Electronic supplemental material

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Using temporally resolved floral resource maps to explain bumblebee colony performance in agricultural landscapes

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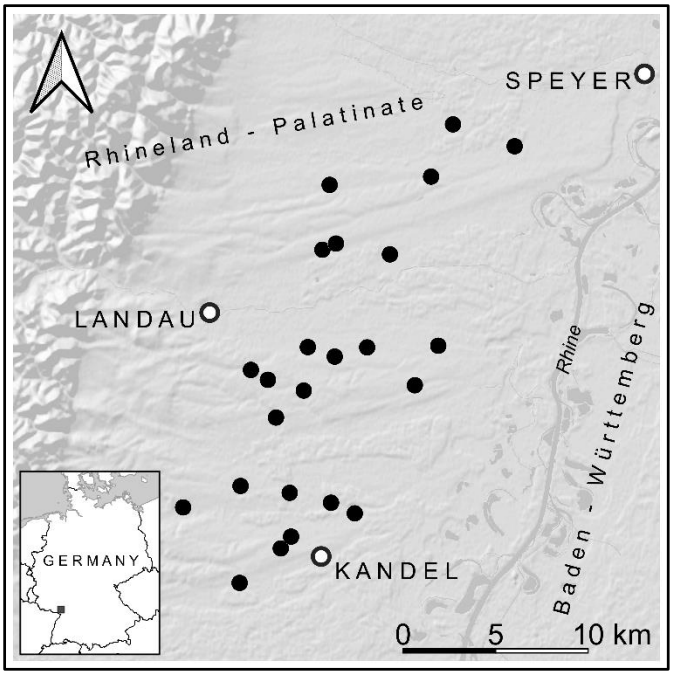

Figure S1 Location of the studied landscapes in Rhineland-Palatinate, south-west Germany

Supplement S1 Floral resource mapping

Herbaceous plants selected for mapping offered morphologically distinguishable pollen types that constituted > 5% of the collected pollen either from April to Mai and/or from June to July [1]. Flower cover of herbaceous plants representative for a field (e.g., one specific meadow inside a landscape) was assessed in ten 1m^2-subplots and extrapolated over the whole area, which was calculated in QGIS 3.6.2 [2]. Cover of all woody plants (along hedgerows, semi-natural orchards, isolated trees and the first ten meters into forest along forest edges) in the landscape was measured in the field. Tree cover in commercial orchards was calculated by multiplying the mean length of tree rows contained in the orchard, which were obtained from QGIS, with the number of rows, their mean width and a mean density factor for rows, which were measured and assessed in the field.

