

Effects of different management regimes on microbial biodiversity in vineyard soils

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Supplementary Information

Supplementary Table 1. Results of soil analyses

management	integrated				organic				biodynamic			
position	in-row		under-vine		in-row		under-vine		in-row		under-vine	
depth (cm)	5-30	30-60	5-30	30-60	5-30	30-60	5-30	30-60	5-30	30-60	5-30	30-60
soil moisture content (%)	7.5 ±0.50 ^d	8.2 ±0.61 ^{cd}	8.6 ±0.54 ^{bc}	9.5 ±0.50 ^a	8.6 ±0.74 ^{abc}	8.9±0.74 ^{abc}	8.4 ±0.38 ^{bc}	8.8 ±1.24 ^{abc}	8.5 ±0.65 ^{bc}	8.7 ±0.79 ^{abc}	9.3 ±0.23 ^{ab}	9.3 ±0.97 ^{ab}
pH	7.3 ±0.18 ^{bc}	7.4 ±0.13 ^{abc}	7.4 ±0.13 ^{abc}	7.4 ±0.15 ^a	7.3 ±0.19 ^{ab}	7.4 ±0.12 ^{ab}	7.3 ±0.22 ^{bc}	7.4 ±0.15 ^{ab}	7.4 ±0.05 ^{ab}	7.4 ±0.10 ^{ab}	7.3 ±0.05 ^{abc}	7.4 ±0.00 ^{ab}
K (mg K ₂ O 100 g soil ⁻¹)	35.5 ±9.32 ^a	29.0 ±7.26 ^{bc}	30.5 ±6.95 ^b	23.8 ±6.85 ^{de}	37.0 ±6.73 ^a	23.8 ±4.19 ^{de}	27.0 ±4.97 ^{bcd}	21.3 ±2.75 ^e	36.5 ±6.02 ^a	25.3 ±5.12 ^{cde}	36.3 ±1.89 ^a	24.3 ±2.63 ^{de}
Mg (mg Mg 100 g soil ⁻¹)	10.8 ±3.50 ^{bc}	12.3 ±2.75 ^{abc}	11.8 ±2.75 ^{bc}	13.0 ±2.58 ^{ab}	12.5 ±2.65 ^{abc}	15.3 ±2.50 ^a	12.5 ±1.91 ^{abc}	11.0 ±5.35 ^{bc}	10.0 ±1.41 ^{bc}	12.5 ±0.58 ^{abc}	10.8 ±1.50 ^{bc}	9.8 ±5.85 ^c
P (mg P ₂ O ₅ 100 g soil ⁻¹)	73.0 ±18.62 ^{ab}	79.5 ±5.92 ^{ab}	78.0 ±23.96 ^{ab}	72.5 ±17.75 ^{ab}	76.5 ±9.95 ^{ab}	71.8 ±5.50 ^{ab}	71.0 ±13.34 ^b	74.5 ±3.70 ^{ab}	80.0 ±14.17 ^{ab}	82.5 ±11.09 ^{ab}	86.5 ±9.47 ^a	80.8 ±10.34 ^{ab}
soil organic matter (%)	2.3 ±0.26 ^a	1.8 ±0.28 ^{cd}	2.1 ±0.05 ^{ab}	1.7 ±0.21 ^{cde}	2.1 ±0.18 ^a	1.7 ±0.16 ^{cde}	1.9 ±0.13 ^{bc}	1.6 ±0.17 ^e	2.1 ±0.17 ^a	1.6 ±0.23 ^{de}	2.1 ±0.12 ^{ab}	1.8 ±0.05 ^{cde}
soil organic carbon (%)	1.31 ±0.15 ^a	1.05 ±0.16 ^{cd}	1.21 ±0.03 ^{ab}	0.97 ±0.10 ^{cde}	1.21 ±0.10 ^a	0.98 ±0.09 ^{cde}	1.08 ±0.07 ^{bc}	0.90 ±0.12 ^e	1.22 ±0.09 ^a	0.95 ±0.12 ^{de}	1.19 ±0.07 ^{ab}	1.02 ±0.05 ^{cde}
total nitrogen (%)	0.10 ±0.02 ^{ab}	0.08 ±0.02 ^{cde}	0.09 ±0.02 ^{abc}	0.08 ±0.02 ^{de}	0.10 ±0.01 ^a	0.08 ±0.01 ^{de}	0.09 ±0.01 ^{bcd}	0.07 ±0.01 ^e	0.10 ±0.02 ^a	0.08 ±0.01 ^{de}	0.10 ±0.01 ^a	0.08 ±0.01 ^{de}
C:N ratio	14.3 ±3.30 ^a	13.0 ±1.41 ^{ab}	13.3 ±2.50 ^{ab}	13.5 ±4.51 ^{ab}	12.5 ±0.58 ^{ab}	13.0 ±1.41 ^{ab}	12.8 ±0.96 ^{ab}	12.3 ±0.50 ^{ab}	12.8 ±0.96 ^{ab}	12.5 ±2.38 ^{ab}	11.75 ±0.96 ^b	12.8 ±0.96 ^{ab}
