Colony size predicts division of labour in Attine ants: Electronic supplementary material

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Table S1. Life history and environmental traits and data sources for 57 species of Attini. W and Q represent Worker and Queen, respectively. Values for colony size, worker and queen head-widths represent per-species means (in mm) calculated by averaging the mean value from each observation weighted by its sample size; Σns is the sum of all the sample sizes of the observations contributing to the per-species mean for each trait (colony size, worker and queen head width) (assumed to be 1 where observation sample sizes were not given); worker size variation is the coefficient of variation in worker head-widths; queen-worker dimorphism is percentage change between mean queen and worker head-width; and mean diurnal temperature range, isothermality, temperature seasonality and precipitation seasonality are taken from BioClim (www.worldclim.org/bioclim). Taxonomy follows Bolton World Catalogue (www.antweb.org), and - denotes missing data.

Species	Mean Colony Size	Σns Colony Size	Mean W Head-Width	Σns W Head-Width	Mean Q Head-Width	Σns Q Head-Width	W Size Variation	Q-W Dimorphism	Polyandrous	Mean Diurnal Temp. Range	Isothermality	Temp Seasonality	Precipitation Seasonality	N Geolocated Points	Data Source
Acromyrmex ameliae	-	-	1.1	30	1.4	21	27.27	24	-	130	69	1681	85	6	[1]
Acromyrmex echinatior	137500	5	1.87571	826	2.58	11	32.05	31.61	Yes	100.02	74.32	745.85	80.9	42	[2-7]
Acromyrmex insinuator	100	1	-	-	2.325	27	-	-	Yes	72	72	724	60	13	[3, 4, 7, 9, 10]
Acromyrmex octospinosus	13375	5	1.80769	581	2.9	5	43.33	46.41	Yes	84	75.6	717.48	39.54	71	[2-4, 6, 11-14]
Acromyrmex subterraneus	4766.2	5	1.58767	16	2.15	17	27.71	30.09	-	130	69	1681	85	4	[1, 15, 16]
Acromyrmex versicolor	-	-	2.0692	5	-	-	33.36	-	Yes	162.56	46.22	6971.11	53.67	18	[1, 2, 15, 17]
Apterostigma collare	23.98	128	0.8695	3	0.91	2	7.56	4.55	No	90.13	77.19	688.05	32.93	165	[3, 15, 19-21]
Apterostigma dentigerum	25	1	1.069	3	1.14	1	9.53	6.43	-	89.3	76.99	715.96	30.42	93	[3, 15]
Apterostigma mayri	20	25	-	-	-	-	-	-	-	70	72.5	706	58.5	10	[12]
Apterostigma sp. 2	25	1	-	-	1.09	1	-	-	-	72	72	724	60	2	[3]
Apterostigma urichii	23	1	-	-	-	-	-	-	-	95	83.33	470.67	46.33	3	[22]
