Supplement figures

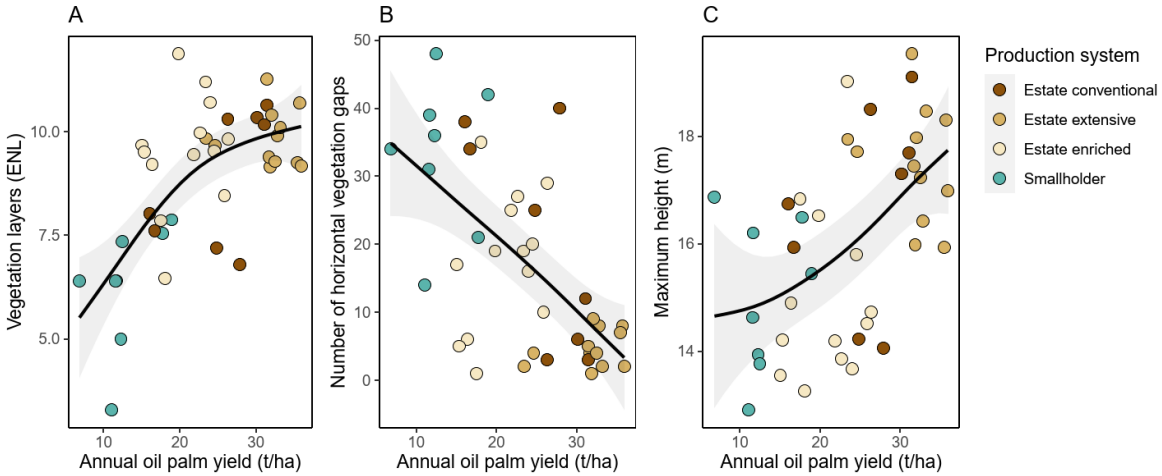

Fig S1: Airborne light detection and ranging (LiDAR) metrics plotted against annual oil palm yield: (A) effective number of vegetation layers, which describes vegetation structural complexity, (B) number of horizontal canopy gaps larger than 2.5 m^2 within the LiDAR point cloud (40x40 m), (C) maximum canopy height in meters. Point color indicates oil palm production systems. Mean general additive model predictions and 95 % confidence intervals are displayed ($p < 0.05$).

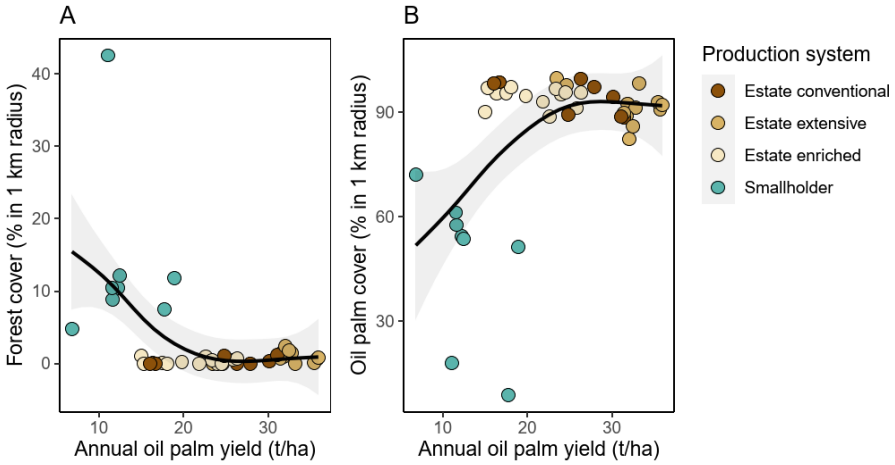

Fig S2: Surrounding forest (A) and mature oil palm cover (B) (in %) within a 1 km landscape buffer plotted against annual oil palm yield. Point color indicates oil palm production systems. Mean general additive model predictions and 95 % confidence intervals are displayed ($p < 0.05$).

