

SUPPLEMENTARY MATERIAL

Figures

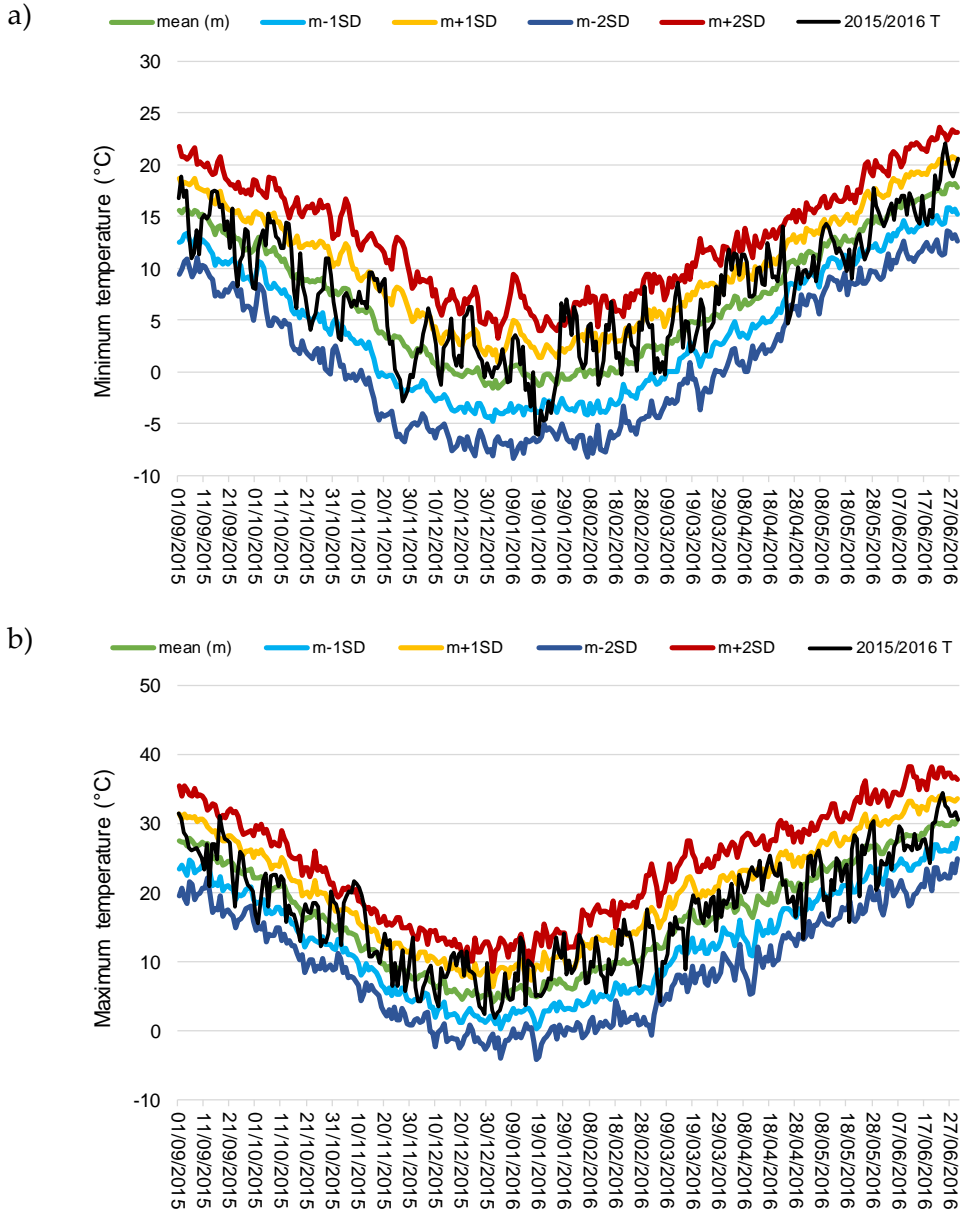


Figure S1 – Minimum (a) and maximum (b) daily temperature of seasons 2015 and 2016 compared with climatology of the period (years 1993-2016). Mean values (m), mean plus one standard deviation (m+1SD), mean plus two standard deviations (m+2SD), mean minus one standard deviation (m-1SD), mean minus two standard deviations (m-2SD) are shown.

