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Impact of long term use of fertilizer on surface invertebrates in experimental plots in a permanent hayfield in Northern-Iceland

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SUMMARY

Surface invertebrates were collected in pitfall traps from beginning of June to end of October 1996 on fertilizer experiment in Akureyri, Northern-Iceland, where impact of long term use of N-fertilizer is studied. Totally 60 species of invertebrates were identified to species level. As a mean for the whole period 1.3–5.6 specimens/day were collected from the plots, dominated by mites and springtails. Flying insects were more frequently trapped on plots with low grass (*Agrostis capillaris*) compared to plots covered with taller grass species (*Alopecurus pratensis*). Fertilization decreased the number of invertebrate species collected but increased substantially total number of specimens, especially number of mites and springtails. Number of mites and springtails was highest where ammonium nitrate was applied, and lowest where calcium nitrate was used. Number of earthworms decreased with fertilization and they disappeared at low soil pH where ammonium sulphate had been applied, while number of Prostigmata mites increased. Although fertilization in most cases increased number of specimens, management reduced number of trapped spiders and hemipterans, but after cutting catches of spiders and beetles increased in fertilized plots. Activity of most groups of invertebrates culminated at temperature peaks, apart from dipterans which culminate in spring and Isotomidae springtails and beetles which culminate in fall.

Key words: fertilizing, hayfields, Iceland, management, surface invertebrates.

YFIRLIT

Áhrif langtíma áburðarnotkunar á hryggleysingja í túnum á Norðurlandi

Hryggleysingjum var safnað í fallgildrur frá júníbyrjun til októberloka 1996 í áburðartilraun 5-45 á Akureyri, þar sem borin eru saman langtímaáhrif mismunandi köfnunarefnisáburðartegunda. Í heild voru greindar 60 tegundir hryggleysingja. Að meðaltali yfir söfnunartímann söfnuðust 1,3–5,6 dýr í gildrurnar á dag á reitunum, mest af mítlum og mordýrum. Fljúgandi skordýr voru algengari í lágvöxnu hálíngresi en hávöxnu háliðagrasi. Áburðarnotkun fækkaði smádýrategundum, en jók mikið einstaklingsfjölda, einkum fjölda mítla og mordýra. Fjöldi mítla og mordýra var mestur þar sem borið var á ammóníumnítrat, en minnstur þar sem notað var kalsíumnítrat. Ánamöðkum fækkaði við áburð og þeir hurfu alveg við lágt sýrustig þar sem ammóníumsúlfat var borið á, en þar fjölgaði hins vegar flosmítlum (Prostigmata). Enda þótt áburðargjöf yki í flestum tilvikum fjölda einstaklinga, þá leiddu áburðargjöf og sláttur til fækkunar köngulóa og skortítna, en eftir slátt fjölgaði veiddum köngulóm og bjöllum í ábornum reitum. Veiði á flestum dýrahópum tengdist hámörkum í lofthita, nema hvað flugur náðu hámarki snemma vors og Isotomidae mordýr og einnig bjöllur náðu hámarki að hausti.

Table 1. Nitrogen fertilizer and yield in experiment 5-45 in Akureyri (Björnsson and Kristjánsdóttir, 1997).
1. tafla. Köfnunarefnisáburður og uppskera í tilraun 5-45 á Akureyri (Hólmgeir Björnsson and Þórdís Anna Kristjánsdóttir, 1997).

	Treatment			
	A	B	C	D
	Type of N-fertilizer			
	No nitrogen	Ammonium nitrate NH_4NO_3	Ammonium sulphate $(NH_4)_2SO_4$	Calcium nitrate $Ca(NO_3)_2$
N, kg/ha	0	82	82	82
DM yield 1996, t/ha	3.6	5.3	3.9	6.3
Mean DM yield 55 years, t/ha	2.6	4.8	3.6	4.8

INTRODUCTION

Agriculture in Iceland is mainly based on perennial grasses on permanent hayfields. The hayfields are originally cultivated, sown with desirable grass species, and fertilized annually and cut for hay and sometimes grazed. Gradually sown grasses are substituted by hardier grass species of domestic origin, but usually not as well suited for production of high quality feed. This kind of management influences soil properties and vegetation.

