

Long-term field experiments in plant nutrition

The Swedish University of Agricultural Sciences
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Field experiments at the Lanna research station.

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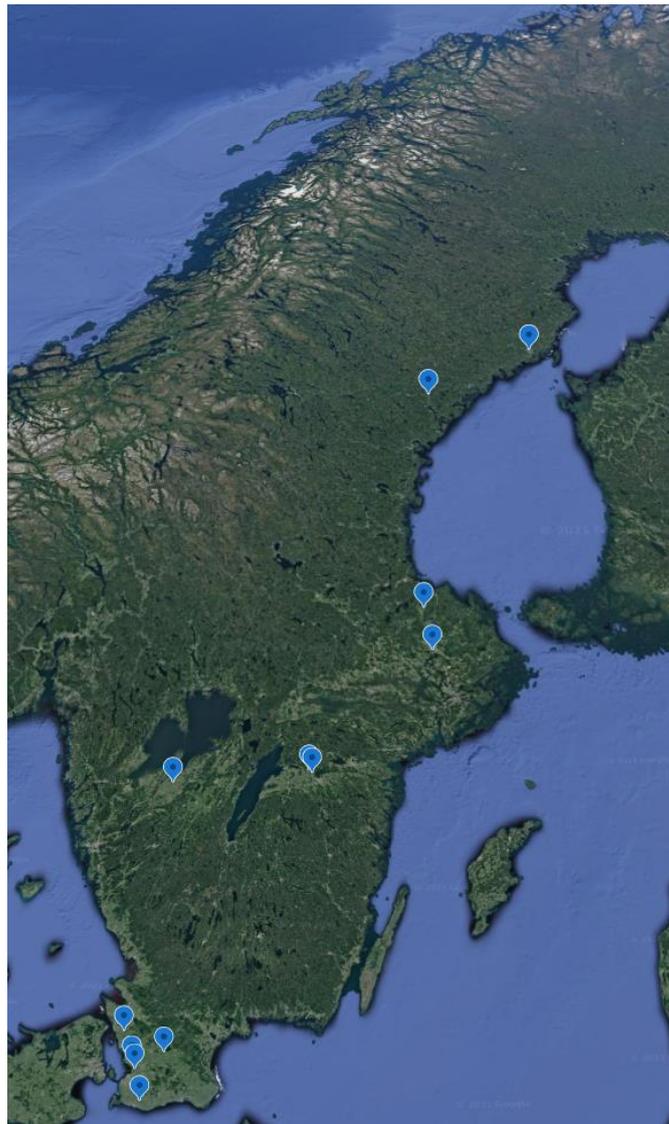
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1. Introduction

This is an overview of the experimental design of the 24 active long-term field experiments in plant nutrition and soil fertility managed by the Department of Soil and Environment at the Swedish University of Agricultural Sciences. The experiments are composed of eight different experimental series and focus on themes such as liming, long-term soil fertility, soil organic matter and soil biology. Plant and soil samples have been archived since the start of the experiments. All experiments are managed as in a conventional farming system. Chemical weed and pest control is used as needed.

Researchers and students are welcome to utilize the experiments, the collected data and the archived samples. See section 8 for information about how to obtain access.



The long-term field experiments (marked by blue pins) span much of Sweden, from Umeå in the north to Trelleborg in the south. The majority are attached to SLU research stations in Lövsta (Uppsala), Lanna (Skara), Lönnstorp (Alnarp) or Röbbäcksdalen (Umeå).

2. Lime and phosphorus, R3-1001

The lime and phosphorus experiments are the oldest field experiments at SLU. They consist of two separate experimental sites established in 1936 and 1941, both located at Lanna, Skara, and have a three-factor split-split plot design with two field replicates. The three tested factors are i) limed or not limed at start, ii) limed or not limed again (in 1974 and 1977, respectively), and iii) different levels of phosphorus addition, as described in Table 1. Phosphorus fertilizer is applied either as superphosphate (P20) or as Thomas phosphate, a byproduct of iron mining. Crop samples are collected every year, and top soil samples are collected every 6th year. Crop rotation and application of mineral fertilizers (excluding phosphorus) follow the management of the field where the experimental plots are located, and are not detailed in the experimental plan.

Table 1. Treatments in the R3-1001 experiments.