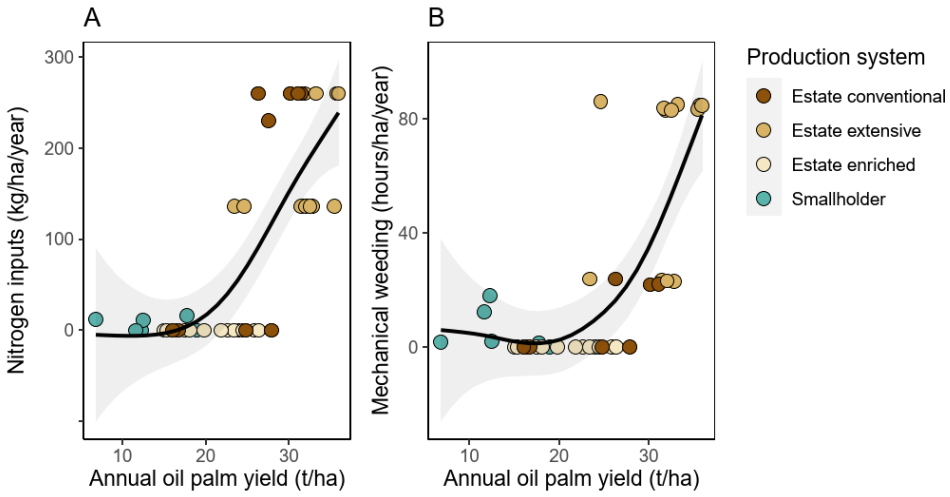

Fig S3: Nitrogen fertilization (kg per hectare and year) (A) and mechanical weeding effort (labor hours per hectare and year) (B) plotted against annual oil palm yield. Point color indicates oil palm production systems. Mean general additive model predictions and 95 % confidence intervals are displayed ($p < 0.05$).