total Cu (mg kg soil ⁻¹)	96.3 ±17.54 ^a	82.6 ±24.39 ^a	94.9 ±16.02 ^a	82.3 ±30.06 ^a	105.7 ±50.89 ^a	106.3 ±14.26 ^a	101.7 ±16.53 ^a	97.3 ±25.07 ^a	97.1 ±4.11 ^a	81.8 ±23.20 ^a	111.7 ±22.74 ^a	84.0 ±29.93 ^a
total Fe (mg kg soil ⁻¹)	22183 ±2478 ^{bc}	23043 ±1708 ^{abc}	21765 ±3012 ^c	22110 ±2709 ^c	23298 ±2266 ^{abc}	22395 ±1435 ^{abc}	22920 ±1994 ^{abc}	22453 ±1608 ^{abc}	23253 ±3396 ^{abc}	23468 ±3538 ^{abc}	24160 ±3514 ^{ab}	24285 ±3303 ^a
total Mn (mg kg soil ⁻¹)	620 ±26.1 ^{cd}	669 ±105.8 ^{abc}	623 ±35.2 ^{cd}	593 ±28.0 ^d	649 ±21.5 ^{abcd}	614 ±48.6 ^{cd}	637 ±35.6 ^{bcd}	616 ±62.2 ^{cd}	674 ±46.8 ^{abc}	718 ±63.1 ^a	700 ±41.0 ^{ab}	715 ±51.2 ^a
total Ni (mg kg soil ⁻¹)	25.7 ±2.91 ^c	27.6 ±3.21 ^{abc}	25.8 ±4.03 ^c	25.9 ±3.71 ^c	28.2 ±4.09 ^{abc}	27.3 ±4.23 ^a	27.2 ±4.21 ^{bc}	26.6 ±4.36 ^{bc}	28.4 ±4.92 ^{abc}	28.7 ±4.90 ^{abc}	30.1 ±5.54 ^{ab}	31.3 ±9.91 ^a
total Zn (mg kg soil ⁻¹)	93.9 ±10.76 ^{abc}	90.7 ±1.98 ^{bc}	101.2 ±18.85 ^{abc}	87.3 ±14.36 ^c	104.3 ±13.69 ^{abc}	89.9 ±12.04 ^{bc}	96.9 ±16.09 ^{abc}	94.6 ±20.52 ^{abc}	105.9 ±14.60 ^{abc}	109.3 ±35.05 ^{ab}	112.7 ±21.35 ^a	93.0 ±10.36 ^{abc}
bioavailable Cu (mg kg soil ⁻¹)	23.6 ±3.47 ^{abc}	19.5 ±3.56 ^{bcd}	24.4 ±8.60 ^{abc}	23.5 ±8.33 ^{abcd}	27.3 ±6.11 ^a	19.0 ±0.74 ^{cd}	24.2 ±4.30 ^{abc}	24.4 ±4.17 ^{abc}	21.3 ±6.09 ^{abcd}	17.5 ±3.88 ^d	25.1 ±7.27 ^{ab}	18.6 ±3.85 ^{cd}
bioavailable Fe (mg kg soil ⁻¹)	30.6 ±12.87 ^{ab}	25.6 ±10.11 ^{abcd}	28.9 ±11.44 ^{abc}	24.6 ±7.36 ^{abcd}	33.9 ±22.17 ^a	21.4 ±5.70 ^{bcd}	22.8 ±8.27 ^{bcd}	27.6 ±15.45 ^{abcd}	23.3 ±1.89 ^{abcd}	20.8 ±2.83 ^{bcd}	19.9 ±1.99 ^{cd}	18.1 ±1.94 ^d
bioavailable Mn (mg kg soil ⁻¹)	41.4 ±22.88 ^{ab}	30.2 ±13.20 ^b	34.5 ±21.04 ^{ab}	33.6 ±19.60 ^{ab}	57.2 ±61.42 ^a	25.6 ±9.09 ^b	26.3 ±9.35 ^b	42.9 ±38.55 ^{ab}	28.1 ±2.93 ^b	28.6 ±5.40 ^b	25.2 ±2.01 ^b	20.6 ±6.12 ^b
bioavailable Zn (mg kg soil ⁻¹)	12.7 ±1.25 ^a	11.1 ±2.74 ^a	14.5 ±3.46 ^a	12.0 ±2.94 ^a	14.8 ±2.39 ^a	10.5 ±1.71 ^a	12.1 ±1.49 ^a	12.1 ±2.58 ^a	13.8 ±2.51 ^a	15.7 ±13.00 ^a	14.5 ±3.51 ^a	10.4 ±1.90 ^a
B (mg kg soil ⁻¹)	0.56 ±0.07 ^{abc}	0.59 ±0.21 ^{abc}	0.52 ±0.10 ^{bc}	0.55 ±0.14 ^{abc}	0.50 ±0.19 ^{bc}	0.47 ±0.15 ^{bc}	0.40 ±0.11 ^c	0.49 ±0.12 ^{bc}	0.44 ±0.05 ^{bc}	0.59 ±0.12 ^{abc}	0.83 ±0.61 ^a	0.71 ±0.31 ^{ab}