Treatment	Limed at start	Limed again	Phosphorus level
IA1	No	No	No P
IA2	No	No	17.5 kg P ha ⁻¹ every year as superphosphate
IA3	No	No	105 kg P ha ⁻¹ every 6 th year as superphosphate
IA4	No	No	17.5 kg P ha ⁻¹ every year as Thomas phosphate
IA5	No	No	105 kg P ha ⁻¹ every 6 th year as Thomas phosphate
IB1	Yes	No	No P
IB2	Yes	No	17.5 kg P ha ⁻¹ every year as superphosphate
IB3	Yes	No	105 kg P ha ⁻¹ every 6 th year as superphosphate
IB4	Yes	No	17.5 kg P ha ⁻¹ every year as Thomas phosphate
IB5	Yes	No	105 kg P ha ⁻¹ every 6 th year as Thomas phosphate
IIA1	No	Yes	No P
IIA2	No	Yes	17.5 kg P ha ⁻¹ every year as superphosphate
IIA3	No	Yes	105 kg P ha ⁻¹ every 6 th year as superphosphate
IIA4	No	Yes	17.5 kg P ha ⁻¹ every year as Thomas phosphate
IIA5	No	Yes	105 kg P ha ⁻¹ every 6 th year as Thomas phosphate
IIB1	Yes	Yes	No P
IIB2	Yes	Yes	17.5 kg P ha ⁻¹ every year as superphosphate
IIB3	Yes	Yes	105 kg P ha ⁻¹ every 6 th year as superphosphate
IIB4	Yes	Yes	17.5 kg P ha ⁻¹ every year as Thomas phosphate
IIB5	Yes	Yes	105 kg P ha ⁻¹ every 6 th year as Thomas phosphate

3. The permanent liming experiment, R3-1002

Only one experiment remains of the original seven in the permanent liming experimental series. It was started in 1962 and is located at Röbbäcksdalen, in the north of Sweden. The experiment is organized as a three-factor split-split plot design where three levels of liming are tested together with three levels of phosphorus and potassium additions, and with plant residues being either removed or left on the field. This gives a total of 18 different treatment combinations, as specified in Table 2. All treatment combinations are replicated three times in the field. The removal of phosphorus and potassium at harvest is calculated for each four-year period, and the removed amount is replaced as mineral fertilizer at the levels described in Table 2. Nitrogen levels are tied to the PK level and to the crop type (see Table 3). Liming is performed every four years, to maintain a desired base saturation. This experiment has no set crop rotation, and follows the rotation of the field in which the experimental plots are located. Crop samples are taken every year, top soil samples every 4th year. Only mineral fertilizers are used.

Table 2. Treatments in the R3-1002 experiment

Treatment	Plant residues	Liming	Phosphorus and potassium
IA1	Left on field	No lime	Half replacement
IA2	Left on field	No lime	Full replacement
IA3	Left on field	No lime	Double replacement
IB1	Left on field	Maintenance of 70 % base saturation	Half replacement
IB2	Left on field	Maintenance of 70 % base saturation	Full replacement
IB3	Left on field	Maintenance of 70 % base saturation	Double replacement
IC1	Left on field	Maintenance of 100 % base saturation	Half replacement
IC2	Left on field	Maintenance of 100 % base saturation	Full replacement
IC3	Left on field	Maintenance of 100 % base saturation	Double replacement
IIA1	Removed	No lime	Half replacement
IIA2	Removed	No lime	Full replacement
IIA3	Removed	No lime	Double replacement
IIB1	Removed	Maintenance of 70 % base saturation	Half replacement
IIB2	Removed	Maintenance of 70 % base saturation	Full replacement
IIB3	Removed	Maintenance of 70 % base saturation	Double replacement
IIC1	Removed	Maintenance of 100 % base saturation	Half replacement
IIC2	Removed	Maintenance of 100 % base saturation	Full replacement
IIC3	Removed	Maintenance of 100 % base saturation	Double replacement

Table 3. Nitrogen levels for different crops in the R3-1002 experiment (kg N per hectare). Last number of treatment code indicates N level

Crop	Level 1	Level 2	Level 3
Spring cereals undersown with ley	20	40	80
Peas	0	20	40
Other crops	30	60	120



Liming of a field experiment at the research station in Lanna.

3. Soil fertility in south and central Sweden, R3-9001

In 1957 the first long-term soil fertility experiments were established at different locations in the southernmost region of Sweden, Skåne. In 1963 and 1966 additional experiments were started in central Sweden. In 2021 nine soil fertility experiments remain active, located at Fjärdingslöv, Orup, Borgeby and Ekebo in the southern region, and Bjertorp, Vreta Kloster, Högåsa, Kungsängen and Fors in the central region. See the appendix for more information about the individual sites.