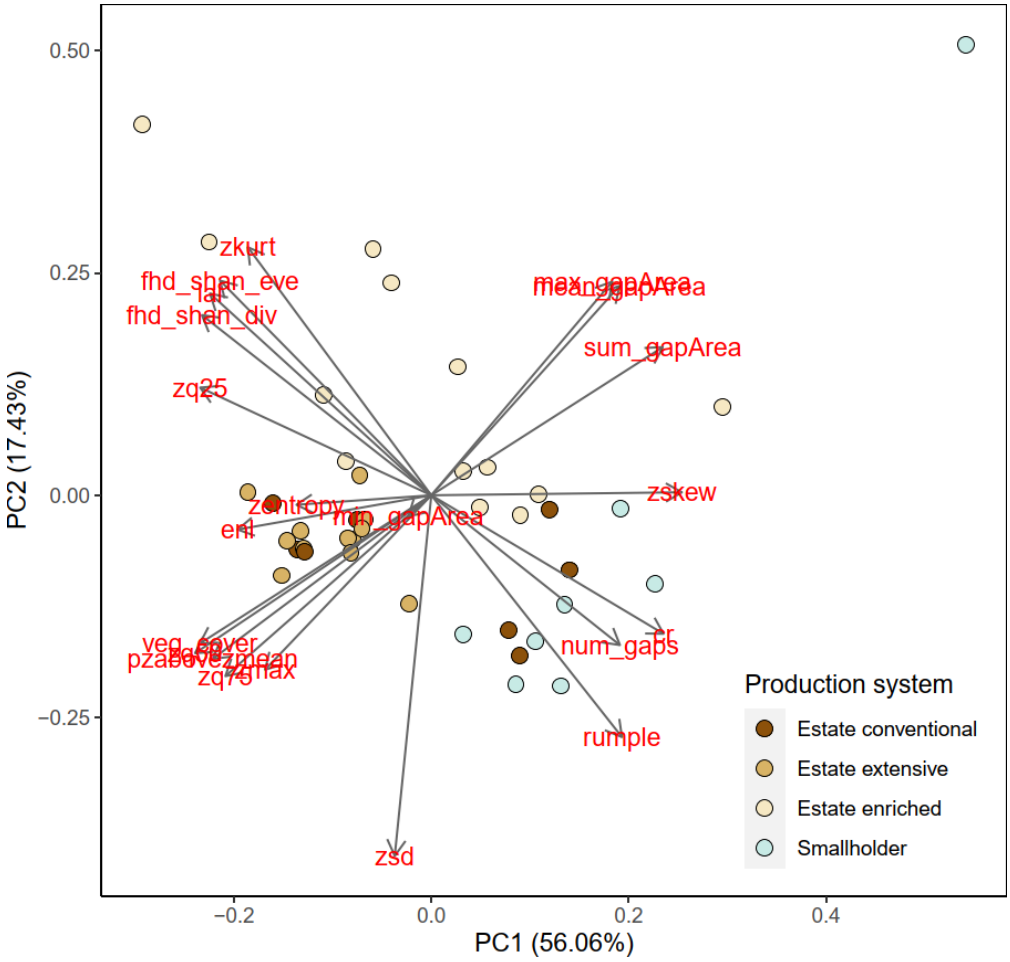

Fig S4: Principal component plot of airborne light detection and ranging (LiDAR) metrics describing vegetation structures considered in this study. We used this plot to identify groups of highly correlated metrics and to select a subset of LiDAR variables for further analysis. From this plot we selected 11 metrics: Effective number of layers (ENL), leaf area index (lai), height distribution kurtosis (zkurt), mean gap area (mean_gap), total gap area (sum_gap), height distribution skewness (zskew), number of gaps (num_gaps), canopy roughness (rumple), height distribution standard deviation (zsd), maximum height (zmax) and vegetation cover (veg_cover).

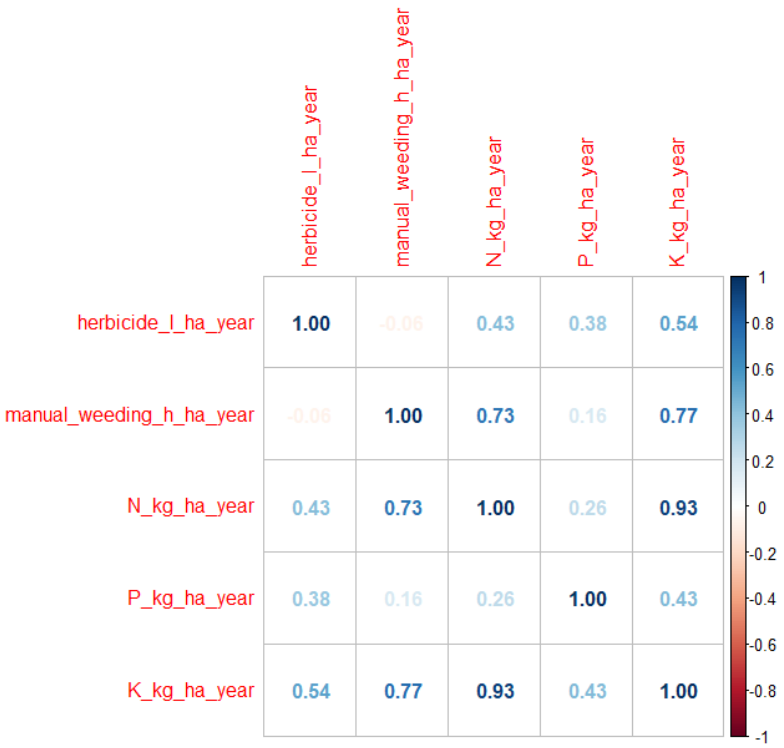

Fig S5: Spearman correlation matrix for management variables. Colors indicate strengths of correlations: the darker the color the stronger the correlation. Red indicates a positive and blue a negative correlation. From this plot we selected the following three management variables: Herbicide inputs (herbicide_l_ha_year), mechanical weeding effort (manual_weeding_h_ha_year), phosphorus inputs (P_kg_ha_year).