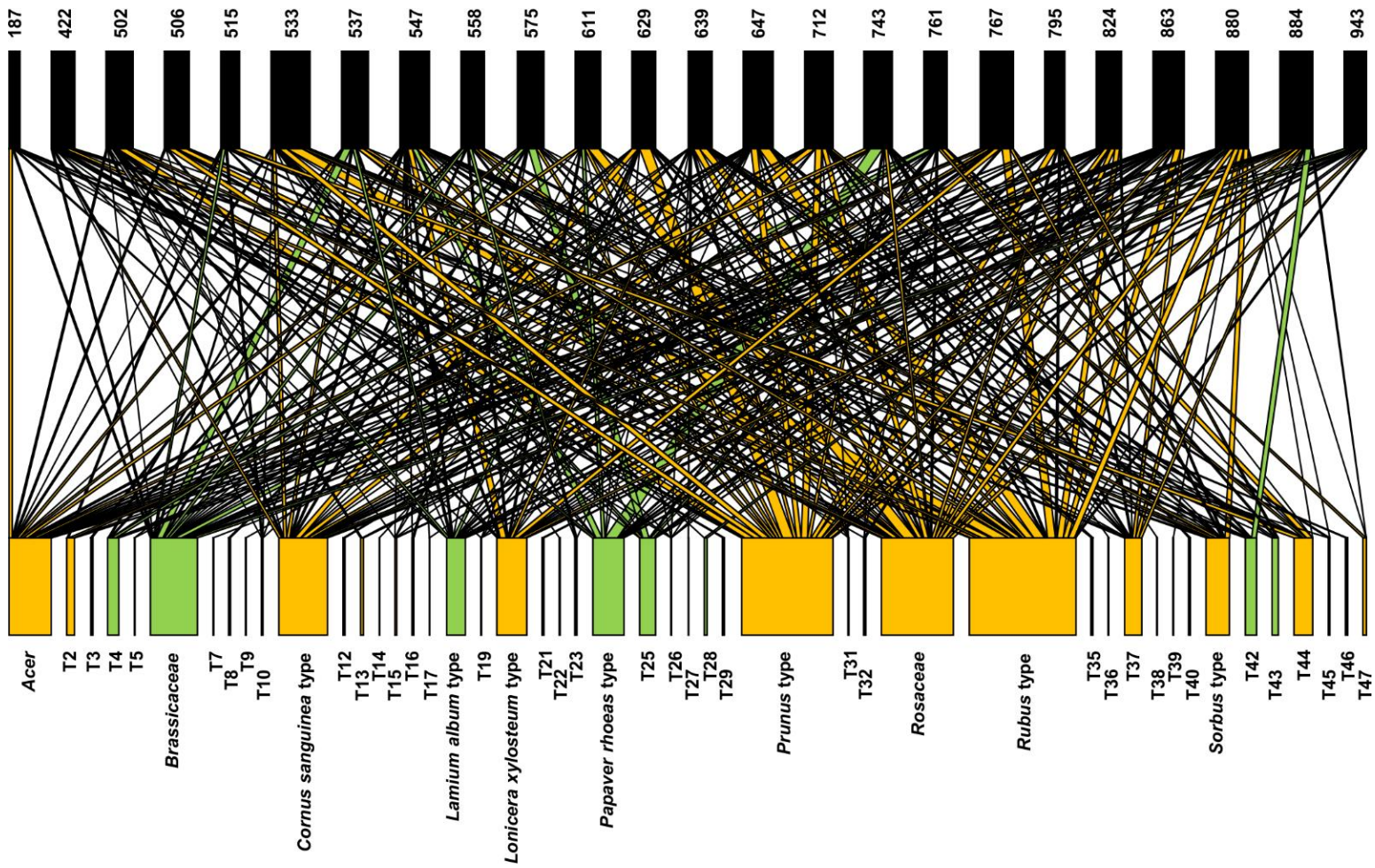

Figure S2 Pollen collection network of 657 returning foragers of 48 *Bombus terrestris* colonies in 24 agricultural landscapes in Rhineland-Palatinate (south-west Germany) across their lifecycle (from end-April till mid-July 2018). Numbers above upper bars indicate average weight gain (in g) of two colonies per landscape. Width of upper bars indicate the number of pollen grains sampled from two colonies in the landscape. Width of lower bars is proportional to the number of pollen

grains collected per pollen type across all colonies. Herbaceous plants are shown in green, woody plants in yellow. Pollen types that constituted < 3% of the collected pollen are abbreviated (see Table S1 and Table S3).