Results as mean values ± standard deviation. Superscript letters correspond to significant differences (α = 0.05)

Supplementary Table 2. PERMANOVA of fungal species communities in topsoil.

	Df	SumsOfSqs	MeanSqs	F.Model	R2	Pr(>F)	
management	2	0.41671	0.20835	1.9347	0.13506	0.002	**
position	1	0.48042	0.48042	4.4609	0.15571	0.001	***
management:position	2	0.2497	0.12485	1.1593	0.08093	0.17	
Residuals	18	1.9385	0.10769		0.6283		
Total	23	3.08533			1		

Significance code: [.] < α = 0.1; [*] < α = 0.05; **[**] < α = 0.01; [***] < α = 0.001

Supplementary Table 3. PERMANOVA of fungal species communities in subsoil.

	Df	SumsOfSqs	MeanSqs	F.Model	R2	Pr(>F)	
management	2	0.32053	0.16027	1.34623	0.11008	0.012	*
position	1	0.34131	0.34131	2.86703	0.11721	0.001	***
management:position	2	0.22621	0.11311	0.95009	0.07769	0.414	
Residuals	17	2.02381	0.11905		0.69502		
Total	22	2.91187			1		

Significance code: [.] < α = 0.1; [*] < α = 0.05; **[**] < α = 0.01; [***] < α = 0.001

Supplementary Table 4. PERMANOVA of fungal species communities in topsoil in-row.

	Df	SumsOfSqs	MeanSqs	F.Model	R2	Pr(>F)	
management	2	0.36536	0.18268	1.6779	0.2716	0.005	**
Residuals	9	0.97985	0.10887		0.7284		
Total	11	1.34521			1		

Significance code: [.] < α = 0.1; [*] < α = 0.05; **[**] < α = 0.01; [***] < α = 0.001

Supplementary Table 5. PERMANOVA of fungal species communities in topsoil undervine.

	Df	SumsOfSqs	MeanSqs	F.Model	R2	Pr(>F)	
management	2	0.30105	0.15052	1.4131	0.23898	0.076	.
Residuals	9	0.95865	0.10652		0.76102		
Total	11	1.2597			1		

Significance code: [.] < α = 0.1; [*] < α = 0.05; **[**] < α = 0.01; [***] < α = 0.001

Supplementary Table 6. Correlation analysis between fungal community and soil parameters.

	NMDS1	NMDS2	r2	Pr(>r)	
soil_moisture	0.9197	0.39261	0.2398	0.002	**
pH	0.84741	-0.53094	0.2014	0.001	***
P	0.99422	-0.1074	0.0261	0.447	
K	-0.9461	0.32389	0.4086	0.001	***
Mg	-0.28325	-0.95905	0.0448	0.403	
organic carbon	-0.98084	0.19482	0.5214	0.001	***
N	-0.89264	0.45076	0.3063	0.001	***
C:N	-0.66766	-0.74447	0.0385	0.241	
Mn_total	0.68427	-0.72923	0.0164	0.674	
Fe_total	0.83153	0.55548	0.0553	0.164	
Cu_total	0.0801	0.99679	0.04	0.457	
Zn_total	0.35337	0.93548	0.0177	0.669	
Ni_total	0.92367	0.38318	0.0684	0.227	
Mn_bioav	-0.98608	0.16624	0.1193	0.046	*
Fe_bioav	-0.99633	0.08555	0.1717	0.01	**
Cu_bioav	-0.31004	0.95072	0.0906	0.09	.
Zn_bioav	-0.96414	0.2654	0.0133	0.693	
B	0.97107	0.23879	0.0015	0.967	

Stress of the underlying two-dimensional NMDS based on Bray-Curtis distances was 0.21.

Supplementary Table 7. Correlation analysis between bacterial community and soil parameters.

	NMDS1	NMDS2	r2	Pr(>r)	
soil_moisture	0.9962	-0.0871	0.102	0.051	.
pH	0.78453	0.62009	0.4885	0.026	*
P	0.57636	-0.8172	0.0255	0.677	
K	-0.99285	-0.11933	0.4186	0.001	***
Mg	-0.20717	-0.9783	0.3704	0.046	*
organic_carbon	-0.93595	0.35213	0.5632	0.001	***
N	-0.99497	-0.10015	0.3615	0.002	**
C:N	-0.04692	0.9989	0.0904	0.315	
Mn_total	0.03222	0.99948	0.1821	0.014	*
Fe_total	0.57548	0.81782	0.0444	0.461	
Cu_total	0.99955	0.0299	0.0386	0.306	
Zn_total	0.17294	0.98493	0.2083	0.017	*
Ni_total	0.70883	0.70538	0.1288	0.404	
Mn_bioav	-0.67922	0.73394	0.07	0.075	.
Fe_bioav	-0.69154	-0.72234	0.3579	0.063	.
Cu_bioav	-0.73283	-0.68041	0.4857	0.01	**
Zn_bioav	-0.79198	0.61054	0.0383	0.324	
B	-0.21804	-0.97594	0.0467	0.668	