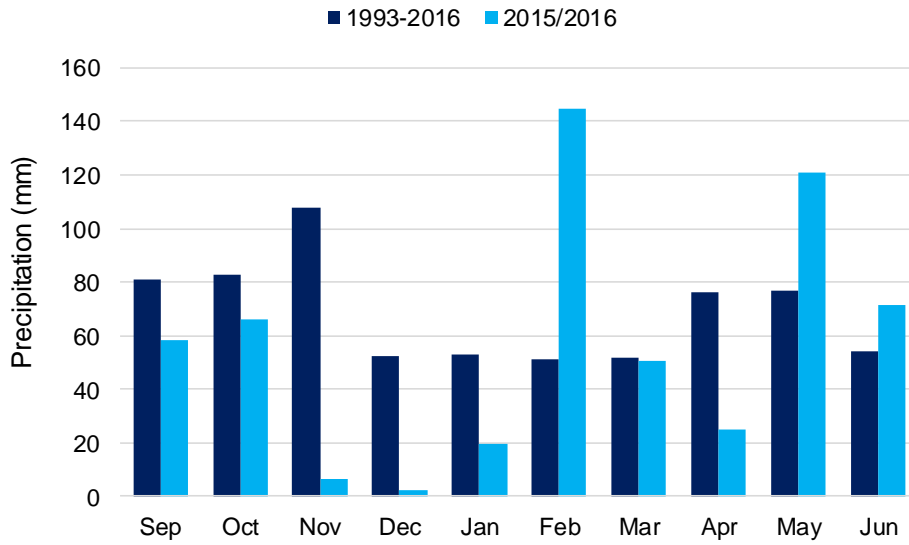


Figure S2 – Monthly precipitation of seasons 2015 and 2016 compared with climatology of the period (years 1993-2016).

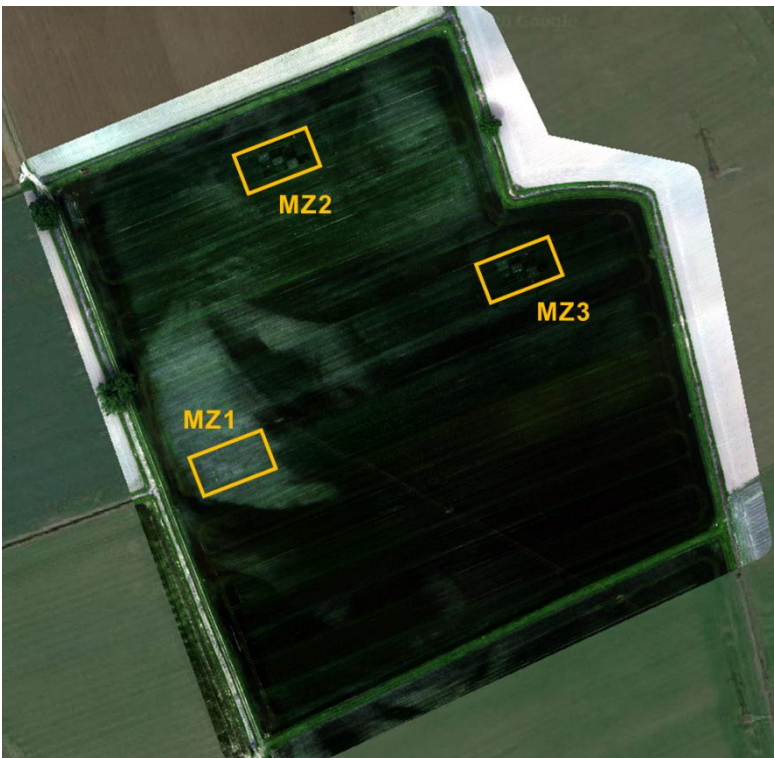


Figure S3 – Trial plots in the field situated in three zones identified through the visually inspection of Google RGB images (low, medium and high crop vigor) and the preliminary analysis of soil ECa

map (low, medium and high). Zone 1 was characterized by low ECa and vigor, zone 2 by medium ECa and vigor and zone 3 by high ECa and vigor.