Atta cephalotes	3000000	1	1.98714	949	4.88	5	64.37	84.25	Yes	90.11	77.19	649.9	30.43	214	[3, 6, 15, 23, 24]
Atta colombica	2266666.67	5	-	-	4.31	5	-	-	-	76.58	74.21	680.68	56.68	30	[3, 12, 25, 26]
Atta laevigata	3500000	1	2.87929	7	-	-	33.5	-	Yes	108.2	74.6	1095.2	62	5	[15, 25, 27, 28]
Atta sexdens	6000000	1	2.46363	1016	3.62	4	50.93	38.16	Yes	84.67	78	667.33	79	6	[2, 3, 15, 25]
Atta texana	-	-	2.304	3	-	-	48.98	-	Yes	132	39	7287	16	7	[15, 29]
Atta vollenweideri	5500000	1	2.99467	3	4.91	2	53.96	48.61	-	122.33	54.67	3465	46.33	5	[15, 25, 26]
Cyphomyrmex cornutus	2021.75	4	-	-	-	-	-	-	-	90.18	77.01	671.58	29.58	73	[15, 30]
Cyphomyrmex costatus	96.5	53	-	-	0.58	5	-	-	-	85.96	76.29	645.87	45.09	48	[3, 12, 15, 31]
Cyphomyrmex faunulus	16	1	-	-	-	-	-	-	-	92	86	338	20	2	[15, 22]
Cyphomyrmex longiscapus	54.13	203	0.65778	93	0.746667	25	10.53	12.66	No	85.24	75.36	637.48	49.14	42	[15, 21, 32, 33]
Cyphomyrmex muelleri	-	-	0.63833	78	0.7	23	6.68	9.22	-	-	-	-	-	-	[33]
Cyphomyrmex rimosus	136.75	69	0.632	4	0.646333	3	15.58	2.24	-	93.68	74.44	1005.29	45.61	259	[3, 12, 15, 34]
Kalathomyrmex emeryi	100	1	0.82467	10	0.8375	2	10.69	1.54	-	97.75	65.75	1826	61.75	5	[3, 15]
Mycetagroicus cerradensis	373	2	0.8705	3	-	-	3.98	-	-	126	69	671.73	44.92	5	[15, 3]
Mycetagroicus inflatus	-	-	0.715	2	-	-	0.99	-	-	-	-	-	-	-	[36]
Mycetarotes carinatus	-	-	-	-	0.88	1	-	-	-	-	-	-	-	-	[58]
Mycetarotes parallelus	110.57	13	0.9175	4	0.95	3	0.23	3.48	-	126.91	56.91	3284.68	20.41	21	[3, 15, 37]
Mycetophylax conformis	72.25	3	-	-	-	-	-	-	-	-	-	-	-	-	[15, 38]
Mycetophylax morschi	72.25	4	-	-	-	-	-	-	-	-	-	-	-	-	[15, 38]
Mycetophylax simplex	191.94	7	-	-	-	-	-	-	-	-	-	-	-	-	[15, 38, 39]
Mycetosoritis clorindae	70.5	2	-	-	-	-	-	-	-	92	48	3306	9	3	[40]
Mycetosoritis explicate	-	-	0.8	2	0.93	1	14.52	15.03	-	-	-	-	-	-	[41, 15]
Mycetosoritis hartmanni	50	2	0.6375	4	0.77	3	4.53	18.83	-	110.4	45.5	5210.9	36.8	10	[3, 15]
Mycocepurus castrator	1	2	-	-	0.6	16	-	-	-	116	63	2405	71	6	[42]
Mycocepurus goeldii	678.86	7	-	-	0.78	2	-	-	-	91.63	76.88	945.63	50.44	16	[15, 42-44, 47]
Mycocepurus obsoletus	-	-	-	-			-	-	-	87	76	594	71	2	[15, 43]
Mycocepurus smithii	62.63	162	0.6275	4	0.614	1	6.65	2.17	-	89.83	78.07	779.41	27	46	[15, 39, 44-47]
Myrmicocrypta bucki	-	-	0.64333	4	-	-	3.91	-	-	105	73	1014	45	3	[48]