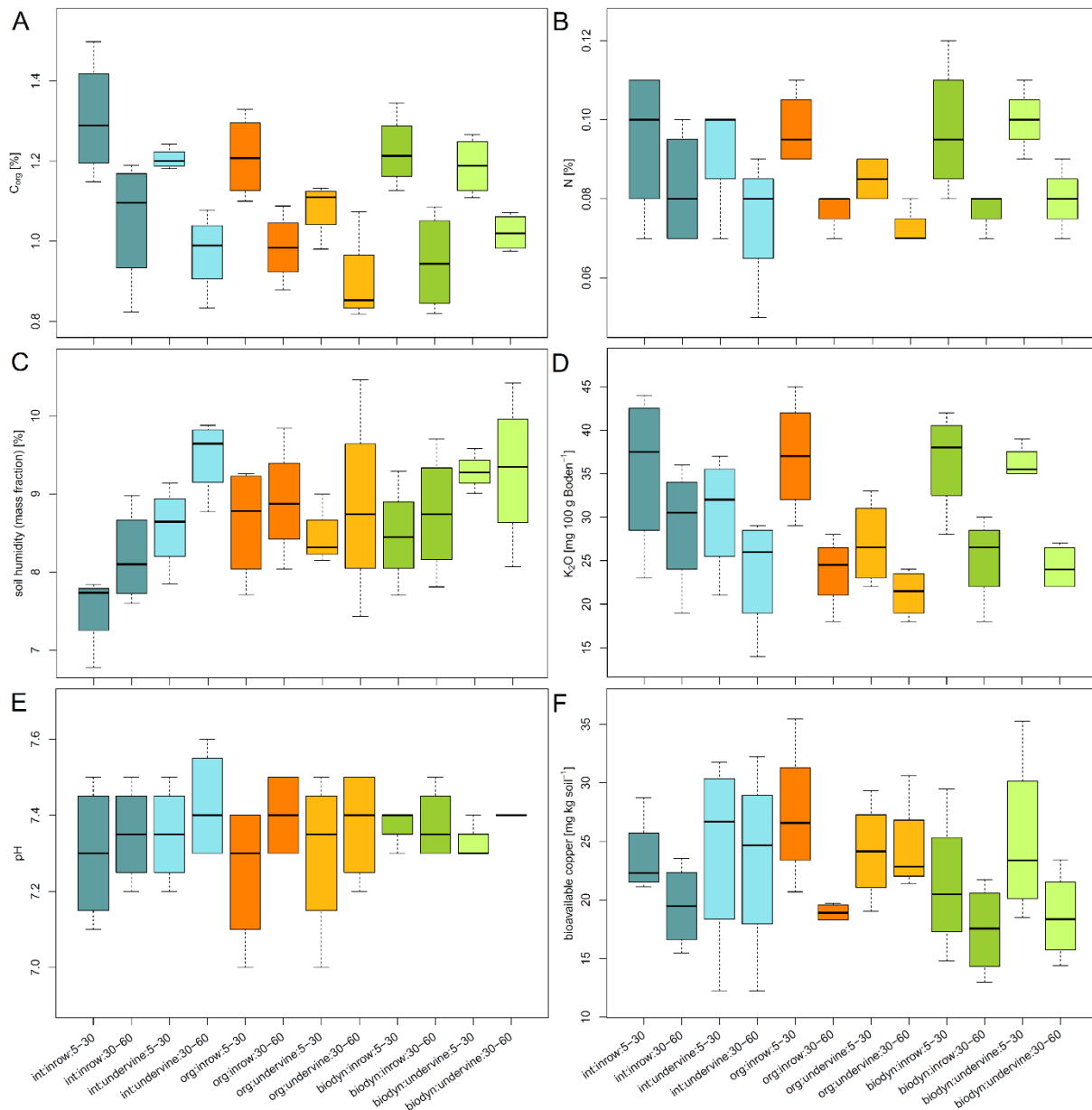
Stress of the underlying two-dimensional NMDS based on Bray-Curtis distances was 0.15.

Supplementary Table 8. Overview of integrated pest management in 2015.

#	date	plant protection agent	quantity	unit
1	04/21/15	Glyfos (under-vine)	5	l ha ⁻¹
2	05/18/15	Delan WG	0.3	kg ha ⁻¹
		wettable sulfur	3.6	kg ha ⁻¹
3	06/01/15	Delan WG	0.3	kg ha ⁻¹
		Vivando	0.16	l ha ⁻¹
4	06/16/15	Delan WG	0.5	l ha ⁻¹
		Veriphos	2.5	l ha ⁻¹
		Collis	0.4	l ha ⁻¹
5	06/29/15	Enervin	3	kg ha ⁻¹
		Talendo	0.3	l ha ⁻¹
6	07/13/15	Folpan	1.6	kg ha ⁻¹
		Luna Experience	0.4375	l ha ⁻¹
7	07/09/15	Teldor (in bunch zone)	0.6	kg ha ⁻¹
8	07/27/15	Mildicut	4	l ha ⁻¹
		Systhane	0.24	l ha ⁻¹
		Steward	0.2	kg ha ⁻¹
9	08/10/15	Mildicut	4	l ha ⁻¹
		Systhane	0.24	l ha ⁻¹
		Steward	0.2	kg ha ⁻¹
10	08/27/15	Switch (in bunch zone)	0.64	kg ha ⁻¹

Supplementary Table 9. Overview of organic and biodynamic pest management in 2015