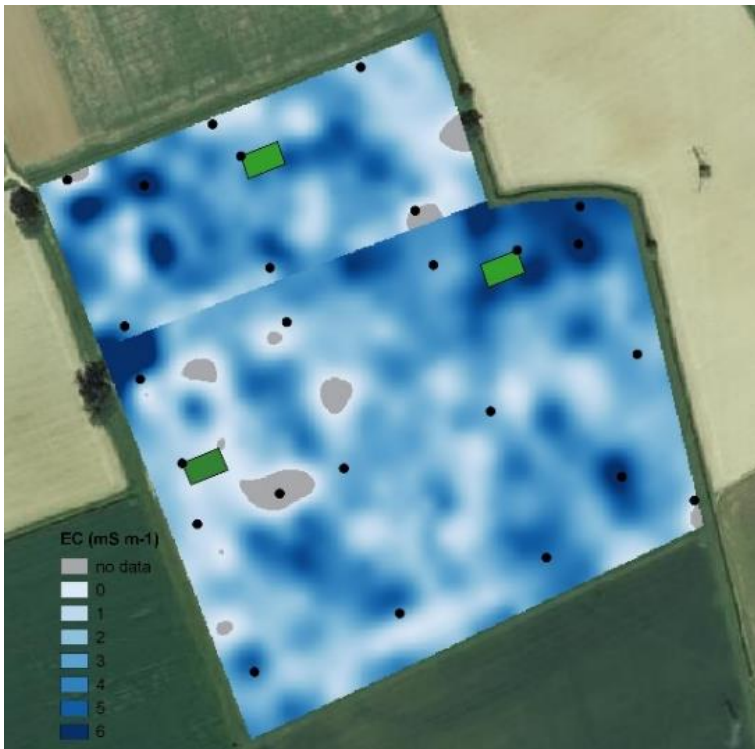


Figure S4 – ECa map (mS m^{-1}) acquired at 15 kHz frequency.

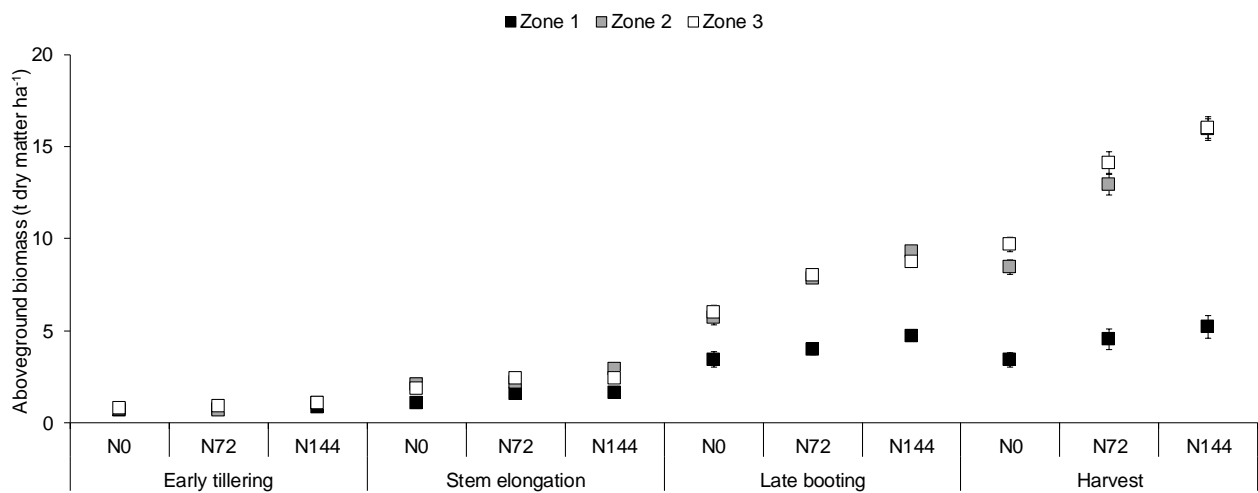


Figure S5 – Mean aboveground biomass values from the plot experiment presented separately by time of monitoring survey, by nitrogen level (N0= 0 kg N ha⁻¹; N72= 0 kg N ha⁻¹; N144=144 kg N ha⁻¹) and by field zone (1, 2 and 3 representative of low, medium and high grain yield, respectively). Error bars represent the standard error of the mean.