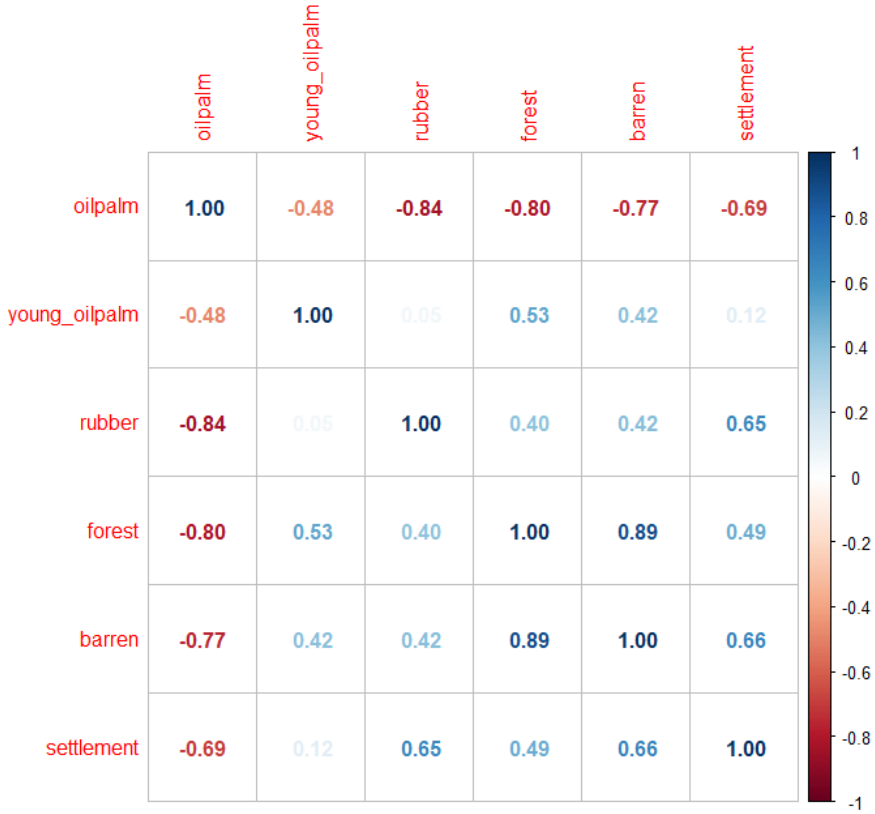

Fig S6: Spearman correlation matrix for landscape cover classes (% cover in a 1km radius around study sites). Colors indicate strengths of correlations: the darker the color the stronger the correlation. Red indicates a positive and blue a negative correlation. From this plot we selected the following three landscape variables: young oil palm plantations (young_oilpalm), forest, rubber.

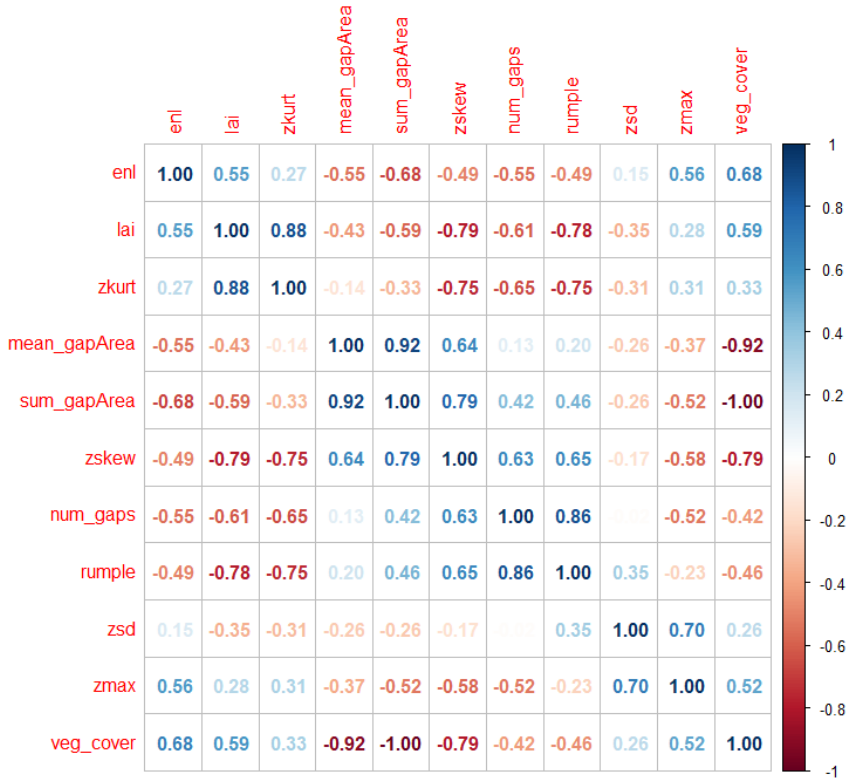

Fig S7: Spearman correlation matrix for LiDAR metrics Colors indicate strengths of correlations: the darker the color the stronger the correlation. Red indicates a positive and blue a negative correlation. For a description of variables see Tab S1. From this plot we selected the following five metrics: effective number of layers (enl), leaf area index (lai), mean canopy gap area (mean_gapArea), number of canopy gaps (num_gaps), maximum height (zmax).