#	date	plant protection agent	quantity	unit	amount of copper [g ha ⁻¹]
1	05/18/15	wettable sulfur	3.6	kg ha ⁻¹	
		Funguran Progress	0.29	kg ha ⁻¹	100
2	06/01/15	wettable sulfur	3.6	kg ha ⁻¹	
		Funguran Progress	0.29	l ha ⁻¹	100
3	06.12.15	wettable sulfur	4.8	kg ha ⁻¹	
		Funguran Progress	0.29	l ha ⁻¹	100
4	06/17/15	wettable sulfur	2.4	kg ha ⁻¹	
		Funguran Progress	0.86	l ha ⁻¹	300
5	06/26/15	wettable sulfur	2.4	kg ha ⁻¹	
		Funguran Progress	0.86	kg ha ⁻¹	300
6	07/03/15	wettable sulfur	3.2	kg ha ⁻¹	
		Funguran Progress	0.57	kg ha ⁻¹	200
		Vitisan	4	kg ha ⁻¹	
7	07/13/15	wettable sulfur	3.2	kg ha ⁻¹	
		Funguran Progress	0.57	kg ha ⁻¹	200
		Vitisan	4	kg ha ⁻¹	
8	07/22/15	wettable sulfur	3.2	kg ha ⁻¹	
		Funguran Progress	0.57	kg ha ⁻¹	200
		Vitisan	4	kg ha ⁻¹	
		PrevB2	1.2	l ha ⁻¹	
9	07/31/15	wettable sulfur	3.2	kg ha ⁻¹	
		Funguran Progress	0.57	kg ha ⁻¹	200
		Vitisan	4	kg ha ⁻¹	
		PrevB2	1.5	l ha ⁻¹	
10	08/11/15	Funguran Progress	0.57	l ha ⁻¹	200
		Vitisan	5	kg ha ⁻¹	
		PrevB2	1.5	l ha ⁻¹	



Supplementary Fig 1. Results of (A) organic carbon, (B) nitrogen, (C) soil humidity, (D) potassium, (E) pH and (F) bioavailable copper by management, position and depth.

Levels of significance:

C_{org} : p (management) < 0.022, p (position) < 0.024, p (depth) < 2.42E-10, no interaction effects

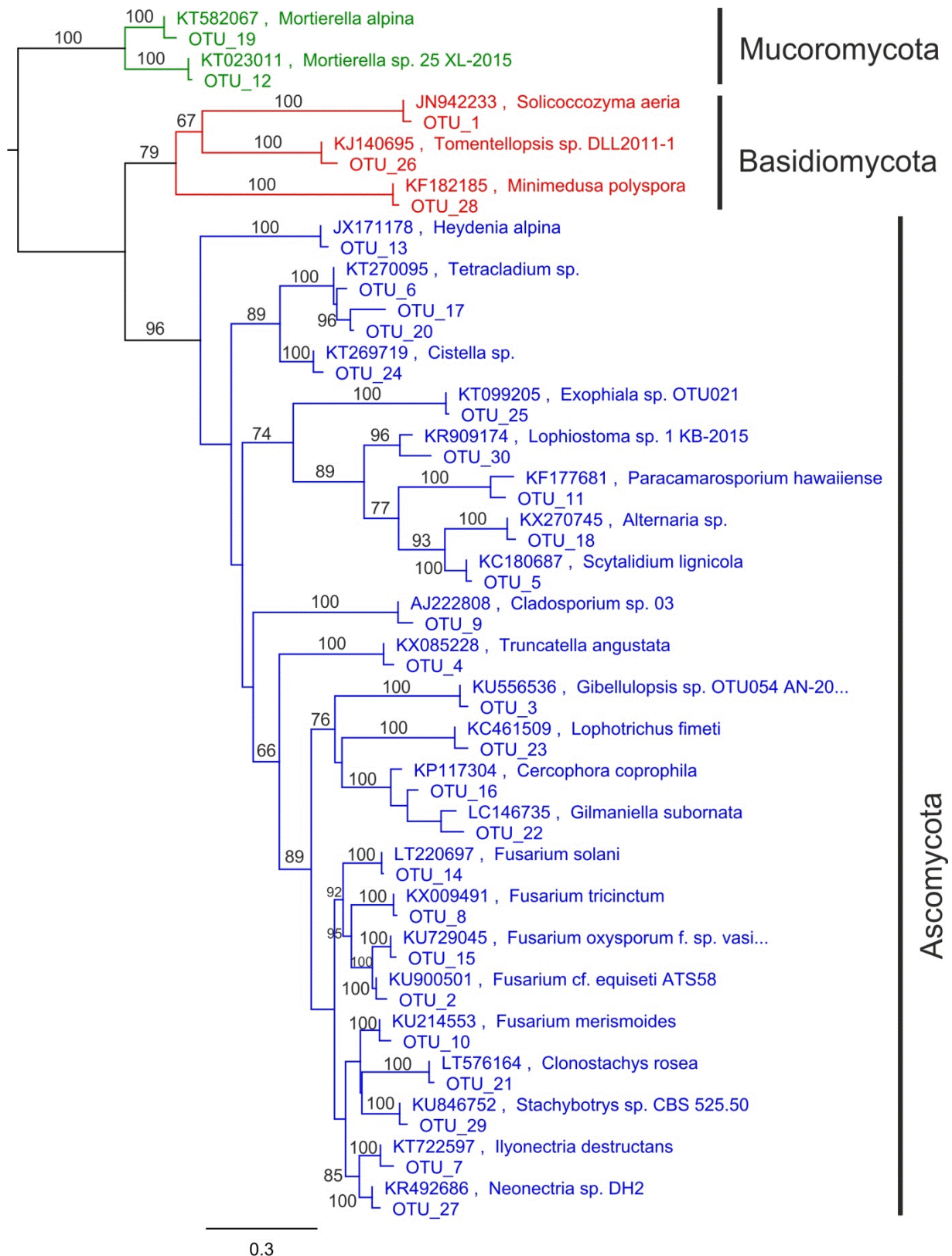
Nitrogen: p (management) < 0.196, p (position) < 0.141, p (depth) < 7.74E-8, no interaction effects