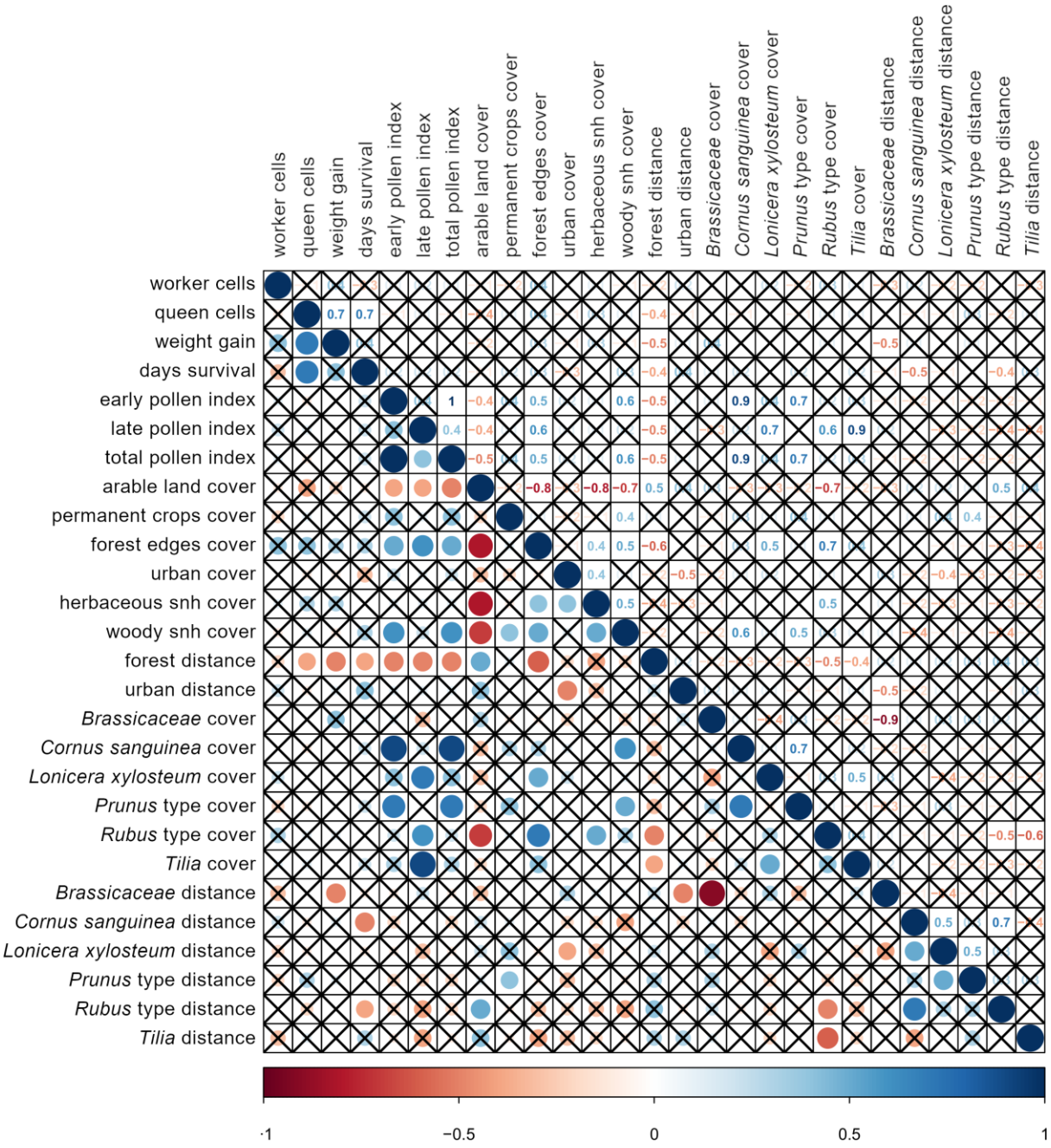

Figure S3 Pearson correlation matrix between observed parameters. Colony fitness parameter of *Bombus terrestris* colonies (number of worker and queen cells, weight gain of colonies and days of survival of colonies) and predictors using different mapping approaches. Floral resource maps are represented by floral resource availability early in the foraging season until colonies reached their maximum weight ("early", from late April until late May), from there on till colony collapse ("late", late May till mid-June) and during the whole period ("total"). Classical habitat maps represented by landscape variables (proportions of arable land, permanent crops, forest edges, other woody and herbaceous semi-natural habitat and urban, as well as Euclidean distances to forest and urban). We also included cover and distance to oilseed rape (*Brassicaceae*), *Cornus sanguinea*, *Lonicera xylosteum* type, *Prunus* type, *Rubus* and *Tilia*, important floral resources for *B. terrestris* ([3,4], Table S1). An "X" was plotted over non-significant relations (i.e. $p \geq 0.05$). The matrix was drawn using the *corrplot* package in R [5,6].