Tables

Table S1 – Characterization of the clusters indicating for each cluster: the categorical variables (development stage, DVS: early tillering “eTl”, stem elongation “StEl”, late booting “IB”; the yield-based MZs corresponding to theyield levels 1 “low”, 2 “medium” and 3 “high”); the percentage of pixels for each category of the categorical variables (Cla/Mod); the percentage of pixels classified with the indicated categorical variable (Mod/Cla); the percentage of pixels of all dataset classified with the indicated categorical variable (Global), the p-value (P) of the student t test used to compare the average of the category with the general average; v.test (the transformation of P into a normal quantile). Categories are ordered by v.test values.

<i>Cluster</i>	<i>Category</i>	<i>Cla/Mod</i>	<i>Mod/Cla</i>	<i>Global</i>	<i>P</i>	<i>v.test</i>
1	DVS= IB	89.1	100.0	33.33	< 0.0001	>10 ²⁰⁰
	MZ=3	33.3	47.1	41.97	< 0.0001	7.19
	MZ=2	32.2	48.4	44.66	< 0.0001	5.20
	MZ=1	10.2	4.6	13.37	< 0.0001	-19.66
	DVS= StEl	0.0	0.0	33.33	< 0.0001	<-10 ²⁰⁰
	DVS= eTl	0.0	0.0	33.33	< 0.0001	<-10 ²⁰⁰
2	DVS= StEl	85.7	60.4	33.33	< 0.0001	>10 ²⁰⁰
	MZ=3	59.5	52.8	41.97	< 0.0001	22.43
	DVS= eTl	55.9	39.4	33.33	< 0.0001	13.14
	MZ=2	46.4	43.8	44.66	< 0.0001	-1.83
	MZ=1	12.2	3.4	13.37	< 0.0001	-31.57
	DVS= IB	0.3	0.2	33.33	< 0.0001	<-10 ²⁰⁰
3	MZ=1	77.6	45.2	13.37	< 0.0001	>10 ²⁰⁰
	DVS= eTl	44.1	63.9	33.33	< 0.0001	37.29
	MZ=2	21.5	41.7	44.66	< 0.0001	-3.50
	DVS= StEl	14.3	20.7	33.33	< 0.0001	-16.24
	DVS= IB	10.6	15.4	33.33	< 0.0001	-23.53
	MZ=3	7.2	13.1	41.97	< 0.0001	-36.37

Table S2 – v.test results for each cluster. The mean and the standard deviation values for each “original variable” used for PCA analysis (“Mean in category” and “SD in category”) are reported. Overall mean and standard deviation are also reported.

