Supplementary material:

Supplementary figure 1: Relationship between Yield and Grain density on raw data

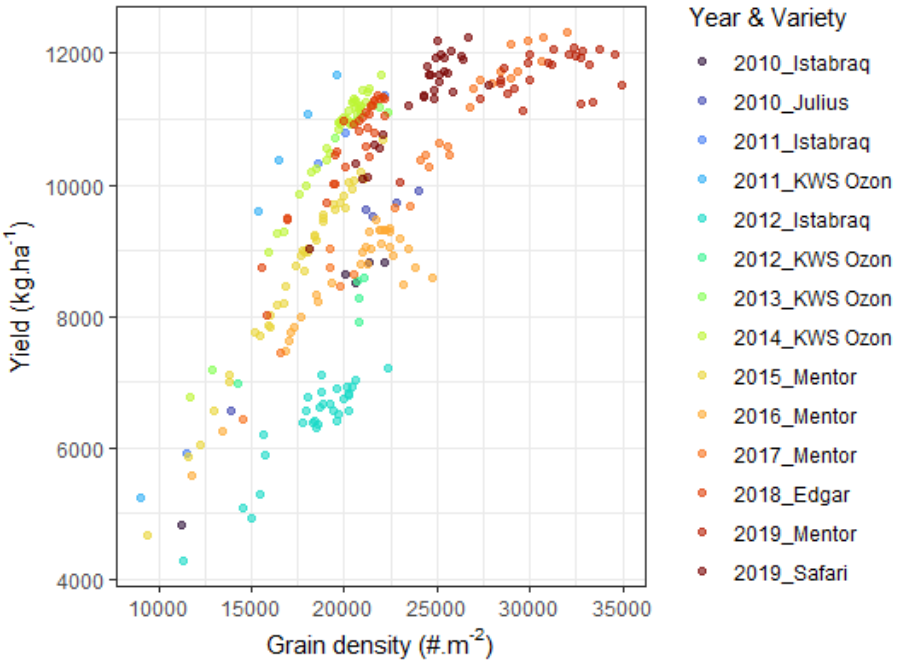


Figure 1: Yield as a function of grain density for each trial (year and variety).

"Year and variety" classification encompass experiment variability due to annual weather, differences in residual soil N available at the end of winter and genotypes.

Supplementary Table 1 : Raw results of observed yield and yield components under the different N fertilization regimes tested each year between 2010 and 2019