Table S1 Use and availability of key pollen types included in the study and used for calculating the resource availability index for *B. terrestris*. Plants selected for mapping were plants offering morphologically distinguishable pollen types that constituted > 5% of the collected pollen either from April to Mai and/or from June to July or across the whole season from April to July [1]. Use of pollen types is given as % in the diet of *B. terrestris* during the time periods until colonies reached their maximum weight ("Early", from late April till end of May), after that until colony collapse ("Late", end of May till mid-June) and pooled across the whole season. Pollen types used for calculating the resource availability indices are mapped plants that were collected during the respective time period. Index % gives the contribution of each pollen type to the resource availability index which is defined by relative cover of a pollen type proportional to the use times the relative volume [7]. "Plant type" is the type of plant species associated to one pollen type ([8]; w = woody, h = herbaceous), "Flower class" is the flower class ([9]; see notes below the table for further explanations and typical pollinators). "Colonies" is the number of bumblebee colonies who foraged on respective pollen types across the season. In total, 71 detected plant species with the respective morphology of 30 pollen types were mapped.

			***B. terrestris* use (%)**			**Index (%)**					
Pollen type		**Plant species**	**Early**	**Late**	**Total**	**Early**	**Late**	**Total**	**Plant type**	**Flower class**	**Colonies**
T1	*Acer*	*A. campestre, A. platanoides, A. pseudoplatanus*	7.338	0.000	6.571	4.571	0.000	4.368	w	A	28
T2	*Aesculus*	*A. hippocastanum*	1.484	0.000	1.329	0.335	0.000	0.320	w	B	6
T4	*Asparagus*	*A. officinalis*	1.455	2.396	1.553	0.269	1.120	0.307	h	B	10
T5	*Betula*	*B. pendula*	0.005	0.000	0.004	0.002	0.000	0.002	w	W	2
T6	*Brassicaceae*	*Brassica napus*	8.387	0.063	7.516	2.538	0.143	2.427	h	AB	35
T8	*Castanea*	*C. sativa*	0.185	0.000	0.166	0.005	0.000	0.005	w	W	1
T10	*Cichorioideae*	*Hypochaeris radicata*	0.377	0.000	0.338	0.690	0.000	0.659	h	B	5
T11	*Cornus sanguinea*	*C. sanguinea*	8.470	0.000	7.584	45.10	0.000	43.09	w	A	33
T14	*Fagus*	*F. sylvatica*	0.002	0.000	0.002	0.002	0.000	0.002	w	W	1
T15	*Fraxinus excelsior*	*F. excelsior*	0.144	0.125	0.142	0.037	0.081	0.078	w	W	6
T17	*Juglans*	*J. regia*	0.010	0.000	0.009	0.015	0.000	0.015	w	W	2
T18	*Lamium album* type	*L. album*	3.465	0.021	3.105	1.333	0.020	1.274	h	H	18
T19	*Ligustrum* type	*Ligustrum vulgare, Syringa vulgaris*	0.019	0.521	0.072	0.011	0.776	0.045	w	B	5
T20	*Lonicera xylosteum* type	*L. xylosteum*	4.791	2.854	4.588	17.13	25.80	17.55	w	Hh	24
T24	*Papaver rhoeas* type	*P. rhoeas*	5.506	0.438	4.976	1.672	0.335	1.610	h	Po	18
T25	*Phacelia tanacetifolia*	*P. tanacetifolia*	1.584	10.25	2.490	0.174	2.834	0.291	h	H	12
T26	*Picea*	*Picea* spec.	0.029	0.000	0.026	0.641	0.000	0.612	w	W	9
T29	*Potentilla* type	*Fragaria* spec. only	0.367	0.000	0.329	0.053	0.000	0.051	h	AB	2
T30	*Prunus* type	*Amelanchier ovalis, Crataegus* spec., *Cydonia oblonga, Malus domestica, Malus sylvestris, Malus* spec., *Mespilus germanica, Prunus armeniaca, P. avium, P. cerasus, P. domestica, P. domestica* subsp. *syriaca, P. dulcis, P. laurocerasus, P. padus, P. persica, P. serotina, P. spinosa, P.* spec., *Pyrus communis, Pyrus domestica, Pyrus pyraster, Pyrus* spec.	16.19	0.000	14.50	12.83	0.000	12.26	w	AB	38
T31	*Quercus*	*Q. alba, Q. petraea, Q. robur, Q. rubra, Q. spec.*	0.012	0.000	0.011	0.006	0.000	0.006	w	W	38
T32	*Ranunculus acris* type	*R. acris, R. repens, R. reptans*	0.290	0.000	0.259	0.111	0.000	0.106	h	AB	5
T33	*Rosaceae*	*R. agrestis, R. canina*	12.30	3.542	11.39	4.109	2.990	4.058	w	Po	5