<i>Cluster</i>	<i>Original variable</i>	<i>v.test</i>	<i>Mean in category</i>	<i>Overall mean</i>	<i>SD in category</i>	<i>Overall SD</i>	<i>P</i>
1	Y	15.78	7.88	7.51	1.26	1.62	< 0.0001
	ECa	7.72	2.92	2.76	1.31	1.42	< 0.0001
	Red	-56.68	568.67	891.25	218.52	398.39	< 0.0001
	NIR	-67.27	13116.90	16878.36	1380.34	3914.26	< 0.0001
	Green	-89.31	1289.32	2128.30	241.66	657.55	< 0.0001
	Blue	-91.54	554.44	891.50	82.69	257.75	< 0.0001
	RedEdge	-92.95	3024.91	4882.71	494.53	1399.04	< 0.0001
2	NIR	76.86	19825.45	16878.36	2930.54	3914.26	< 0.0001
	RedEdge	38.33	5408.07	4882.71	513.00	1399.04	< 0.0001
	Y	34.06	8.05	7.51	1.23	1.62	< 0.0001
	Blue	28.88	964.42	891.50	88.02	257.75	< 0.0001
	Green	27.56	2305.83	2128.30	258.24	657.55	< 0.0001
	ECa	26.68	3.13	2.76	1.31	1.42	< 0.0001
	Red	-13.82	837.30	891.25	148.12	398.39	< 0.0001
3	Red	77.96	1419.18	891.25	405.69	398.39	< 0.0001
	Blue	65.14	1176.89	891.50	158.41	257.75	< 0.0001
	Green	64.29	2846.86	2128.30	421.72	657.55	< 0.0001
	RedEdge	55.46	6201.47	4882.71	944.35	1399.04	< 0.0001
	NIR	-18.16	15670.09	16878.36	2982.51	3914.26	< 0.0001
	ECa	-40.05	1.80	2.76	1.33	1.42	< 0.0001
	Y	-57.57	5.92	7.51	1.72	1.62	< 0.0001

Table S3 – Results of the split-plot ANOVA for wheat above ground biomass at harvest (t dry matter ha⁻¹), separately for each field survey. Significance of the differences between zones, the linear and quadratic trends of above ground biomass to N fertilizer, and their interactions are also reported.

Time of field survey	Source	Sum of square	Degrees of freedom	Mean square	F	P
Early tillering	Zone	0.1222	2	0.0611	3.3500	0.1054
	Zone1 vs Zone2-Zone3	0.0961	1	0.0961	5.2700	0.0615
	Zone2 vs Zone3	0.0261	1	0.0261	1.4300	0.2769
	Block (Zone)	0.1094	6	0.0182		
	Fertilizer	0.3420	2	0.1710	9.2574	0.0037
	Linear trend	0.3092	1	0.3092	36.1527	0.0010
	Quadratic trend	0.0328	1	0.0328	1.1538	0.3240
	Zone × Fertilizer	0.0745	4	0.0186	1.0084	0.4410
	Linear trend at Zone1 vs Linear trend at Zone2-Zone3	0.0095	1	0.0095	1.1151	0.3316
	Quadratic trend at Zone1 vs Quadratic trend at Zone2-Zone3	0.0100	1	0.0100	0.3532	0.5740
	Linear trend at Zone2 vs Linear trend at Zone3	0.0001	1	0.0001	0.0078	0.9327
	Quadratic trend at Zone2 vs Quadratic trend at Zone3	0.0549	1	0.0549	1.9330	0.2138
Residual	0.2217	12	0.0185			
Stem elongation	Zone	4.5959	2	2.2979	42.2348	0.0003
	Zone1 vs Zone2-Zone3	4.5092	1	4.5092	82.8770	0.0001
	Zone2 vs Zone3	0.0867	1	0.0867	1.5926	0.2538
	Block (Zone)	0.3265	6	0.0544		
	Fertilizer	1.9479	2	0.9739	14.3820	0.0007
	Linear trend	1.9295	1	1.9295	27.6502	0.0019
	Quadratic trend	0.0184	1	0.0184	0.2796	0.6160
	Zone × Fertilizer	0.4677	4	0.1169	1.7268	0.2086
	Linear trend at Zone1 vs Linear trend at Zone2-Zone3	0.0128	1	0.0128	0.1841	0.6829
	Quadratic trend at Zone1 vs Quadratic trend at Zone2-Zone3	0.0919	1	0.0919	1.4004	0.2814
	Linear trend at Zone2 vs Linear trend at Zone3	0.0601	1	0.0601	0.8605	0.3894
	Quadratic trend at Zone2 vs Quadratic trend at Zone3	0.3029	1	0.3029	4.6136	0.0753