Myrmicocrypta camargoi	-	-	0.75333	4	1.09	2	5.53	36.53	-	117	63	2333	60	5	[48]
Myrmicocrypta ednaella	86.78	35	-	-	-	-	-	-	No	88.3	78.06	642.76	46.81	67	[12, 21, 34]
Myrmicocrypta erectapilosa	-	-	0.59333	4	0.71	1	5.42	17.9	-	83	81	446	47	5	[48]
Sericomyrmex amabilis	972.67	12	0.9335	10	1.255	6	6.74	29.38	No	88.26	76.74	708.61	32.36	334	[2, 3, 12, 15, 20, 49]
Trachymyrmex arizonensis	1000	1	1.15333	6	1.285	2	14.11	10.8	-	172.5	49.44	6419.72	68.72	17	[15, 50, 52]
Trachymyrmex carinatus	100	1	0.94767	5	1.246	2	13.63	27.2	-	166	51	5626	113	3	[15, 52]
Trachymyrmex cornetzi	161.83	62	0.975	5	1.06	2	12.46	8.35	No	87.96	76.58	721.07	33.04	147	[2, 3, 15, 49, 57]
Trachymyrmex desertorum	-	-	1.0584	5	1.375	2	16.71	26.02	-	-	-	-	-	-	[15, 52]
Trachymyrmex isthmicus	100.67	43	-	-	-	-	-	-	-	81.5	75.29	722.14	39.86	28	[52]
Trachymyrmex jamaicensis	525	2	1.37033	3	1.65	2	5.23	18.52	-	91.5	54.75	2696.25	48.25	7	[15, 52]
Trachymyrmex nogalensis	-	-	1.34225	4	1.425	2	16.57	5.98	-	-	-	-	-	-	[52]
Trachymyrmex pomonae	183	1	0.865	2	1.066667	3	13.9	20.88	-	178	50	6516	70	3	[52]
Trachymyrmex septentrionalis	474.7	93	0.967	552	1.160667	2	7.87	18.2	-	122.93	48	4974.6	44.27	17	[15, 52-55]
Trachymyrmex smithi	652.5	4	1.37329	6	1	2	10.76	31.46	-	167.5	55.5	4822	88.5	5	[15, 52]
Trachymyrmex sp. 3	1000	1			1.22	5	-	-	-	72	72	724	60	3	[3]
Trachymyrmex turrifex	300	1	0.9535	4	1.15	2	11.72	18.68	-	173	51	5626	113	4	[15, 52]
Trachymyrmex urichii	-	-	-	-	-	-	-	-	-	109.5	78	586.5	57	3	[15, 56]
Trachymyrmex zeteki	146.78	136	-	-	1.29	5	-	-	No	80.55	74.62	708.28	46.76	30	[2, 3, 15, 20, 49, 51]