T34	*Rubus*	*R. fruticosus, R. idaeus*	15.51	28.56	16.88	5.984	27.86	6.947	w	BH	36
T36	*Salix*	*S. alba, S. babylonica, S. caprea, S. fragilis, S. matsudana 'Tortuosa', S.* spec.	0.002	0.000	0.002	0.000	0.000	0.000	w	AB	40
T37	*Sambucus nigra* type	*S. nigra, S. racemosa, S.* spec.	2.895	0.000	2.593	0.232	0.000	0.221	w	Po	2
T41	*Sorbus* type	*S. aucuparia, S. domestica, S.* spec.	4.005	1.396	3.732	1.362	1.200	1.354	w	AB	2
T43	*Trifolium pratense* type	*T. pratense*	0.808	2.667	1.002	0.636	5.320	0.843	h	Hh	15
T44	*Tilia*	*T. chordata, T. platyphyllos*	0.007	26.77	2.806	0.003	29.71	1.354	w	A	4
T45	*Viburnum*	*V. lantana, V. opulus*	0.423	0.000	0.379	0.108	0.000	0.103	w	ADe	13
T47	*Vitis*	*V. vinifera, V. vinifera* subsp. *Sylvestris*	0.243	3.625	0.597	0.048	1.819	0.126	w	A	3
	30 pollen types	**71 plant species**	**96.3**	**83.2**	**94.9**	**100**	**100**	**100**			

Notes: **Flower classes**: **A:** Flowers with open accessible nectar. Typical pollinators: beetles, flies, syrphids, wasps, middle-tongued bees / **AB:** Flowers with partly hidden nectar. Typical pollinators: syrphids, bees / **Ade:** Transition type flowers with open nectar - nasty flowers. Typical pollinators: flies, beetles / **B:** Flowers with hidden nectar. Typical pollinators: bees, bumblebees, wasps, Bombyliidae, syrphids / **BH:** Transition type flowers with totally hidden nectar - bee flowers. Typical pollinators: Hymenoptera / **H:** Flowers for Hymenoptera. Typical pollinators: Hymenoptera / **Hh:** Flowers for bumblebees. Typical pollinators: bumblebees / **Po:** Pollen flowers. Typical pollinators: short tongued bees, syrphids, flies, beetles.