In the experiments two cropping systems are tested, one representing a typical farm with livestock and one representing a typical farm with no animals, referred to as crop rotation I and II, respectively (Table 4). Crop rotation I receives a combination of cattle manure and mineral fertilizers, and straw and plant residues is removed from the field. In crop rotation II only mineral fertilizers are used and straw and plant residues is left on the field after harvest. Both crop rotations receive four levels of nitrogen addition (Table 4) and four levels of PK addition (Table 5). Crop samples are collected every year and topsoil samples every 4th year in the south region and every 6th year in the central region.

Table 4. Crop rotations and addition of nitrogen (kg ha^{-1}) for the four nitrogen levels (N1-N4) in the R3-9001 experiments.

	Crop rotation I	Crop rotation II	N1	N2	N3	N4
South	Spring barley	Spring barley	0	30	60	90
	Ley	Oil seed	0	50	100	150
	Winter wheat	Winter wheat	0	50	100	150
	Sugar beets	Sugar beets	0	70	140	210
Central	Spring barley	Spring barley	0	25	50	75
	Ley I	Oats	0	40	80	120
	Ley II	Oil seed	0	50	100	150
	Winter wheat	Winter wheat	0	40	80	120
	Oats	Oats	0	40	80	120
	Winter wheat	Winter wheat	0	50	100	150

Table 5. Phosphorus and potassium levels, in kg per hectare and year in the R3-9001 experiments. Removal of P and K by crop is calculated for each rotation, and replaced during the following rotation.

	Treatment	Phosphorus	Potassium level
South	A	0	0
	B	Replacement	Replacement
	C	Replacement + 15	Replacement + 40
	D	Replacement + 30	Replacement + 80
Central	A	0	0
	B	Replacement	Replacement
	C	Replacement + 20	Replacement + 50
	D	Replacement + 30	Replacement + 80



The soil fertility experiment at Orup.

4. Soil fertility in northern Sweden, R3-2037

The northern soil fertility experiments were designed to extend and complement the R3-9001 experimental series. They started in 1969 and consist of two experiments located at Röbbäcksdalen and Offer. The crop rotation consists of barley, ley I, ley II, oil seed (harvested as forage), barley, and oats. In autumn, after ley II and oats, cattle slurry, corresponding to 4 000 kg dry matter ha⁻¹, is applied to all treatments. The removal of P and K at harvest is calculated for each six year rotation and is replaced as mineral fertilizer during the next rotation, according to Table 6. Nitrogen is applied every year at five levels, as specified in Table 7. Crop samples are collected every year and top soil samples every third year.

Table 6. Phosphorus and potassium application rates (per year) in the treatments included in the R3-2037 experiments.

Treatment	Phosphorus level	Potassium level
A1	Replacement	Replacement
A2	Replacement	Replacement
A3	Replacement	Replacement
A4	Replacement	Replacement
A5	Replacement	Replacement
B1	Replacement + 20 kg ha ⁻¹	Replacement
B2	Replacement + 20 kg ha ⁻¹	Replacement
B3	Replacement + 20 kg ha ⁻¹	Replacement
B4	Replacement + 20 kg ha ⁻¹	Replacement
B5	Replacement + 20 kg ha ⁻¹	Replacement
C1	Replacement + 40 kg ha ⁻¹	Replacement
C2	Replacement + 40 kg ha ⁻¹	Replacement
C3	Replacement + 40 kg ha ⁻¹	Replacement
C4	Replacement + 40 kg ha ⁻¹	Replacement
C5	Replacement + 40 kg ha ⁻¹	Replacement
D1	Replacement	Half replacement
D2	Replacement	Half replacement
D3	Replacement	Half replacement
D4	Replacement	Half replacement
D5	Replacement	Half replacement
E1	Replacement + 20 kg ha ⁻¹	No K
E2	Replacement + 20 kg ha ⁻¹	No K
E3	Replacement + 20 kg ha ⁻¹	No K
E4	Replacement + 20 kg ha ⁻¹	No K
E5	Replacement + 20 kg ha ⁻¹	No K
F1	No P	No K
F2	No P	No K
F3	No P	No K
F4	No P	No K
F5	No P	No K

Table 7. Nitrogen levels in the R3-2037 experiment.