	N Management				Yield (kg ha^{-1})		Grain.dens. (# m^{-2})		TKW (g)		Spike.dens. (# m^{-2})	
Years	DC_{23-25}	DC_{31}	DC_{39}	Total N fertilizer supplied	Avg.	Std.dev	Avg.	Std.dev	Avg.	Std.dev	Avg.	Std.dev
2010 -> 2019	0	0	0	0	6539.5	1661	13467.9	3687	49.0	5.8	285.3	43.8
2012, 2014 -> 2019	0	0	50-70	50-70	7974.8	2176	17226.4	5634	47.1	7.9	308.9	70.8
2012, 2014 -> 2019	0	0	100+	100-120	8901.1	2178	19376.4	4708	46.2	7.4	309.0	52.2
2012, 2014 -> 2019	0	50-70	0	50-70	8737.7	1904	19031.5	4668	46.4	6.3	358.7	68.1
2012, 2014 -> 2019	0	50-70	50-70	100-140	9612.5	1930	21014.5	4859	46.4	7.1	363.6	56.0
2012	0	50-70	100+	150-190	6363.2	12	18453.5	226	34.5	0.5	328.0	1.9
2012, 2014 -> 2019	0	100+	0	100-120	9980.8	1533	22284.8	4153	45.3	5.6	396.3	46.7
2014, 2015	0	100+	50-70	150-190	9869.3	1079	18754.3	1137	52.5	3.0	392.7	75.8
2012, 2014 -> 2019	0	100+	100+	200	9963.4	1864	22122.6	4181	45.5	7.6	384.2	43.5
2019	30-40	30-40	30-40	90-120	10079.3	-	20954.9	-	48.1	-	350.0	-
2012 -> 2018	30-40	50-70	100+	180-230	10768.1	983	24521.8	3352	44.3	5.5	388.3	19.2
2016, 2018	30-40	100+	50-70	180-230	10179.2	1625	21750.4	432	46.7	6.5	407.5	-
2012, 2014 -> 2019	50-70	0	0	50-70	8655.7	1937	18719.1	4539	46.6	5.4	369.3	46.0
2012, 2014 -> 2019	50-70	0	50-70	100-140	9601.7	2170	20771.3	5166	46.8	6.7	377.8	53.8
2012	50-70	0	100+	150-190	6486.5	259	18681.8	210	34.7	1.0	336.9	12.0
2016	50-70	30-40	100+	180-230	9473.3	-	21702.9	-	43.7	-	400.8	-
2012, 2014 -> 2019	50-70	50-70	0	100-140	9847.8	1775	22217.6	4901	44.9	6.2	413.2	38.5
2010 -> 2019	50-70	50-70	50-70	150-210	10301.3	1440	21956.0	4813	48.1	8.3	419.0	61.9
2010, 2012 -> 2019	50-70	50-70	100+	200-260	9782.7	1523	21290.8	3534	46.4	7.5	426.6	60.4
2016	50-70	100+	30-40	180-230	9044.8	-	22421.4	-	40.3	-	463.3	-
2011, 2014, 2015, 2019	50-70	100+	50-70	200-260	10918.5	902	23115.7	5485	48.5	7.0	413.2	57.5
2010, 2012, 2014,2015	50-70	100+	100+	250-310	9637.6	1741	20669.7	562	46.5	7.8	415.1	64.5
2016 -> 2019	70-90	0	0	70-90	10024.2	1229	22376.4	4138	45.3	4.9	429.9	31.8
2014, 2015	70-90	0	50-70	120-160	9466.1	2063	17907.1	2689	52.6	3.6	369.6	31.2
2012, 2014 -> 2019	70-90	0	70-90	140-180	10191.9	1733	21726.0	4533	47.5	6.7	401.6	47.2
2016, 2018, 2019	70-90	30-40	50-70	150-200	10560.3	1307	22895.2	2211	46.1	3.3	444.4	34.6
2016 -> 2019	70-90	50-70	30-40	150-200	10806.7	1316	24679.7	3562	44.1	5.5	462.5	40.5
2012, 2014 -> 2019	70-90	70-90	0	140-180	10202.7	1736	23928.6	5025	43.3	7.2	434.9	43.8
2014, 2015, 2018, 2019	70-90	70-90	50-70	190-250	10887.5	867	21737.0	2417	50.3	3.3	417.8	53.1
2010 -> 2019	70-90	70-90	70-90	210-270	10398.2	1561	22902.5	4199	46.2	8.1	469.1	64.5
2012, 2014 -> 2019	100+	0	0	100-120	9806.8	1755	22230.9	4757	44.7	6.2	416.5	50.4
2014, 2015	100+	0	50-70	150-190	9409.3	2173	18093.6	3040	51.7	3.3	405.8	55.4
2012 -> 2019	100+	0	100+	200-240	10173.8	1980	22824.2	4938	45.3	8.3	439.6	71.1
2012, 2014 -> 2019	100+	100+	0	200-240	10351.5	1786	24479.2	4880	43.0	7.8	477.4	59.2
2010 -> 2019	100+	100+	100+	300-360	10416.7	1550	24154.9	4031	43.8	8.0	490.9	54.7

Supplementary panel 1: Model fitting procedure for the prediction of grain density with spike density and spike fertility

The following models were compared to evaluate the fit improvement using generalized additive model (GAM) over linear model.

Linear : $E(y_i) = \beta 0 + \beta 1 x_i + \beta 2 z_i + \epsilon$
GAM_1 : $g(E(y_i)) = \beta 0 + \beta 1 x_i + f2(z_i) + \epsilon$
GAM_2 : $g\big(E(y_i)\big) = \beta 0 + f1(x_i) + f2(z_i) + \epsilon$
GAM_3 : $g\big(E(y_i)\big) = \beta 0 + f1(x_i) + f2(z_i) + f3(x_i, z_i) + \epsilon$