Table S2 Proportions of habitat types across the landscapes

	Habitat type							
landscape	Arable	Perm. Crops	Forest interior	Forest edge	Other	Herb. SNH	Woody SNH	Rural
1	0.89	0.00	0.00	0.00	0.04	0.04	0.01	0.02
2	0.26	0.00	0.26	0.03	0.03	0.31	0.10	0.01
3	0.29	0.00	0.02	0.01	0.04	0.50	0.04	0.10
4	0.91	0.01	0.00	0.00	0.04	0.04	0.01	0.00
5	0.75	0.03	0.00	0.00	0.05	0.09	0.04	0.05
6	0.77	0.00	0.07	0.01	0.02	0.14	0.00	0.00
7	0.39	0.10	0.09	0.02	0.03	0.32	0.05	0.00
8	0.86	0.01	0.00	0.00	0.05	0.05	0.03	0.00
9	0.47	0.17	0.04	0.03	0.07	0.12	0.07	0.02
10	0.65	0.14	0.00	0.00	0.09	0.05	0.07	0.00
11	0.62	0.06	0.10	0.02	0.07	0.06	0.07	0.00
12	0.80	0.00	0.02	0.01	0.04	0.09	0.04	0.01
13	0.62	0.14	0.00	0.00	0.06	0.12	0.06	0.00
14	0.89	0.00	0.00	0.00	0.06	0.04	0.02	0.00
15	0.97	0.00	0.00	0.00	0.01	0.01	0.00	0.00
16	0.86	0.03	0.00	0.00	0.06	0.04	0.00	0.00
17	0.87	0.03	0.00	0.00	0.04	0.02	0.03	0.00
18	0.94	0.01	0.00	0.00	0.04	0.01	0.00	0.00
19	0.91	0.00	0.00	0.00	0.02	0.07	0.00	0.00
20	0.32	0.00	0.44	0.03	0.04	0.12	0.03	0.03
21	0.89	0.00	0.00	0.00	0.02	0.04	0.00	0.05
22	0.44	0.05	0.33	0.03	0.05	0.08	0.01	0.00
23	0.71	0.19	0.00	0.00	0.04	0.03	0.03	0.00
24	0.48	0.00	0.00	0.00	0.07	0.19	0.05	0.21
mean	0.69	0.04	0.06	0.01	0.04	0.11	0.03	0.02
min	0.26	0.00	0.00	0.00	0.01	0.01	0.00	0.00
max	0.97	0.19	0.44	0.03	0.09	0.50	0.10	0.21
se	0.05	0.01	0.02	0.00	0.00	0.02	0.01	0.01

Table S3 Composition of pollen diet of returning foragers of *B. terrestris* excluded from index calculations. Use of pollen types is given as % in the diet of *B. terrestris* during the time periods until colonies reached their maximum weight ("Early", from late April until end of May), after that until colony collapse ("Late", end of May till mid-June) and pooled across the whole season. Plant type is the type of plant species associated to one pollen type ([8]; w = woody, h = herbaceous). Pollen types were excluded from index calculations because they constituted < 5% of pollen diet of *B. terrestris* in our study region in 2016 [1]. Cucurbitaceae were excluded because they were not found flowering in our landscapes during sampling rounds.

		B. terrestris use (%)			
Pollen type		Early	Late	Total	Vegetation type
T3	*Apiaceae*	0.000	2.063	0.216	h
T7	*Calystegia* type	0.000	0.063	0.007	h
T9	*Cerealia*	0.000	0.375	0.039	h
T12	*Cucurbitaceae*	0.000	2.667	0.279	h
T13	*Ericaceae*	0.467	0.000	0.418	w/h
T16	*Hypericum perforatum* type	0.000	4.167	0.436	h
T21	*Lotus* type	0.178	0.000	0.159	h
T22	*Oenothera biennis*	0.000	0.313	0.033	h
T23	*Onobrychis*	0.370	0.000	0.331	h
T27	*Poaceae*	0.007	0.000	0.007	h
T28	*Polygala comosa*	0.000	5.938	0.621	h
T35	*Rumex* type	0.384	0.000	0.344	h
T38	*Scrophulariaceae*	0.063	0.000	0.057	h
T39	*Aster* type	0.002	0.000	0.002	h
T40	*Solanum nigrum* type	0.000	1.188	0.124	h
T42	*Symphytum*	2.015	0.000	1.804	h
T46	*Vicia* type	0.197	0.000	0.176	h
		3.7	**16.8**	**5.1**	

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