Humidity: p (management) < 0.085, p (position) < 0.003, p (depth) < 0.024, p (treatment:position) < 0.020

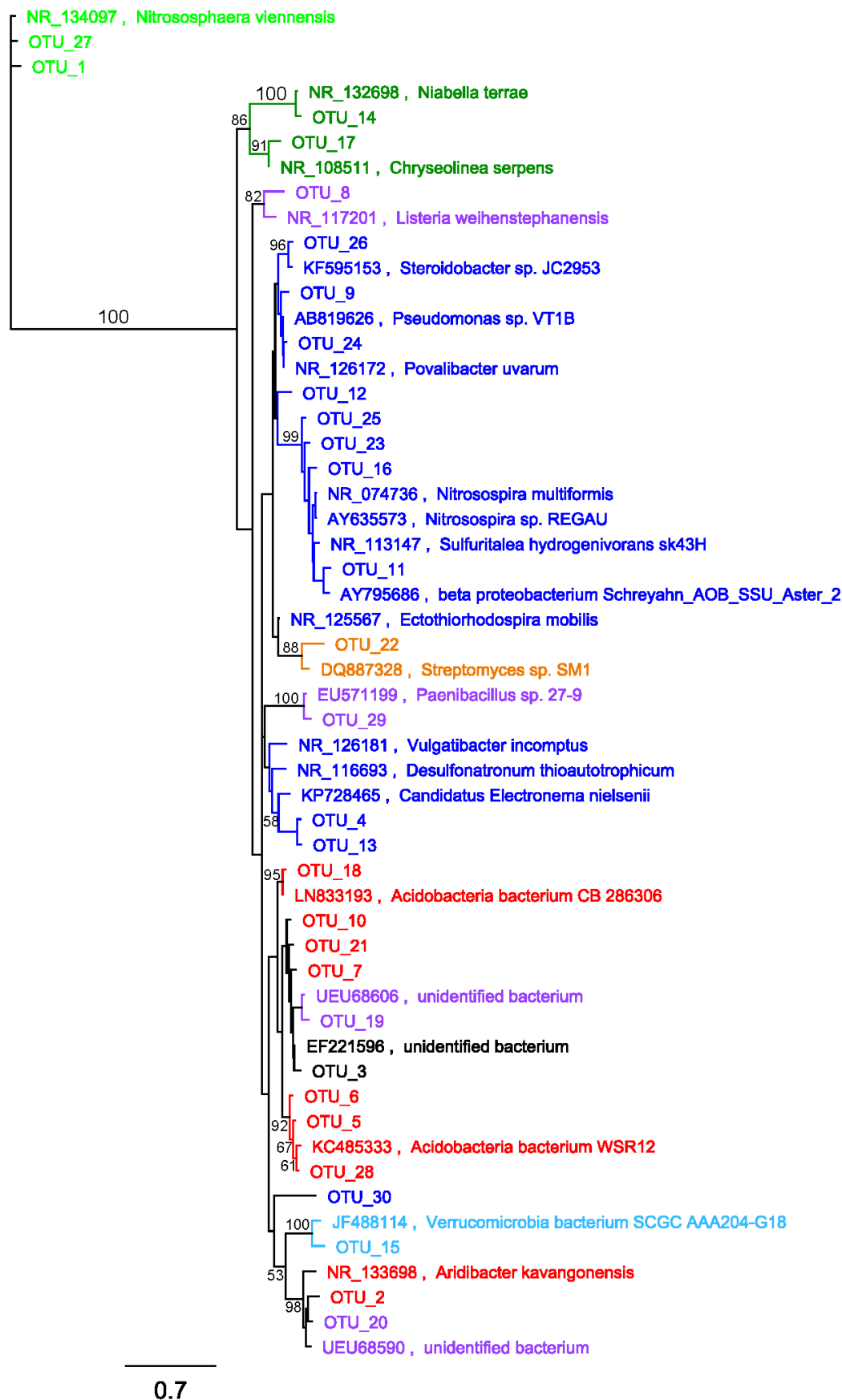
Potassium: p (management) < 0.019, p (position) < 1.48E-4, p (depth) < 2.02E-11, p (treatment:position) < 0.046

pH: p (management) < 0.390, p (position) < 0.359, p (depth) < 0.003, no interaction effects