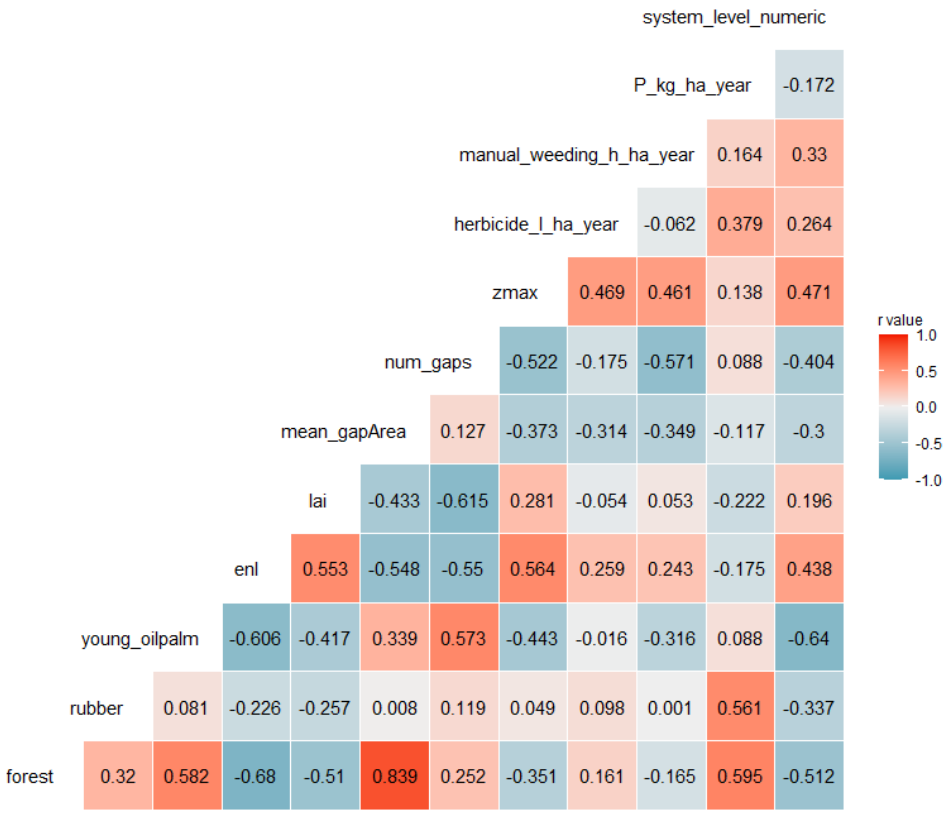

Fig S8: Spearman correlation matrix for all selected predictor variables, including their correlation to production system identity (coded as numeric values). Colors indicate strengths of correlations: the darker the color the stronger the correlation. Red indicates a positive and blue a negative correlation.

Supplement tables

Tab S1: Overview and description of LiDAR variables considered in this study. Descriptions are taken from (25).

LiDAR metric	*Description*
cr	Canopy ratio, calculated as (zmax—zq25)/zmax
enl	Effective Number of Layers, a structural complexity index used in this study
fhd_shan_div	Foliage Height Diversity, calculated as Shannon diversity
fhd_shan_eve	Foliage Height Diversity, calculated as Shannon evenness
lai	Leaf area index
max_gapArea	maximum gap size > 2.5 m
mean_gapArea	minimum gap size > 2.5 m
min_gapArea	minimum gap size > 2.5 m
num_gaps	Total number of gaps in the canopy > 2.5 m
pzabovemean	Number of points above the mean height
rumple	Rumple index, a measure of top canopy surface roughness
sum_gapArea	Total extent of gaps > 2.5 m
sum_gapArea	Total extent of gaps > 2.5 m
veg_cover (%)	Vegetation cover above 2.5 m
zentropy	Entropy of height points
zkurt	Kurtosis of height points
zmax (m)	Maximum height within the LiDAR point cloud.
zq25	25% quartile of height points
zq75	75% quartile of height points
zsd	Standard deviation of height points
zskew	Skewness of height points

Tab S2: Regression table for a logistic model with the occurrence of win-win cases as response with the system identity as predictors. The estimated log odds, standard errors, 95 % confidence intervals, p-values and the per system probability of a win-win occurrence (calculated from estimated log-odds) are displayed. Significant p-values (p <= 0.05) are highlighted in bold.

	Win-Win			
Predictors (System identity)	*Estimated Odds Ratios*	*Confidence intervals*	*p-values*	*Probability of Win-win (%)*
(Intercept) Estate conventional	0.31	0.17 – 0.52	**<0.001**	23.6%
Estate enriched	0.63	0.31 – 1.30	0.2	16.3%
Estate extensive	2.41	1.24 – 4.84	**0.011**	42.7%
Smallholders	0.00	0.00 – 0.00	0.980	0%

Tab S3: Correlations of environmental and management variables to the yield and ecological indicator axis of the global ordination plot, i.e. in which yields have been plotted against all standardized indicators. Displayed are the correlation coefficients (r) to each individual axis and the corresponding goodness-of-fit statistic (r^2) and p-values from permutation tests. Significant correlations (p > 0.05) are displayed in bold.