Table S1 Data Sources.

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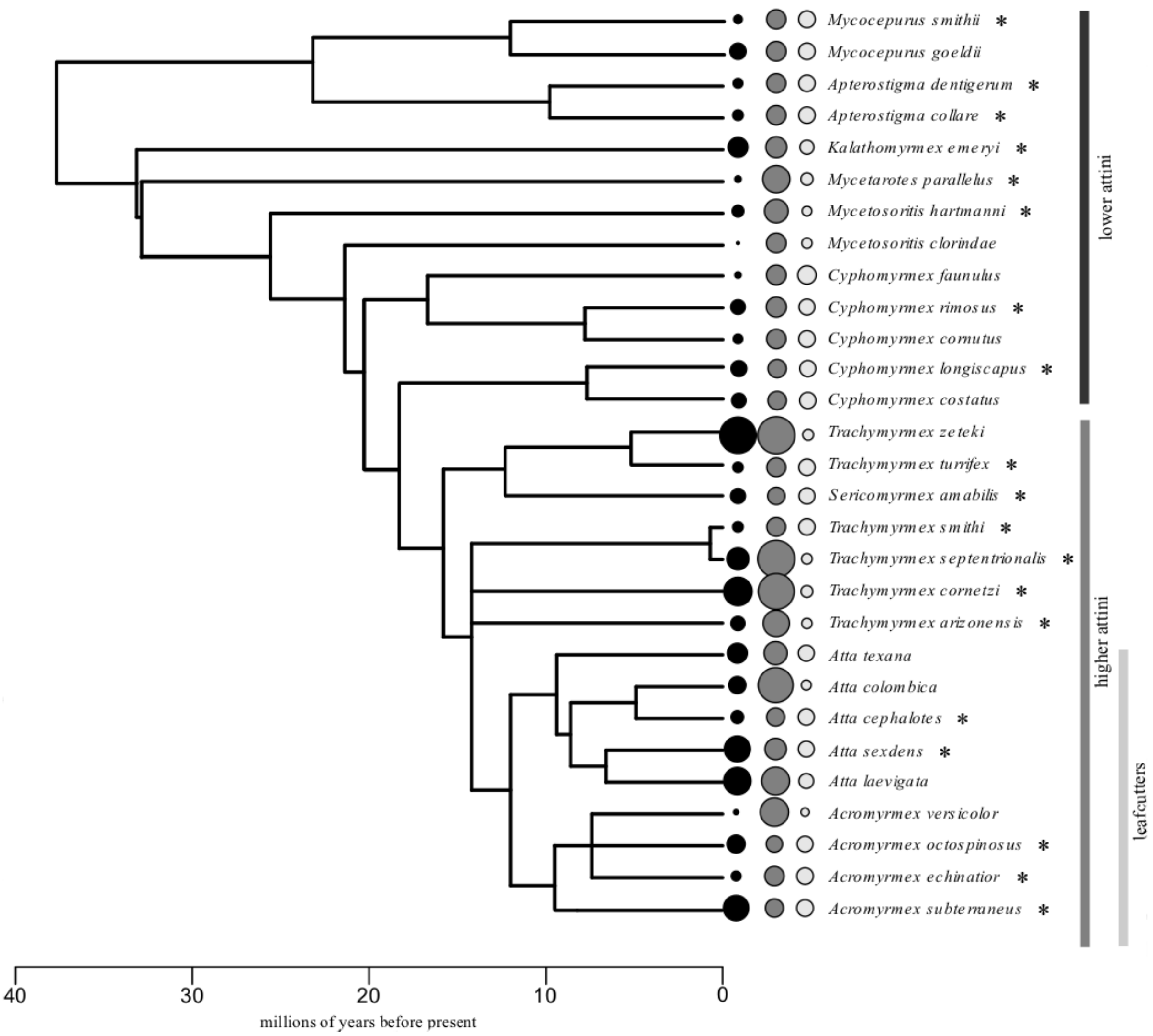