In 1945 a plot experiment was established in Akureyri, Eyjafjörður, Northern-Iceland. The experiment was placed on a hayfield seeded with *Alopecurus pratensis*, which was commonly sown grass species at that time. Since 1945 the plots have got the same fertilizer treatment every year and have been cut once or twice annually. The experimental plan includes comparison of different types and amounts of nitrogen fertilizer, and the size of each plot was 7.07×7.07 m with five replicates. The basic fertilizer has been 23.6 kg P/ha and 79.7 kg K/ha annually. Annual nitrogen fertilization has been according to Table 1, where the hay yield is also presented. Compared to no nitrogen, ammonium nitrate and calcium nitrate increase the DM yield substantially and ammonium sulphate to lesser extent.

As the plots were rather large (49.98 m^2), they offered the possibility to study the impact of long-term fertilization on the invertebrate population. The aim of this study was to evaluate the surface invertebrate population during summer in different plant communities derived from different fertilization.

MATERIALS AND METHODS

Invertebrates were collected from June 4th to October 29th 1996 on four plots in experiment 5-45 in Akureyri, and at one location 4 m away from the experiment as a reference (marked O in result tables). This spot had not got any fertilizer for years, but was usually cut for hay every year. One pitfall trap (Barber, 1931) was placed in the center of each plot in replicate 3 of the experiment and also at location O. Traps were 200 ml plastic beakers with 38.5 cm^2 opening placed at the soil surface, filled with 80 ml water with a drop of detergent. Wider lids were placed about 5 cm above the surface of the beakers to hinder rain from entering the traps. Traps were usually renewed at weekly intervals and after collection the content was stored in 50% isopropanol at 4°C for later sorting and identification under a stereoscope. Invertebrates were mainly identified by author, but assistance in identification was given by Erling Ólafsson (mainly Diptera and Hymenoptera) and Ingi Agnarsson (Areneae). In 1996 the experiment was fertilized on May 30th and the continuity of invertebrate collection was bro-

Table 2. Soil properties in experiment 5-45 in Akureyri.
2. tafla. Efna- og eðliseiginleikar jarðvegs í tilraun 5-45 á Akureyri.

	Treatment				
	A	B	C	D	O
Soil measurements	No nitrogen	Ammonium nitrate	Ammonium sulphate	Calcium nitrate	No fertilizer
pH	5.4	5.4	4.7	6.2	5.9
P, mg/100g	22.0	17.6	21.2	19.8	1.2
K, meq/100g	2.7	1.7	2.8	2.4	1.2
Ca, meq/100g	14.0	14.5	7.5	36.5	18.5
Mg, meq/100g	3.2	3.4	2.4	3.6	6.8
Organic matter 0–5 cm, %	48	58	>75	46	46
Organic matter 0–12 cm, %	27	32	34	28	29
Pore volume, %	56	62	64	61	60

ken for 4 days on August 23–26th when the experiment was cut and harvested.

On June 16th soil samples (30×30 cm) were taken to 30 cm depth for earthworm counting by hand sorting. On October 29th soil samples were taken down to 5 cm in each test plot used in this study, at least 20 stitches mixed to one sample. These samples were analyzed chemically by methods traditionally used in the Agricultural Extension Service in Eyjafjörður, minerals in ammonium lactate solution (Guðleifsson, 1984). In conventional soil analysis of hayfields following values are considered satisfactory: pH and P>5.0; K>0.5; Ca>10.0; Mg>2.0. At the same time one soil sample (12 cm depth, 4.3 cm diameter) was collected from each test plot for volume weight analysis and that sample was also used for determination of content of organic matter, measured as loss on ignition at 500°C. Volume weight was calculated according to Sigvaldason (1993).

The three different nitrogen fertilizers have had a clear impact on the soil properties (Table 2). Compared to the unmanaged spot outside the experimental area (O in the tables), the pH has in most cases decreased as has the content of Ca and Mg, while the soil content of P and K has increased. Calcium nitrate on the other hand increases pH and Ca-content. The organic matter in the top layer has increased markedly in plots with ammonium fertilizer as has the pore volume. Similar changes in soil properties have been reported before (Helgason, 1975).