Variable	*Correlation to yield axis*	*Correlation to ecological indicator axis*	r^2	*p-value*
Young oil palm	-0.99	0.13	0.38	**0.001**
Forest	-0.96	0.26	0.26	**0.001**
Rubber	-0.59	0.81	0.02	**0.031**
Vegetation layers	1.00	-0.08	0.38	**0.001**
Leaf area index	1.00	0.02	0.02	**0.039**
Vegetation gaps	-1.00	-0.01	0.42	**0.001**
Maximum height	1.00	0.07	0.22	**0.001**
Herbicides	0.99	0.13	0.06	**0.001**
Mechanical weeding	0.99	0.11	0.44	**0.001**
Phosphorus	0.21	0.98	0.02	**0.049**

Tab S4: Correlations of environmental and management variables to the yield and ecological indicator axis of individual ordination plot, i.e. in which yields have been plotted against each individual ecological indicator. Displayed are the correlation coefficients (r) to each individual axis and the corresponding goodness-of-fit statistic (r2) and p-values from permutation tests.

Ecological indicator	*Variable*	*Correlation to yield axis*	*Correlation to indicator axis*	*p-value*
Aboveground biomass	Forest	-0.73	0.68	0.001
Aboveground biomass	Herbicides	1.00	-0.06	0.334
Aboveground biomass	Leaf area index	0.46	-0.89	0.559
Aboveground biomass	Mechanical weeding	0.84	0.54	0.001
Aboveground biomass	Maximum height	0.88	0.48	0.003
Aboveground biomass	Phosphorus	0.31	0.95	0.159
Aboveground biomass	Rubber	-0.01	1.00	0.175
Aboveground biomass	Vegetation gaps	-1.00	0.02	0.001
Aboveground biomass	Vegetation layers	0.90	-0.43	0.001
Aboveground biomass	Young oil palm	-0.95	0.32	0.002
Bacteria richness	Forest	0.00	-1.00	0.004
Bacteria richness	Herbicides	0.84	0.55	0.323
Bacteria richness	Leaf area index	-0.54	0.84	0.126
Bacteria richness	Mechanical weeding	0.86	0.50	0.001
Bacteria richness	Maximum height	-0.10	1.00	0.001
Bacteria richness	Phosphorus	0.68	-0.73	0.237
Bacteria richness	Rubber	0.57	-0.82	0.271
Bacteria richness	Vegetation gaps	-0.27	-0.96	0.001
Bacteria richness	Vegetation layers	0.89	0.45	0.001
Bacteria richness	Young oil palm	-0.65	-0.76	0.001
Bird richness	Forest	-0.82	0.57	0.002
Bird richness	Herbicides	0.33	0.94	0.027
Bird richness	Leaf area index	0.18	0.98	0.368
Bird richness	Mechanical weeding	0.91	0.41	0.001
Bird richness	Maximum height	0.82	0.57	0.002
Bird richness	Phosphorus	-0.18	0.98	0.003
Bird richness	Rubber	-0.38	0.92	0.039
Bird richness	Vegetation gaps	-0.86	-0.51	0.001
Bird richness	Vegetation layers	1.00	0.10	0.001
Bird richness	Young oil palm	-1.00	-0.02	0.001