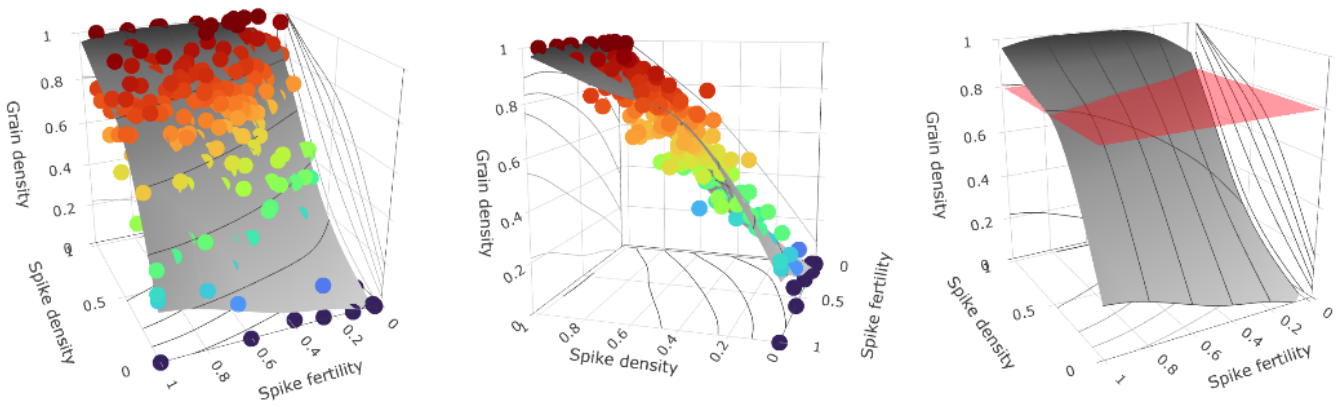
where *y* is the response variable, here the normalized grain density, *β0* is the intercept, *β1* and *β2* are the parameters of x and y in linear mode. X is the normalized spike density and z is the normalize spike fertility. The functions *f1*, *f2* refer to a smooth function when *f3* refers to a tensor product interaction.

Restricted maximum likelihood (REML) was used to fit models individually to the data.

Supplementary Table 2: Performance parameters of the tested models during the fitting procedure

	Adjusted R^2	REML	AIC
Linear	0.860	-230.4	-472.8
GAM_1	0.864	-231.2	-476.9
GAM_2	0.872	-235.8	-489.9
GAM_3	0.904	-260.2	-548.9

Supplementary Figure 2: Visualization of the fitted Generalized Additive Model



3D representation of the generalized additive model and the normalized values of grain density over spike fertility and spike density. Points colors represent the level of grain density, blue being the lowest values while red being the highest grain densities. The red surface on the 3rd panel represents the grain $density_n$ = 0.8.

Supplementary Table 3 : Linear regressions of normalized grain density, spike density and spike fertility and the influence of total N fertilizer. Normalization procedures correspond to equation 5 in Material & Method.

Linear regression of grain density and spike density by level of spike fertility			Linear regression of grain density and spike fertility by level of spike density			Linear regression of spike density and N supply (DC 25 & DC 30) by level of spike fertility			Linear regression of spike fertility and N supply (DC 39) by level of spike density		
Spike fertility	R^2	p-value	Spike density	R^2	p-value	Spike fertility	R^2	p-value	Spike density	R^2	p-value
0	0.883	0.00005	0	0.584	0.0770	0	0.905	0.00002	0	0.205	0.367
0.1	0.869	0.00676	0.1	0.724	0.0674	0.1	0.841	0.01	0.1	0.771	0.0502
0.2	0.917	0	0.2	0.581	0.0464	0.2	0.708	0.00001	0.2	0.0669	0.575
0.3	0.828	0	0.3	0.687	0.00013	0.3	0.622	0	0.3	0.427	0.00824
0.4	0.826	0	0.4	0.678	0	0.4	0.651	0	0.4	0.664	0
0.5	0.675	0	0.5	0.753	0	0.5	0.374	0.0002	0.5	0.608	0
0.6	0.769	0	0.6	0.556	0	0.6	0.875	0	0.6	0.448	0
0.7	0.821	0	0.7	0.407	0.00003	0.7	0.593	0.00001	0.7	0.416	0.00002
0.8	0.893	0	0.8	0.394	0.00303	0.8	0.77	0	0.8	0.173	0.0681
0.9	0.651	0.00003	0.9	0.519	0.0285	0.9	0.457	0.00148	0.9	0.0104	0.794
1	0.728	0.00001	1	0.294	0.0200	1	0.679	0.00005	1	0.00646	0.751

Supplementary Table 4 : Linear regressions of normalized spike density and different fertilizer N supplies. Normalization procedures correspond to Eq. 5 in Material & Method.