Crop	Level 1	Level 2	Level 3	Level 4	Level 5
Barley and oats	0	30	60	90	120
Canola	0	60	120	180	240
Ley first year	0	25	50	100	200
Ley second and third year	0	40	80	160	320

5. The frame experiment, R3-RAM56

The frame trial is one of the most utilized long-term field experiments and is located right at SLU Ultuna Campus. It consists of 2·2 m plots with steel frames surrounding each plot going down to a depth of 0.5 m. The effect of different combinations of organic material and nitrogen fertilization on soil organic matter and soil microbial community's has been tested since 1956. The plots also includes bare fallow and cropping without any nutrient input. Due to the small plot size, destructive soil sampling is restricted for this experiment.

The experiment consist of 15 treatments (Table 8) with four field replicates, resulting in a total of 60 plots organized in four blocks. Plots are randomized except for block 1. Organic material is added in autumn every second year. Nitrogen is applied yearly. All treatments receive 20 kg P ha and 38 kg K ha⁻¹. The type of mineral P and K fertilizer is not specified in the experimental plan. Crop rotation were alternating spring cereals and spring oil seed until 2000, after that only maize harvested as green forage has been grown. Crops are sampled every year and topsoil was samples every year after harvest until 2019. Since 2019 soil samples have been collected every second year.

Table 8. Treatments in the R3-RAM56 experiment.

Treatment	Organic material	Nitrogen
A	No organic material, bare fallow	No N
B	No organic material	No N
C	No organic material	80 kg ha as calcium nitrate
D	No organic material	80 kg ha as ammonium sulphate
E	No organic material	80 kg ha as calcium cyanamide
F	Straw	No N
G	Straw	80 kg ha as calcium nitrate
H	Grass	No N
I	Peat	No N
J	Manure	No N
K	Super manure	No N
L	Sawdust	No N
M	Peat	80 kg ha
N	Sawdust	80 kg ha as calcium nitrate
O	Biogas digestate	No N



All management of the frame experiment is done by hand, ensuring minimal carry-over of soil between plots.

6. The soil biology experiment, R3-0130

The usefulness of the frame experiments combined with the small plot size led to the establishment of a sister experiment in 1996, located at the SLU research station in Lanna, Skara. This experiment has a plot size of 8·14 m² except for plots 9, 10, 27, and 27 which are 6·14 m². Input of organic materials and mineral fertilizers for the nine treatments are specified in Table 9. All treatments have four field replicates. Crop rotation consists of only cereals, and grain and straw samples are collected every year. Topsoil samples are collected every second year. In order to install a new sub-surface drainage system, this experiment will be paused in 2022.

Table 9. Treatments in the R3-0130 experiment.

Treatment	Management
A	Black fallow, no inputs
B	80 N ha ⁻¹ in Ks every year. 40 kg P and 30 kg K ha ⁻¹ every second year.
C	80 kg N ha ⁻¹ as ammonium sulfate every year. 40 kg P and 30 kg K ha ⁻¹ every second year.
D	8 ton ash free dry mass as grass hay every second year
E	8 ton ash free dry mass as manure every second year
F	8 ton ash free dry mass as sewage sludge every second year
G	Before 2010: Digestate and Cd, Cu and Ni salts. From 2013: 80 kg N ha ⁻¹ as Ks every year. 40 kg P and 30 kg K ha ⁻¹ every second year.
H	80 kg N ha ⁻¹ as biogas digestate every second year
I	Cropped, no inputs



Spreading of organic amendments at Lanna.

7. Soil organic matter experiments, R3-0020 and R3-0021

The soil organic matter experiments, also called the “humic balance” experiments, consist of two paired experimental series, one with only cereals and one with mostly grass/clover ley, for a total of eight experimental sites. The experiments were started at four different locations between 1970 and 1981. The aim of these experiments is to study the change in soil organic matter after either long-term exclusive cereal production or mixed ley production at four levels of nitrogen addition (Table 10 and 11). Nitrogen is added as mineral fertilizer (Axan, N28). In addition, the effect on soil carbon from removing or leaving the straw is investigated for the cereal experiment (Table 10). Phosphorus and potassium removed by harvest is calculated for each four year rotation and the corresponding amount is applied as mineral fertilizer during the following rotation. Other plant nutrients are added as needed. Chemical pest and weed control are used.

The crop rotation for R3-0020 consists of only cereals, such as winter wheat, spring barley and oats. For R3-0021 the crop rotation is one year of barley undersown with grass and clover, then three years of unbroken ley. At the experiment located at Röbbäcksdalen no barley is included in the rotation, and grass and clover is re-sown every fourth year. Ley is harvested twice per season, except for year 1 at Röbbäcksdalen when only one harvest is taken. In both experiments crop samples are collected every year and top soil samples every 4th year.