Figure S1. Distribution of precipitation seasonality, mean temperature fluctuation and isothermality on a phylogenetic supertree of the Attini (29 species). The full tree (electronic supplementary material, figure S2) was pruned to include only the species for which there were data on at least one trait and appeared in the phylogeny. Black, grey and white circles are proportional to precipitation seasonality, mean temperature fluctuation and isothermality, respectively. * denotes species used in the final analysis. Branch lengths are proportional to time (millions of years).

Table S2. Phylogenetic sources for the Attini supertree.

Reference	**Figure number**	**Data type**	**No. Attini species**
Bacci Jr et al 2009	1	mtDNA + tRNA	13
	2	nDNA	13
	3	mtDNA + nDNA	13
Brandao and Mayhé-Nunes 2007	2	Morphology	32
Moreau et al 2006	1	nDNA + mtDNA	4
Schultz and Brady 2008	1	nDNA + mtDNA	65
Shultz and Meier 1995	3	Larval morphology	51
Sumner et al 2004	1	mtDNA	19
Villesen et al 2004	6	mtDNA	12
Wetterer et al 1998	1	mtDNA + tRNA	14
	2	Amino acid sequence + morphology	14

Table S2 references.

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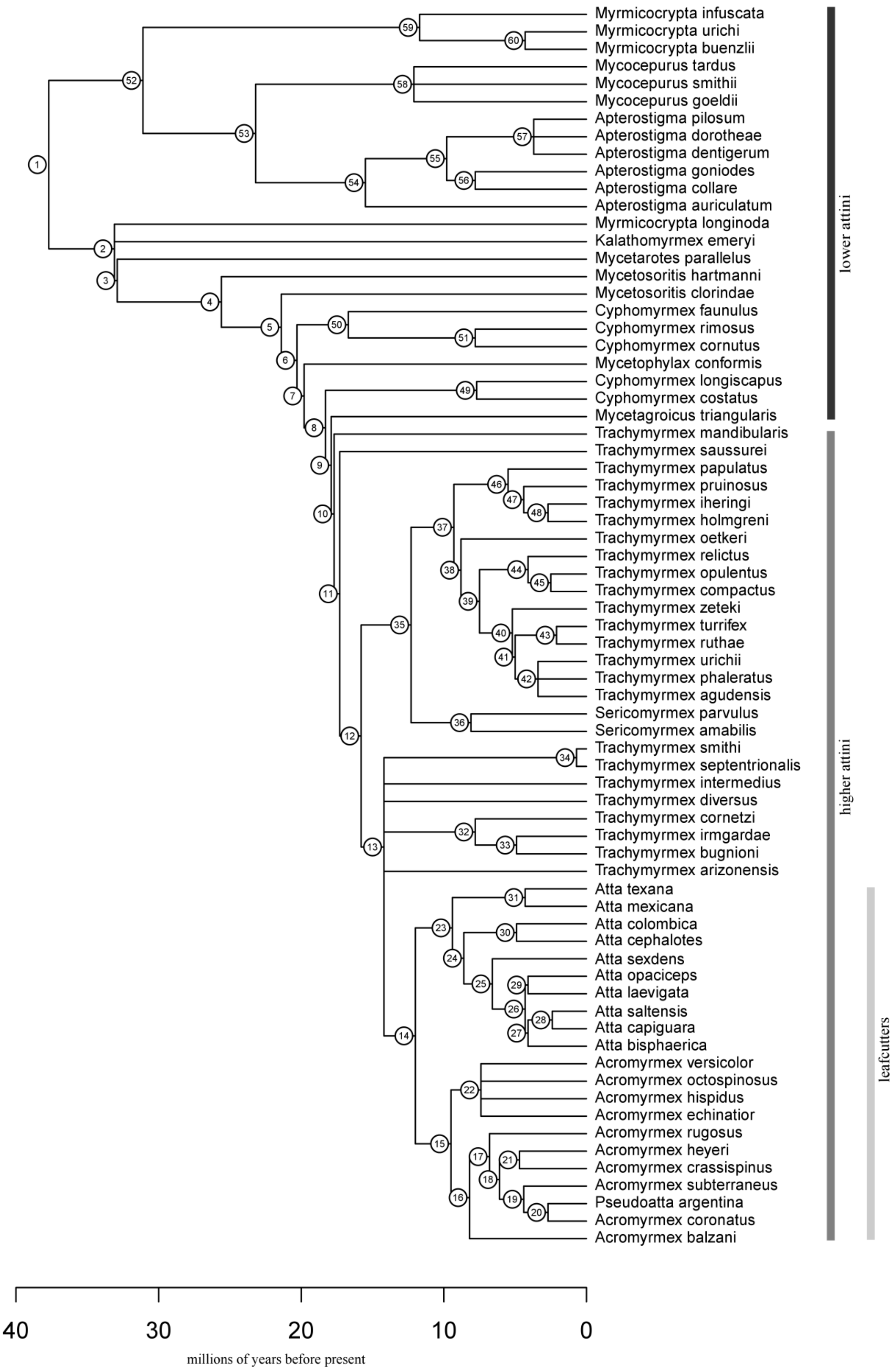

Figure S2. A phylogenetic supertree for 71 species of the Attini. Numbers on nodes are arbitrary numbers. Branch lengths are proportional to time (millions of years). See table S3 for nodal support values.

Table S3. Reduced qualitative support (rQS) scores for the Attini supertree (figure S1). rQS values range between 1 and -1 where 1 indicates full agreement for a node in the source trees, and -1 full disagreement.

Node #	rQS value	Node #	rQS value	Node #	rQS value
1	0.83	21	0.08	41	0.00
2	0.75	22	0.42	42	0.00
3	0.75	23	0.50	43	0.00
4	0.67	24	0.50	44	0.00
5	0.67	25	0.00	45	0.00
6	0.67	26	0.00	46	0.00
7	0.67	27	0.08	47	0.00
8	0.58	28	0.08	48	0.00
9	0.58	29	0.00	49	0.00
10	0.58	30	0.33	50	0.33
11	0.58	31	0.08	51	0.33
12	0.58	32	0.17	52	-0.83
13	0.33	33	0.00	53	0.25
14	0.50	34	0.08	54	0.42
15	0.33	35	0.17	55	0.25
16	0.83	36	0.33	56	0.25
17	0.42	37	0.00	57	0.01
18	0.17	38	0.00	58	0.25
19	0.17	39	0.00	59	-0.17
20	0.17	40	0.00	60	-0.17

Table S4. All models with ΔAICc < 7 describing the predictors of a) worker size variation, b) queen-worker dimorphism and c) colony size in the Attini. Regression slope estimates from phylogenetic least squares (PGLS) models are reported.

Table S4a.