Spike fertility levels	Linear regression of spike density and N supply at DC 25		Linear regression of spike density and N supply at DC 30		Linear regression of spike density and total N supply	
	R^2	p-value	R^2	p-value	R^2	p-value
0	0.805	0.0000	0.508	0.0009	0.822	0.0000
0.1	0.744	0.0125	0.498	0.0765	0.879	0.0018
0.2	0.554	0.0004	0.701	0.0000	0.817	0.0000
0.3	0.326	0.0029	0.170	0.0403	0.597	0.0000
0.4	0.185	0.0112	0.237	0.0035	0.617	0.0000
0.5	0.228	0.0058	0.082	0.1124	0.493	0.0000
0.6	0.490	0.0001	0.203	0.0183	0.656	0.0000
0.7	0.351	0.0018	0.128	0.0791	0.618	0.0000
0.8	0.519	0.0002	0.423	0.0011	0.781	0.0000
0.9	0.390	0.0043	0.066	0.2888	0.609	0.0001
1	0.406	0.0025	0.556	0.0002	0.903	0.0000

Supplementary Table 5 : Games - Howell test. Results of the Games-Howel post-hoc test on (**a**) grain density and (**b**) TKW. both variables being normalized between their trial's minimal and maximal values

a — Normalized Grain density

strategies	2 N1-_N2-_N3+	3 N1-_N2+_N3-	4 N1-_N2+_N3+	5 N1+_N2-_N3-	6 N1+_N2-_N3+	7 N1+_N2+_N3-	8 N1+_N2+_N3+
1 N1-_N2-_N3-	ns	***	****	**	****	****	****
2 N1-_N2-_N3+		ns	****	ns	***	****	****
3 N1-_N2+_N3-			*	ns	*	***	****
4 N1-_N2+_N3+				*	ns	ns	****
5 N1+_N2-_N3-					*	***	****
6 N1+_N2-_N3+						ns	****
7 N1+_N2+_N3-							**

b — Normalized TKW

strategies	2 N1-_N2-_N3+	3 N1-_N2+_N3-	4 N1-_N2+_N3+	5 N1+_N2-_N3-	6 N1+_N2-_N3+	7 N1+_N2+_N3-	8 N1+_N2+_N3+
1 N1-_N2-_N3-	ns	*	***	**	***	****	****
2 N1-_N2-_N3+		ns	ns	ns	ns	**	**
3 N1-_N2+_N3-			ns	ns	ns	***	**
4 N1-_N2+_N3+				ns	ns	*	*
5 N1+_N2-_N3-					ns	**	**
6 N1+_N2-_N3+						*	ns
7 N1+_N2+_N3-							ns

Supplementary Table 6 : Games - Howell test including the impact of N_{SRW}. Results of the Games-Howel post-hoc test on (**a**) grain density and (**b**) TKW, both variables being normalized between their trial's minimal and maximal values

a. Normalized grain density

N_{SRW}	Strategies	2 N1-_N2-_N3+_	3 N1-_N2+_N3-_	4 N1-_N2+_N3+_	5 N1+_N2-_N3-_	6 N1+_N2-_N3+_	7 N1+_N2+_N3-_	8 N1+_N2+_N3+_
Under 46 kg ha^{-1}	1 N1-_N2-_N3-	ns	**	****	*	****	****	****
	2 N1-_N2-_N3+		ns	**	ns	**	***	****
	3 N1-_N2+_N3-			ns	ns	ns	*	***
	4 N1-_N2+_N3+				ns	ns	ns	****
	5 N1+_N2-_N3-					ns	ns	**
	6 N1+_N2-_N3+						ns	**
	7 N1+_N2+_N3-							ns
Above 46 kg ha^{-1}	1 N1-_N2-_N3-	ns	ns	*	ns	*	**	***
	2 N1-_N2-_N3+		ns	ns	ns	ns	*	**
	3 N1-_N2+_N3-			ns	ns	ns	*	***
	4 N1-_N2+_N3+				ns	ns	ns	**
	5 N1+_N2-_N3-					ns	*	**
	6 N1+_N2-_N3+						ns	*
	7 N1+_N2+_N3-							*