Time of field survey	<i>Source</i>	<i>Sum of square</i>	<i>Degrees of freedom</i>	<i>Mean square</i>	<i>F</i>	<i>P</i>
	Residual	0.8126	12	0.0677		
Late booting	Zone	76.6520	2	38.3260	280.7816	< 0.0001
	Zone1 vs Zone2-Zone3	76.6440	1	76.6440	561.5051	< 0.0001
	Zone2 vs Zone3	0.0079	1	0.0079	0.0581	0.8176
	Block (Zone)	0.8190	6	0.1365		
	Fertilizer	29.4500	2	14.7250	41.6573	< 0.0001
	Linear trend	28.9363	1	28.9363	50.7374	0.0004
	Quadratic trend	0.5137	1	0.5137	3.7591	0.1006
	Zone × Fertilizer	4.7543	4	1.1886	3.3625	0.0458
	Linear trend at Zone1 vs Linear trend at Zone2-Zone3	3.6241	1	3.6241	6.3545	0.0452
	Quadratic trend at Zone1 vs Quadratic trend at Zone2-Zone3	0.4979	1	0.4979	3.6441	0.1049
	Linear trend at Zone2 vs Linear trend at Zone3	0.5162	1	0.5162	0.9051	0.3781
	Quadratic trend at Zone2 vs Quadratic trend at Zone3	0.1161	1	0.1161	0.8497	0.3922
	Residual	4.2418	12	0.3535		
Harvest	Zone	433.2158	2	216.6079	139.0218	< 0.0001
	Zone1 vs Zone2-Zone3	430.1079	1	430.1079	276.0489	< 0.0001
	Zone2 vs Zone3	3.1079	1	3.1079	1.9947	0.2076
	Block (Zone)	9.3485	6	1.5581		
	Fertilizer	126.0423	2	63.0212	138.1929	< 0.0001
	Linear trend	122.5441	1	122.5441	192.9010	< 0.0001
	Quadratic trend	3.4982	1	3.4982	12.6377	0.0120
	Zone × Fertilizer	28.4770	4	7.1193	15.6111	0.0001
	Linear trend at Zone1 vs Linear trend at Zone2-Zone3	26.3862	1	26.3862	41.5355	0.0007
	Quadratic trend at Zone1 vs Quadratic trend at Zone2-Zone3	0.8368	1	0.8368	3.0231	0.1327
	Linear trend at Zone2 vs Linear trend at Zone3	0.9773	1	0.9773	1.5384	0.2612
	Quadratic trend at Zone2 vs Quadratic trend at Zone3	0.2767	1	0.2767	0.9995	0.3560
	Residual	5.4725	12	0.4560		

Table S4 – Results of the split-plot ANOVA for wheat N uptake at harvest (kg N ha⁻¹), separately for each field survey. Significance of the differences between zones, the linear and quadratic trends of N uptake to N fertilizer, and their interactions are also reported.

<i>Time of field survey</i>	<i>Source</i>	<i>Sum of square</i>	<i>Degrees of freedom</i>	<i>Mean square</i>	<i>F</i>	<i>P</i>
<i>Early tillering</i>	Zone	448.0952	2	224.0476	14.6844	0.0049
	Zone1 vs Zone2-Zone3	433.5082	1	433.5082	28.4127	0.0018
	Zone2 vs Zone3	14.5870	1	14.5870	0.9561	0.3659
	Block (Zone)	91.5453	6	15.2575		
	Fertilizer	1608.7313	2	804.3657	22.8194	0.0001
	Linear trend	1501.6101	1	1501.6101	74.0956	0.0001
	Quadratic trend	107.1212	1	107.1212	2.1325	0.1945
	Zone × Fertilizer	168.6718	4	42.1680	1.1963	0.3619
	Linear trend at Zone1 vs Linear trend at Zone2-Zone3	41.4249	1	41.4249	2.0441	0.2027
	Quadratic trend at Zone1 vs Quadratic trend at Zone2-Zone3	20.9048	1	20.9048	0.4162	0.5427
	Linear trend at Zone2 vs Linear trend at Zone3	22.0997	1	22.0997	1.0905	0.3366
	Quadratic trend at Zone2 vs Quadratic trend at Zone3	84.2424	1	84.2424	1.6770	0.2429
	Residual	422.9906	12	35.2492		
<i>Stem elongation</i>	Zone	3602.6387	2	1801.3193	16.1883	0.0038
	Zone1 vs Zone2-Zone3	3401.1362	1	3401.1362	30.5657	0.0015
	Zone2 vs Zone3	201.5025	1	201.5025	1.8109	0.2270
	Block (Zone)	667.6384	6	111.2731		
	Fertilizer	9480.9813	2	4740.4906	48.5768	< 0.0001
	Linear trend	9350.1529	1	9350.1529	84.9056	0.0001
	Quadratic trend	130.8284	1	130.8284	1.5382	0.2612
	Zone × Fertilizer	1072.7983	4	268.1996	2.7483	0.0782
	Linear trend at Zone1 vs Linear trend at Zone2-Zone3	163.9402	1	163.9402	1.4887	0.2682
	Quadratic trend at Zone1 vs Quadratic trend at Zone2-Zone3	78.2311	1	78.2311	0.9198	0.3746
	Linear trend at Zone2 vs Linear trend at Zone3	391.7055	1	391.7055	3.5569	0.1083
	Quadratic trend at Zone2 vs Quadratic trend at Zone3	438.9215	1	438.9215	5.1607	0.0635