Decomposition	Forest	-0.08	-1.00	0.001
Decomposition	Herbicides	0.76	-0.65	0.148
Decomposition	Leaf area index	-0.06	1.00	0.317
Decomposition	Mechanical weeding	0.99	-0.14	0.001
Decomposition	Maximum height	0.83	0.56	0.004
Decomposition	Phosphorus	0.42	-0.91	0.002
Decomposition	Rubber	0.20	-0.98	0.386
Decomposition	Vegetation gaps	-0.84	-0.55	0.001
Decomposition	Vegetation layers	0.99	0.12	0.002
Decomposition	Young oil palm	-0.61	-0.80	0.001
Microclimatic stability	Forest	-0.82	-0.58	0.315
Microclimatic stability	Herbicides	0.00	0.00	1
Microclimatic stability	Leaf area index	-0.50	0.87	0.115
Microclimatic stability	Mechanical weeding	-0.71	-0.71	0.062
Microclimatic stability	Maximum height	-0.97	0.25	0.467
Microclimatic stability	Phosphorus	-0.77	0.63	0.947
Microclimatic stability	Rubber	-0.71	0.70	0.931
Microclimatic stability	Vegetation gaps	0.29	-0.96	0.139
Microclimatic stability	Vegetation layers	0.99	0.14	0.029
Microclimatic stability	Young oil palm	-0.02	-1.00	0.247
Phosphorus	Forest	-0.88	0.48	0.009
Phosphorus	Herbicides	-0.65	0.76	0.414
Phosphorus	Leaf area index	0.86	-0.51	0.942
Phosphorus	Mechanical weeding	-0.75	0.67	0.01
Phosphorus	Maximum height	-0.99	0.16	0.807
Phosphorus	Phosphorus	-0.37	0.93	0.047
Phosphorus	Rubber	-0.90	0.44	0.682
Phosphorus	Vegetation gaps	-1.00	0.01	0.622
Phosphorus	Vegetation layers	0.87	-0.50	0.028
Phosphorus	Young oil palm	-0.95	0.31	0.058
Root fungi richness	Forest	-0.84	0.54	0.002
Root fungi richness	Herbicides	-0.19	-0.98	0.721
Root fungi richness	Leaf area index	0.79	-0.62	0.001

Root fungi richness	Mechanical weeding	1.00	0.08	0.009
Root fungi richness	Maximum height	0.59	-0.81	0.012
Root fungi richness	Phosphorus	-0.24	0.97	0.532
Root fungi richness	Rubber	-0.01	1.00	0.158
Root fungi richness	Vegetation gaps	-0.93	0.37	0.001
Root fungi richness	Vegetation layers	0.88	-0.47	0.001
Root fungi richness	Young oil palm	-0.88	0.48	0.001
Soil fauna richness	Forest	-0.43	0.90	0.001
Soil fauna richness	Herbicides	0.91	-0.41	0.312
Soil fauna richness	Leaf area index	-0.17	-0.98	0.235
Soil fauna richness	Mechanical weeding	1.00	-0.05	0.001
Soil fauna richness	Maximum height	0.99	-0.13	0.009
Soil fauna richness	Phosphorus	0.53	0.85	0.088
Soil fauna richness	Rubber	0.24	0.97	0.567
Soil fauna richness	Vegetation gaps	-0.78	0.63	0.001
Soil fauna richness	Vegetation layers	0.97	-0.25	0.002
Soil fauna richness	Young oil palm	-0.85	0.53	0.001
Soil organic carbon	Forest	-0.96	0.27	0.001
Soil organic carbon	Herbicides	0.71	0.70	0.894
Soil organic carbon	Leaf area index	0.99	0.14	0.001
Soil organic carbon	Mechanical weeding	0.99	-0.16	0.003
Soil organic carbon	Maximum height	0.97	-0.23	0.032
Soil organic carbon	Phosphorus	-0.73	0.68	0.562
Soil organic carbon	Rubber	-0.95	-0.32	0.446
Soil organic carbon	Vegetation gaps	-0.97	0.23	0.001
Soil organic carbon	Vegetation layers	0.98	0.20	0.001
Soil organic carbon	Young oil palm	-0.99	0.13	0.001
Transpiration	Forest	-0.82	0.57	0.011
Transpiration	Herbicides	0.99	-0.14	0.927
Transpiration	Leaf area index	0.96	0.30	0.938
Transpiration	Mechanical weeding	-0.61	-0.80	0.485
Transpiration	Maximum height	-0.54	-0.84	0.399
Transpiration	Phosphorus	0.07	1.00	0.33

Transpiration	Rubber	0.10	1.00	0.093
Transpiration	Vegetation gaps	-1.00	0.02	0.335
Transpiration	Vegetation layers	1.00	0.00	0.044
Transpiration	Young oil palm	-0.93	0.36	0.03
Understory vegetation richness	Forest	-0.32	0.95	0.002
Understory vegetation richness	Herbicides	-0.84	0.55	0.206
Understory vegetation richness	Leaf area index	-0.28	-0.96	0.111
Understory vegetation richness	Mechanical weeding	0.98	-0.18	0.001
Understory vegetation richness	Maximum height	0.45	-0.89	0.002
Understory vegetation richness	Phosphorus	-0.62	0.79	0.668
Understory vegetation richness	Rubber	-0.60	0.98	0.712
Understory vegetation richness	Vegetation gaps	-0.60	0.80	0.001
Understory vegetation richness	Vegetation layers	0.83	-0.55	0.001
Understory vegetation richness	Young oil palm	-0.28	0.96	0.001

Tab S5: Regression table for linear model with surrounding landscape cover of forest and young oil palm (within a 1 km radius) response and with the system identity as predictor. The estimated log odds, 95 % confidence interval and p-values are displayed. Significant p-values (p <= 0.05) are highlighted in bold.