Table 10. Treatments in the R3-0020 experiments

Treatment	Straw handling	Nitrogen level
A1	Straw removed	No N
A2	Straw removed	40 kg N ha ⁻¹
A3	Straw removed	80 kg N ha ⁻¹
A4	Straw removed	120 kg N ha ⁻¹
B1	Straw left on field	No N
B2	Straw left on field	40 kg N ha ⁻¹
B3	Straw left on field	80 kg N ha ⁻¹
B4	Straw left on field	120 kg N ha ⁻¹

Table 11. Treatments in the R3-0021 experiments

Treatment	Nitrogen level
A	No N
B	50 kg N ha ⁻¹
C	100 kg N ha ⁻¹
D	150 kg N ha ⁻¹

8. Access to data and material from the long-term soil nutrients experiments

Researchers are allowed to use data and material from the long-term experiments, as long as the proposed activity does not cause large difficulties for SLU staff or diminish the future value of the field experiments. If the proposed activity entails more than a moderate cost to the Institution of Soil and Environment, the user will be expected to cover it. The long-term field experiments can be used for commercial research, but special legal contracts might be required.

Data and materials from the long-term field experiments are not allowed to be delivered to any third party without written permission from the person responsible for the field experiment. The user's right to use data that they neither collected nor financed to collection expires four years after the signing of the application form. After this time, the user has no right to keep any copies of the provided data. A new application is required for continued use.

Procedure to access long-term experiments in soil nutrition

1. Users should make contact with the person responsible for the long-term experiments, via email at the following address: soilnutrientcycling@slu.se
2. Needs and resources are discussed. In most cases, a cooperation partner from the Department of Soil and Environment is selected, either the person responsible for the field experiments or someone with other relevant expertise. The conditions for cooperation are agreed upon. These can include future co-authorship of papers and the covering of costs.
3. A formal application is submitted to the person responsible for the field experiments. A copy must also be sent to the coordinator of SLUs long-term experiments
4. The application is handled by the person responsible for the field experiment.
5. The user gets access to data and material when the application is granted.
6. The person responsible for the field experiments are responsible for providing information about experimental design, sampling techniques, and other scientific and practical issues.
7. Before any results are published, the selected cooperation partner at SLU should have the opportunity to review the manuscript.
8. All published material should be sent to the person responsible for the field experiments, for archiving.

Appendix

Table 12. Overview of selected experimental metadata

Experiment serie	Experiment number	Site name	Plot size (m ²)	Field replicates	Set crop rotation	Types of fertilizer/amendments	Soil sampling frequency
R3-0021	M-354-1980	Lönnstorp	105	4	Yes	Mineral NPK	Every 4 years
R3-0021	R-621-1981	Lanna	105	4	Yes	Mineral NPK	Every 4 years
R3-0021	AC-14-1980	Röbäcksdalen	105	4	Yes	Mineral NPK	Every 4 years
R3-0021	C-55-1970	Säby	105	4	Yes	Mineral NPK	Every 4 years
R3-0130	R-306-1996	Lanna	112 and 84	4	Only cereals	Mineral NPK, grass hay, manure, sewage sludge, biogas digestate	Every 2 years
R3-1001	R-27-1941	Lanna	50	2	No	Mineral NPK	Every 6 years
R3-1001	R-29-1936	Lanna	50	2	No	Mineral NPK	Every 6 years
R3-1002	AC-2-1962	Röbäcksdalen	120	3	No	Mineral NPK	Every 4 years
R3-2037	Y-7-1969	Offer		2	Yes	Mineral NPK and cattle manure	Every 3 years
R3-2037	AC-410-1969	Röbäcksdalen		2	Yes	Mineral NPK and cattle manure	Every 3 years
R3-9001	C-7-1963	Kungsängen	108	2	Yes	Mineral NPK and cattle manure	Every 6 years
R3-9001	C-8-1963	Fors	108	2	Yes	Mineral NPK and cattle manure	Every 6 years
R3-9001	E-9-1966	Vreta Kloster	125	2	Yes	Mineral NPK and cattle manure	Every 6 years
R3-9001	E-10-1966	Högåsa	125	2	Yes	Mineral NPK and cattle manure	Every 6 years
R3-9001	M-1-1957	Fjärdingslöv	125	2	Yes	Mineral NPK and cattle manure	Every 4 years
R3-9001	M-2-1957	Orup	112.5	2	Yes	Mineral NPK and cattle manure	Every 4 years
R3-9001	M-4-2010	Borgeby	112.5	2	Yes	Mineral NPK and cattle manure	Every 4 years
R3-9001	M-6-1957	Ekebo	125	2	Yes	Mineral NPK and cattle manure	Every 4 years
R3-9001	R-94-1966	Bjertorp	125	2	Yes	Mineral NPK and cattle manure	Every 6 years
R3-RAM-56	C-RAM-1956	Ultuna	4	4	Only maize	Mineral NPK, cattle manure, peat, sawdust, straw, grass, biogas digestate	Every 2 years
R3-0020	C-54-1970	Säby	90	4	Only cereals	Mineral NPK	Every 4 years
R3-0020	M-353-1980	Lönnstorp	90	4	Only cereals	Mineral NPK	Every 4 years
R3-0020	R-620-1981	Lanna	90	4	Only cereals	Mineral NPK	Every 4 years
R3-0020	AC-13-1980	Röbäcksdalen	90	4	Only cereals	Mineral NPK	Every 4 years