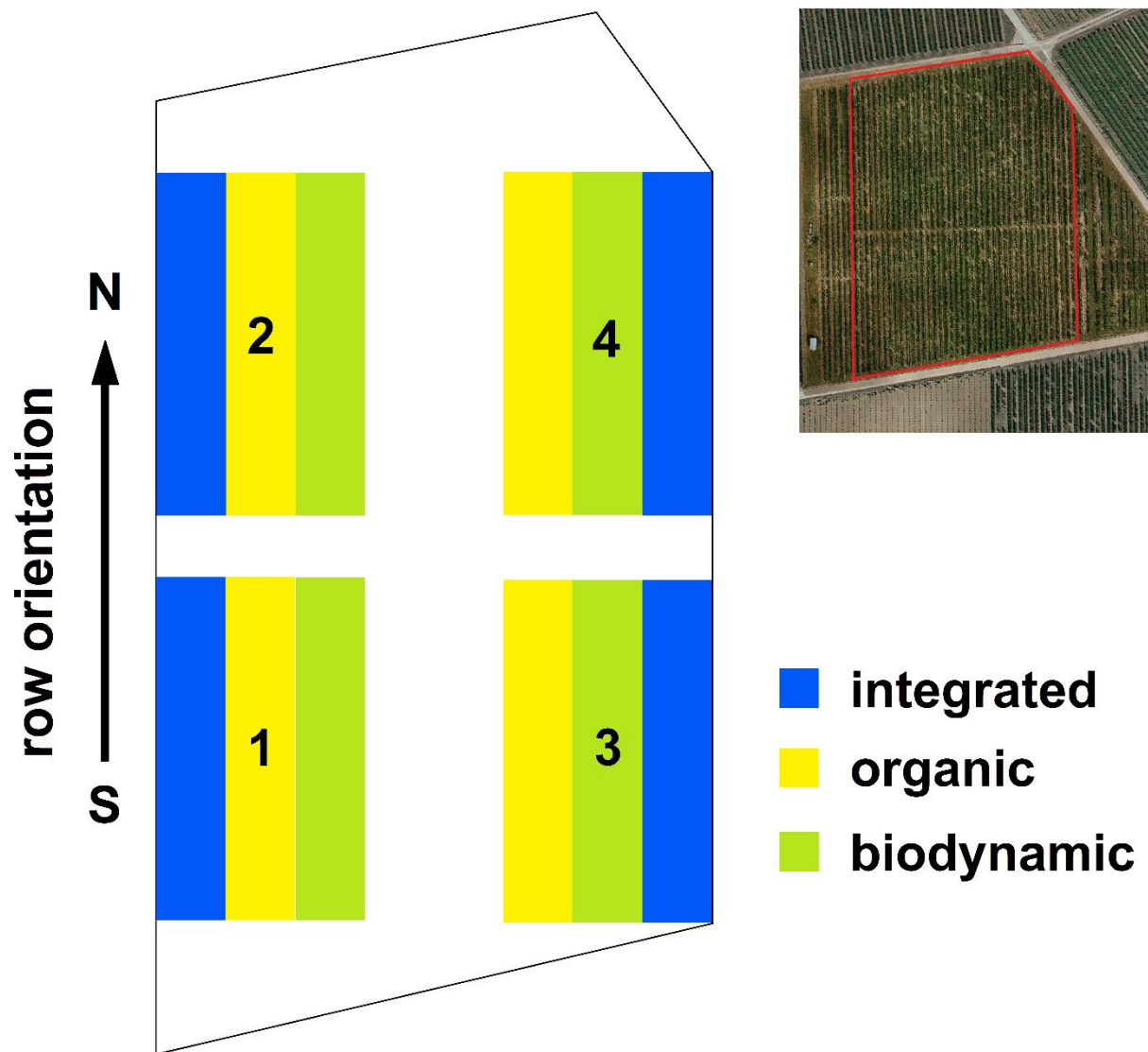
bioavailable copper: p (management) < 0.126, p (position) < 0.111, p (depth) < 0.003, no interaction effects (n = 4)