b. Normalized TKW

N_{SRW}	Strategies	2 N1-_N2-_N3+_	3 N1-_N2+_N3-_	4 N1-_N2+_N3+_	5 N1+_N2-_N3-_	6 N1+_N2-_N3+_	7 N1+_N2+_N3-_	8 N1+_N2+_N3+_
Under 46 kg ha^{-1}	1 N1-_N2-_N3-	ns	ns	*	ns	ns	**	*
	2 N1-_N2-_N3+		ns	ns	ns	ns	ns	ns
	3 N1-_N2+_N3-			ns	ns	ns	*	ns
	4 N1-_N2+_N3+				ns	ns	ns	ns
	5 N1+_N2-_N3-					ns	ns	ns
	6 N1+_N2-_N3+						ns	ns
	7 N1+_N2+_N3-							ns
Above 46 kg ha^{-1}	1 N1-_N2-_N3-	ns	ns	ns	ns	ns	***	****
	2 N1-_N2-_N3+		ns	ns	ns	ns	**	***
	3 N1-_N2+_N3-			ns	ns	ns	ns	**
	4 N1-_N2+_N3+				ns	ns	ns	*
	5 N1+_N2-_N3-					ns	ns	**
	6 N1+_N2-_N3+						ns	*
	7 N1+_N2+_N3-							ns

Supplementary Table 7 : Median, 1st and 3rd quantiles of normalized yield components values per strategies of N fertilization. Normalization procedure corresponds to Eq. 5 of the material & method.

N fertilization strategies	Normalized spike density	Normalized spike fertility	Normalized grain density	Normalized thousand Kernel Weight	Yield
1 N1-_N2-_N3-	0.36 [0.01 ; 0.54]	0.39 [0.24 ; 0.72]	0.41 [0.00 ; 0.61]	0.71 [0.49 ; 0.95]	0.51 [0.00 ; 0.73]
2 N1-_N2-_N3+	0.29 [0.13 ; 0.46]	0.77 [0.65 ; 0.89]	0.51 [0.32 ; 0.68]	0.62 [0.38 ; 0.86]	0.67 [0.43 ; 0.79]
3 N1-_N2+_N3-	0.48 [0.44 ; 0.66]	0.40 [0.29 ; 0.63]	0.62 [0.52 ; 0.70]	0.57 [0.42 ; 0.68]	0.71 [0.65 ; 0.81]
4 N1-_N2+_N3+	0.56 [0.44 ; 0.65]	0.66 [0.51 ; 0.84]	0.78 [0.71 ; 0.82]	0.53 [0.35 ; 0.58]	0.88 [0.83 ; 0.93]
5 N1+_N2-_N3-	0.58 [0.49 ; 0.68]	0.34 [0.19 ; 0.46]	0.55 [0.50 ; 0.71]	0.51 [0.39 ; 0.61]	0.68 [0.54 ; 0.85]
6 N1+_N2-_N3+	0.62 [0.52 ; 0.69]	0.54 [0.36 ; 0.64]	0.77 [0.69 ; 0.87]	0.51 [0.41 ; 0.63]	0.91 [0.79 ; 0.95]
7 N1+_N2+_N3-	0.73 [0.63 ; 0.82]	0.41 [0.21 ; 0.61]	0.84 [0.79 ; 0.86]	0.30 [0.20 ; 0.41]	0.87 [082 ; 0.90]
8 N1+_N2+_N3+	0.90 [0.75 ; 1.00]	0.45 [0.25 ; 0.71]	0.92 [0.85 ; 1.00]	0.22 [0.02 ; 0.35]	0.92 [0.84 ; 1.00]

Supplementary figure 3: Distribution of normalized yield within each N strategy. Each yield level is colored with the total amount of N provided. The vertical dotted line corresponds to a normalized yield value of 0.9.