Table 13 Climate and location data R3 LTEs

Experiment serie	Experiment number	Site name	Longitude	Latitude	Nearest SMHI climate station	Altitude† (m)	Average yearly temperature† 1961-1990 (°C)	Average yearly temperature† 1991-2020 (°C)	Average yealy percipitation† 1961-1990 (mm)	Average yealy percipitation† 1991-2020 (mm)
R3-0021	M-354-1980	Lönnstorp	55.6689	13.1028	Alnarp	10	7.7	8.8	567	612
R3-0021	R-621-1981	Lanna	58.3461	13.1233	Lanna	80	6.1	7.3	558	584
R3-0021	AC-14-1980	Röbäcksdalen	63.8099	20.2327	Röbäcksdalen	10	2.7	4.1	588	635
R3-0021	C-55-1970	Säby	59.8192	17.6460	Ultuna	15	5.4	6.7	529	541
R3-0130	R-306-1996	Lanna	58.3461	13.1233	Lanna	80	6.1	7.3	558	584
R3-1001	R-27-1941	Lanna	58.3461	13.1233	Lanna	80	6.1	7.3	558	584
R3-1001	R-29-1936	Lanna	58.3461	13.1233	Lanna	80	6.1	7.3	558	584
R3-1002	AC-2-1962	Röbäcksdalen	63.8099	20.2327	Röbäcksdalen	10	2.7	4.1	588	635
R3-2037	Y-7-1969	Offer	63.1400	17.7500	Offer	27	2.2	3.5	488	542
R3-2037	AC-410-1969	Röbäcksdalen	63.8099	20.2327	Röbäcksdalen	10	2.7	4.1	588	635
R3-9001	C-7-1963	Kungsängen	59.8362	17.6880	Ultuna	15	5.4	6.7	529	541
R3-9001	C-8-1963	Fors	60.3153	17.5044	Untra	35	5.0	6.3	636	640
R3-9001	E-9-1966	Vreta Kloster	58.4776	15.5074	Malmslätt	94	6.1	7.1	516	565
R3-9001	E-10-1966	Högåsa	58.4936	15.4789	Malmslätt	94	6.1	7.1	516	565
R3-9001	M-1-1957	Fjärdingslöv	55.4105	13.2283	Smygehuk	5	7.5	8.6	583	634
R3-9001	M-2-1957	Orup	55.8208	13.5059	Hörby A	113	7.0	8.1	693	755
R3-9001	M-4-2010	Borgeby	55.7379	13.0526	Lund LTH	73	7.7	8.8	665	676
R3-9001	M-6-1957	Ekebo	55.9916	12.8809	Svalöv	72	7.6	8.7	703	722
R3-9001	R-94-1966	Bjertorp	58.2400	13.0700	Lanna	80	6.1	7.3	558	584
R3-RAM-56	C-RAM-1956	Ultuna	59.8192	17.6460	Ultuna	15	5.4	6.7	529	541
R3-0020	C-54-1970	Säby	59.8192	17.6460	Ultuna	15	5.4	6.7	529	541
R3-0020	M-353-1980	Lönnstorp	55.6689	13.1028	Alnarp	10	7.7	8.8	567	612
R3-0020	R-620-1981	Lanna	58.3461	13.1233	Lanna	80	6.1	7.3	558	584
R3-0020	AC-13-1980	Röbäcksdalen	63.8099	20.2327	Röbäcksdalen	10	2.7	4.1	588	635

†Of nearest SMHI climate station