	Forest cover			**Young oil palm cover**		
Predictors	*Estimates*	*CI*	*p*	*Estimates*	*CI*	*p*
(Intercept) Estate conventional	-4.71	-7.53 – -1.90	**0.002**	2.05	-0.94 – 5.04	0.174
Estate extensive	2.32	-1.31 – 5.95	0.204	-0.98	-4.85 – 2.88	0.610
Estate enriched	0.52	-3.06 – 4.09	0.771	2.43	-1.38 – 6.23	0.204
Smallholders	7.11	3.13 – 11.09	**0.001**	12.01	7.78 – 16.25	**<0.001**

Tab S6: Comparing species richness of oil palm production systems to forest plots. Mean, max, and min richness for four taxonomic groups in oil palm, expressed as a percentage of forest mean, max and min richness is displayed. Note that soil amendments can favor bacteria and fungi in agricultural systems, explaining values exceeding 100% of forest richness for these groups. Across production systems, understory vegetation richness reached 11% of the mean forest richness, while bird richness attained 22% of the forest mean. The data from forest plots was extracted from Grass et al. (2022). Sampling protocols were either identical or very similar for the displayed groups (for further details see the original publication).

Taxa	*Production system*	*Mean richness*	*% of forest*	*Max richness*	*% of forest*	*Min richness*	*% of forest*
Bacteria	Estate conventional	3546	159	4039	137	3001	188
	Estate extensive	3988	179	4358	147	3638	228
	Estate enriched	3366	151	3802	129	2574	161
	Smallholder upland	2692	121	2887	98	2530	158
Fungi	Estate conventional	293	85	412	91	169	98
	Estate extensive	326	95	422	93	233	135
	Estate enriched	-	-	-	-	-	-
	Smallholder upland	462	134	553	122	366	213
Understory	Estate conventional	18	9	26	10	11.4	9
	Estate extensive	16	8	20.4	8	12.4	10
	Estate enriched	21	10	29	11	13	11
	Smallholder upland	31	15	46.8	18	18.2	15
Birds	Estate conventional	4	22	7	24	0	0
	Estate extensive	5	28	7	24	4	36
	Estate enriched	3	17	7	24	0	0
	Smallholder upland	4	22	6	21	2	18

Tab S7: Average (AVG), standard deviation (StDev) and standard error (SE) of air temperature (°C), air relative humidity (%), soil temperature (°C), and total accumulated precipitation (mm) at two reference meteorological stations (Bungku situated at Bukit Duabelas National Park and REKI situated in the Harapan rainforest) in the study region for three years. Air temperature and relative humidity were measured at a height of 2 m above the surface. Soil temperature was measured at a depth of 30 cm. Precipitation was measured at a height of 1.5 m above the surface.

	Humidity (% in 2m height)		Air temperature (°C in 2 m height)		Accumulated precipitation (mm)		Soil temperature (°C in 30cm)	
2013-14	Bungku	REKI	Bungku	REKI	Bungku	REKI	Bungku	REKI
AVG	-	89.32	-	26.67	-	2221.25	-	29.95
StDev	-	13.80	-	3.67	-	0.49	-	0.93
SE	-	0.06	-	0.02	-	0.00	-	0.00
2016-17	Bungku	REKI	Bungku	REKI	Bungku	REKI	Bungku	REKI
AVG	89.56	83.68	27.01	26.64	1685.55	1418.50	30.33	32.10
StDev	14.32	25.26	4.30	11.63	0.43	0.39	0.73	0.89
SE	0.06	0.11	0.02	0.05	0.00	0.00	0.01	0.00
2017-18	Bungku	REKI	Bungku	REKI	Bungku	REKI	Bungku	REKI
AVG	89.73	-	26.70	NA	1945.60	-	29.72	33.26
StDev	14.05	-	4.11	NA	0.42	-	0.83	8.64
SE	0.06	-	0.02	NA	0.00	-	0.00	0.04