<i>Time of field survey</i>	<i>Source</i>	<i>Sum of square</i>	<i>Degrees of freedom</i>	<i>Mean square</i>	<i>F</i>	<i>P</i>
	Residual	1171.0514	12	97.5876		
<i>Late booting</i>	Zone	14044.9906	2	7022.4953	60.0757	0.0001
	Zone1 vs Zone2-Zone3	13857.8164	1	13857.8164	118.5501	< 0.0001
	Zone2 vs Zone3	187.1742	1	187.1742	1.6012	0.2526
	Block (Zone)	701.3652	6	116.8942		
	Fertilizer	21765.0451	2	10882.5225	93.9276	< 0.0001
	Linear trend	21168.4722	1	21168.4722	112.3133	< 0.0001
	Quadratic trend	596.5728	1	596.5728	13.7954	0.0099
	Zone × Fertilizer	2208.0646	4	552.0162	4.7645	0.0156
	Linear trend at Zone1 vs Linear trend at Zone2-Zone3	1894.0745	1	1894.0745	10.0494	0.0193
	Quadratic trend at Zone1 vs Quadratic trend at Zone2-Zone3	55.9503	1	55.9503	1.2938	0.2987
	Linear trend at Zone2 vs Linear trend at Zone3	252.7671	1	252.7671	1.3411	0.2908
	Quadratic trend at Zone2 vs Quadratic trend at Zone3	5.2727	1	5.2727	0.1219	0.7389
	Residual	1390.3284	12	115.8607		
<i>Harvest</i>	Zone	46342.4296	2	23171.2148	172.0725	< 0.0001
	Zone1 vs Zone2-Zone3	40045.4337	1	40045.4337	297.3826	< 0.0001
	Zone2 vs Zone3	6296.9959	1	6296.9959	46.7623	0.0005
	Block (Zone)	807.9577	6	134.6596		
	Fertilizer	26065.0355	2	13032.5178	125.4473	< 0.0001
	Linear trend	25995.3783	1	25995.3783	207.6351	< 0.0001
	Quadratic trend	69.6573	1	69.6573	0.8435	0.3938
	Zone × Fertilizer	3703.7368	4	925.9342	8.9128	0.0014
	Linear trend at Zone1 vs Linear trend at Zone2-Zone3	3606.1077	1	3606.1077	28.8034	0.0017
	Quadratic trend at Zone1 vs Quadratic trend at Zone2-Zone3	14.3499	1	14.3499	0.1738	0.6913
	Linear trend at Zone2 vs Linear trend at Zone3	57.2281	1	57.2281	0.4571	0.5242
	Quadratic trend at Zone2 vs Quadratic trend at Zone3	26.0511	1	26.0511	0.3155	0.5947
	Residual	1246.6611	12	103.8884		