Intercept	**Precipitation seasonality**	**Mean diurnal temperature fluctuation**	**log Colony size**	**Queen-worker dimorphism**	**Degrees of freedom**	**Log likelihood**	**AICc**	**ΔAICc**	**AICc weight**
2.342		-0.011	0.394		3	-23.97	55.7	0.68	0.19
1.027			0.401		2	-25.83	56.4	1.43	0.13
2.563	0.020	-0.020	0.347		4	-22.73	56.5	1.57	0.12
2.253	0.018	-0.020	0.353	0.152	5	-20.70	56.9	1.88	0.12
0.627	0.003		0.430	0.028	4	-22.79	56.9	1.93	0.10
0.832	0.005		0.391		3	-24.85	57.4	2.43	0.08

Table S4b.

Intercept	**Precipitation seasonality**	**Isothermality**	**log Colony size**	**Degrees of freedom**	**Log likelihood**	**AICc**	**ΔAICc**	**AICc weight**
0.912			0.154	2	-20.45	45.7	0	0.44
1.358		-0.007	0.168	3	-19.79	47.3	1.64	0.20
0.911	-0.001		0.159	3	-19.87	47.5	1.8	0.18
1.637				1	-23.84	49.9	4.26	0.05
1.291	0.008			2	-22.75	50.3	4.64	0.04
1.536	-0.002	-0.009	0.174	4	-19.76	50.6	4.93	0.04
0.681		0.014		2	-22.94	50.7	5.02	0.04
0.253	0.007	0.016		3	-22.34	52.4	6.74	0.02

Table S4c.

Intercept	**Precipitation seasonality**	**Mean diurnal temperature fluctuation**	**Isothermality**	**Lattitude**	**Precipitation seasonality * isothermality**	**Degrees of freedom**	**Log Likelihood**	**AICc**	**ΔAICc**	**AICc weight**
1.040			0.056			2	-61.93	128.4	0	0.17
6.658	0.044	-0.035				3	-60.73	128.6	0.18	0.16
4.245	0.015					2	-62.04	128.6	0.23	0.15
7.291	-0.173		-0.055		0.003	4	-59.81	129.5	1.14	0.10
4.976		-0.002				2	-62.57	129.7	1.29	0.09
1.437	0.011		0.044			3	-61.67	130.4	2.05	0.06
1.249		-0.002	0.056			3	-61.91	130.9	2.54	0.05
0.926			0.057	0.006		3	-61.92	130.9	2.55	0.05
4.240	0.015			0.002		3	-62.04	131.2	2.8	0.04
5.520	0.040	-0.032	0.015			4	-60.69	131.3	2.91	0.04
6.663	0.045	-0.035		0.007		4	-60.71	131.3	2.96	0.04
7.581	-0.202		-0.062	0.037	0.003	5	-59.36	131.7	3.34	0.03
4.992		-0.002		-0.005		3	-62.56	132.2	3.84	0.03

Multinomial Model Analysis

We categorised species by their agricultural system as follows: lower Attines (lower agriculture), higher Attines, excluding leafcutters (higher agriculture), and leafcutter ants (leafcutting agriculture). These classifications can be seen on figure 1, supplementary material figures S1 and S2. Using the fungal-agricultural system as the dependent variable and ln mean colony size as the independent variable, we fitted a univariate, multinomial logistic regression model using the R package MCMCglmm [1]. We used non-informative priors with a low degree of belief across all parameters, and ran the model for 6,000,000 generations, sampling every 1000th generation and discarding the first 25% of samples as burnin. We visually inspected the trace output to ensure model convergence and proper mixing, and made sure effective sample sizes were large enough to ensure robust parameter estimates.

We found strong evidence that the degree of fungal-agricultural system is predicted by colony size. Specifically, larger colony sizes are associated with a higher probability of higher agriculture versus lower agriculture (expected log-odds change per unit increase in ln colony size=1.21, CI_{95}=2.34, pMCMC=0.02), and leafcutter agriculture versus lower agriculture (expected log-odds change per unit increase in ln colony size=4.71, CI_{95}=7.19, pMCMC<<0.001).

1. Hadfield J.D. 2010 MCMC methods for multi-response generalized linear mixed models: the MCMCglmm R package. *Journal of Statistical Software* **33**(2), 1-22.