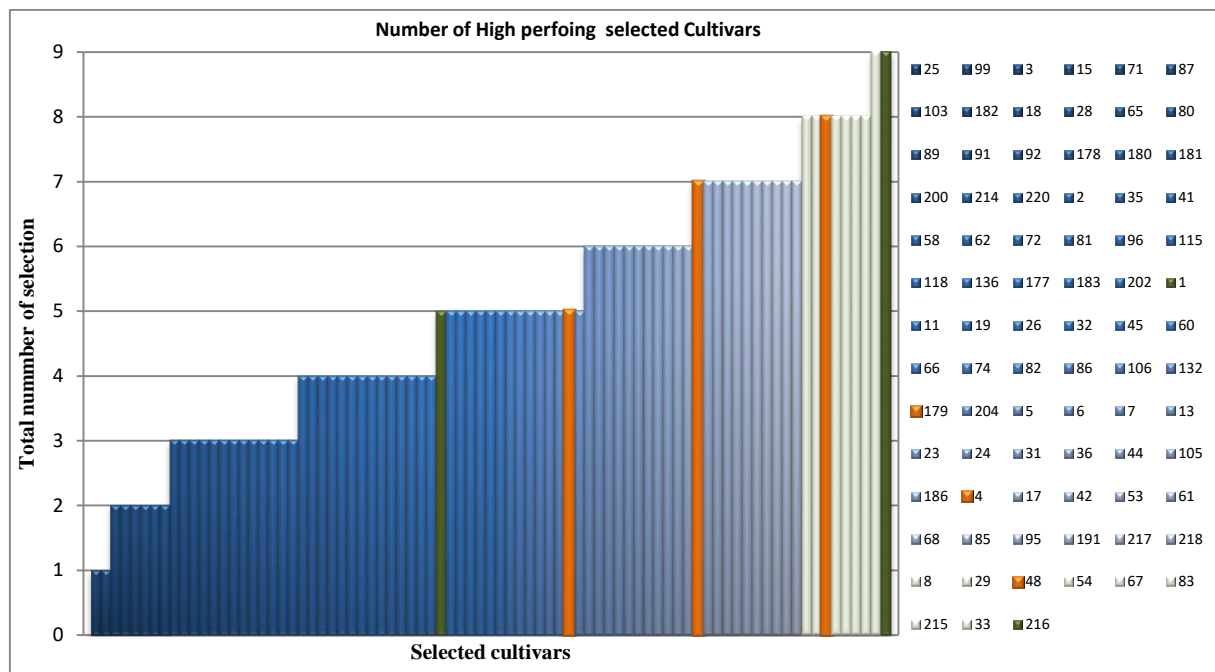


**Figure S6.** Relationship between GY and traits of interest. **(A)** average SPAD in 2016; **(B)** average SPAD in 2017; **(C)** plant height (cm); **(D)** grain starch content (%); **(E)** grain crude protein content (%) under each CS. The regressions equations, the significance of the slopes and comparison among slopes of the three CS is given Table S14.





**Figure S7.** Temporal trends observed in evaluated traits in relation to year of registration among 209 cultivars under three CS, HN-WF in green, HN-NF in red and LN- NF in blue color. The center lines represent the regression lines and the shaded regions represent the 95% confidence intervals. The signs ns stands for the slope is not significant at 0.05; \* is significant at 0.05; \*\* is significant at 0.01, \*\*\* is significant at 0.001.



**Figure S8.** Graphical representation of selected cultivars based on performance index. The 46 cultivars comprised between 1 and 216 (colored in green) were used in the stability analysis. Among 46 high performing cultivars, only three cultivars colored in orange (Apache=179, Claire=4, and Gaucho=48) were older released cultivars (released before 2000).