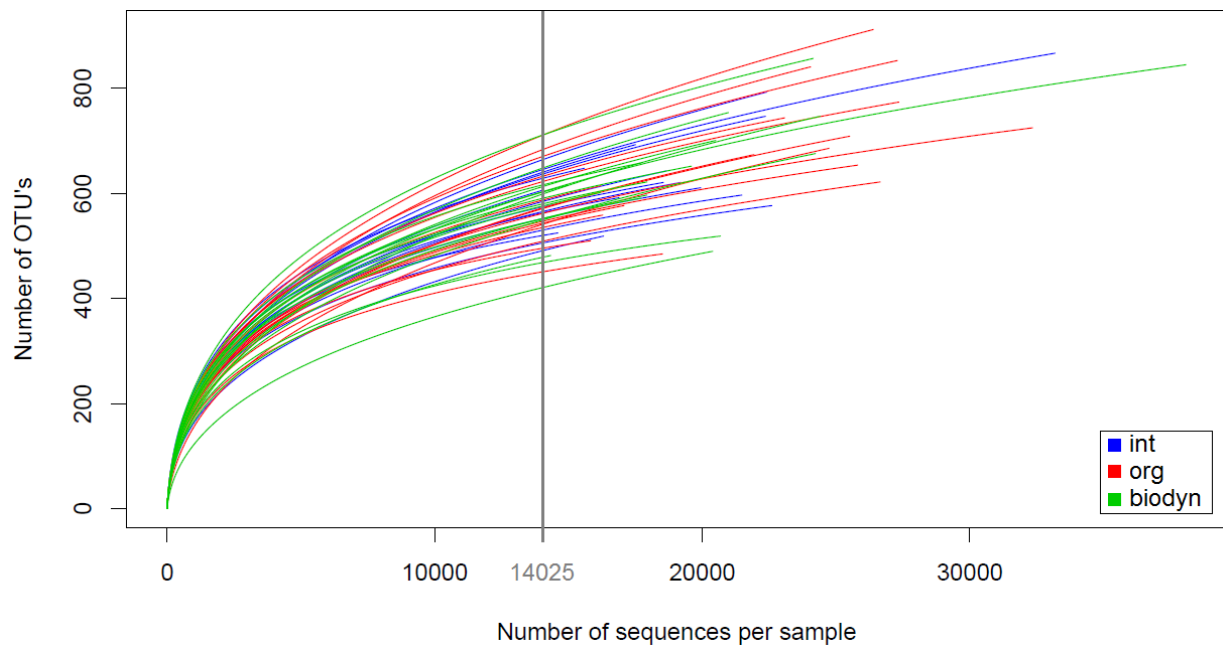
Supplementary Fig 2. Maximum-Likelihood dendrogram of fungal top-30 OTU's plus database hits.
 Bootstrap values on the branches are based on 100 permutations.
 green: Mucoromycotina, red: Basidiomycota, blue: Ascomycota



Supplementary Fig 3. Maximum-Likelihood dendrogram of bacterial top-30 OTU's plus database hits.
 Bootstrap values on the branches are based on 100 permutations.
 light green: Archaea, red: Acidobacteria, orange: Actinobacteria, purple: Firmicutes, dark green: Bacteroidetes,
 light blue: Verrucomicrobia, dark blue: Proteobacteria, black: non-allocated

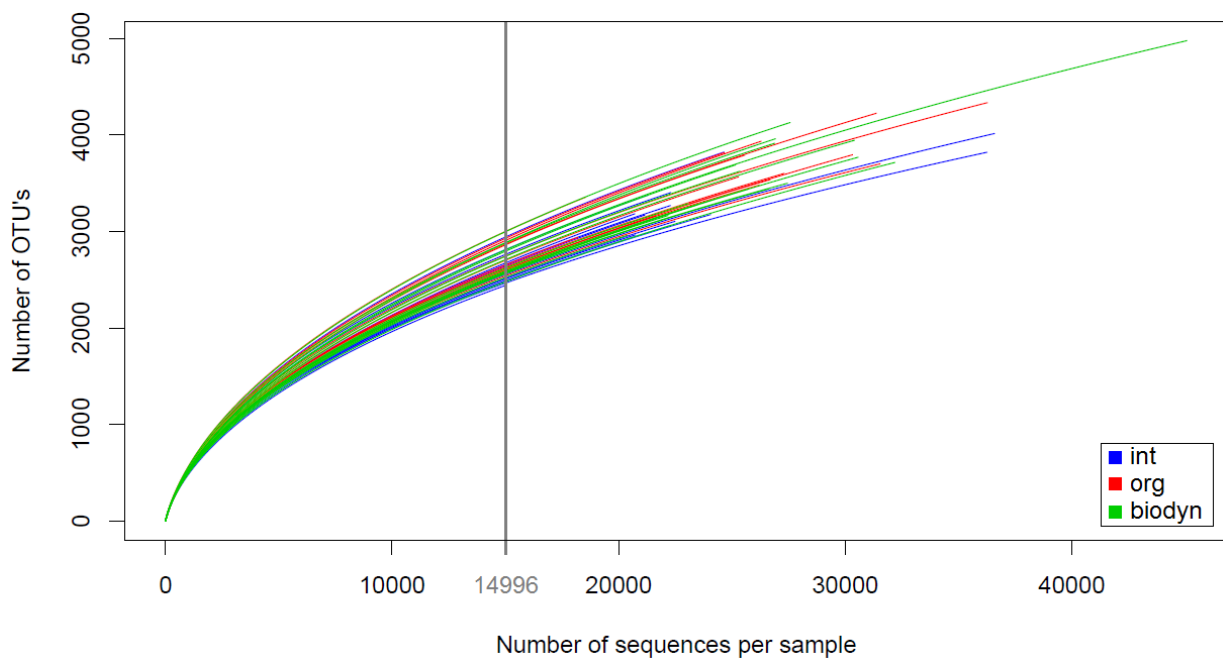


Supplementary Fig 4. Field plan of the experimental site.
The blocks are numbered 1 to 4.



Supplementary Fig 5. Fungal rarefaction curves, based on raw data consisting of 992,075 sequences and 5,176 OTU's.

The grey line at 14025 sequences illustrates the limiting sample size for subsequent normalization.



Supplementary Fig 6. Bacterial rarefaction curves, based on raw data consisting of 1,219,717 sequences and 27,516 OTU's.

The grey line at 14,025 sequences illustrates the limiting sample size for subsequent normalization.