The changes in soil properties have marked impact on the botanical composition of the plots. Botanical composition in each plot of the experiment was evaluated visually by two persons on June 30th, the mean is presented (Table 3). *Alopecurus pratensis* is dominating in plots fertilized with ammonium nitrate and calcium nitrate and in plots with no nitrogen it is also dominating along with *Trifolium repens* and outside the experiment along with *Deschampsia caespitosa*. In plots fertilized with ammonium sulphate *Agrostis capillaris* is dominating. The dominance of *Alopecurus pratensis* seems to be related to fairly high pH while *Agrostis capillaris* is related to low pH.

It is to be expected that these differences in soil characters and plant composition have impact on the activity of invertebrate populations in the plots.

RESULTS

The number of earthworms sampled in special collections in June is presented in Table 4. Earthworms are more numerous outside the experiment than in the experimental plots and they are larger where no fertilizer has been used. It is remarkable that no earthworms were found in the plots with ammonium sulfate fer-

Table 3. Vegetation cover (%) on June 30th 1996 in experiment 5-45 in Akureyri.
3. tafla. Gróðurhula (%) 30. júní 1996 í tilraun 5-45 á Akureyri.

	Treatment				
	A	B	C	D	O
	No	Ammonium	Ammonium	Calcium	No
Plant species	nitrogen	nitrate	sulphate	nitrate	fertilizer
Alopecurus pratensis	48	88	3	91	65
Deschampsia caespitosa	3	1	16	+	25
Festuca rubra	15	6	14	4	5
Agrostis capillaris	3	1	65	+	5
Trifolium repens	27	2	+	1	+
Other	4	2	2	4	+

Table 4. Number and weight of earthworms collected in experiment 5-45 on June 16th 1996.
4. tafla. Fjöldi og þungi ánamaðka sem safnað var 16. júní 1996 í tilraun 5-45 á Akureyri.

	Treatment				
	A	B	C	D	O
	No	Ammonium	Ammonium	Calcium	No
	nitrogen	nitrate	sulphate	nitrate	fertilizer
Total number/m^2	117	117	0	61	217
Number of juveniles	0	6	0	6	11
Dry weight, g/m^2	6.7	6.3	0	3.0	12.4
Mature specimens, mg/specimen	57	49	0	53	60

tilization, where the pH is lowered, and the number and size of earthworms has decreased substantially where pH is raised as a result of calcium nitrate fertilization. Only two species of earthworms were identified in this collection, *Aporrectodea caliginosa*, which was dominating, and *Lumbricus rubellus*, which was only in plot O and A where no N-fertilizer was applied.

Table 5 shows the number of specimens collected/day in pitfall traps in each plot during the whole summer, June 4th to October 29th. It was not possible to determine all specimens to species level. This was especially the case with slugs and earthworms, which are damaged during prolonged storage. The only species of slugs identified was *Deroceras agreste* and three species of earthworms, *A. caliginosa*, *A. rosea* and *L. rubellus*. It is worth noting that earthworms were in this case collected in treatment C, indicating that they migrate across the plot borders. Mites and springtails were only determined to family level.

Plots with no fertilizer (O) had the highest frequency of Araneae, Hemiptera, Thysanoptera and the Collembola family Entomobryidae, indicating that these groups thrive best without fertilization, whereas catches of Acari family Astigmata and Coleoptera and Hymenoptera are low.

On plots (A), with no nitrogen fertilizer but fertilized annually with P and K, the Acari family Astigmata was most numerous and collected Mesostigmata were low in number as well as the number of the Collembola families Entomobryidae and Sminthuridae.

In plots fertilized with ammonium nitrate (B), Acari (Mesostigmata and Cryptostigmata) and Collembola (Hypogastruridae, Onychiuridae and Isotomidae) and larvae were numerous whereas the catches of slugs and Hemiptera were low. The abundance of mites and

Table 5. Number of collected specimens/day in experiment 5-45 in 1996. Specimens collected in pitfall traps from June 4th to October 29th.
5. tafla. Hryggleysingjar sem veiddust á dag í fallgildrur 4. júní til 29. október 1996 í tilraun 5-45 á Akureyri.

CLASS Order Family Species	Number of trapped specimens/day A No nitrogen	 B Ammonium nitrate	 C Ammonium sulphate	 D Calcium nitrate	 O No fertilizer
ANNELIDA					
Tubificida					
Enchytraeidae	-	0.0065	-	-	0.0023
Lumbricidae (Sum)	**0.0113**	**0.0220**	**0.0214**	**0.0268**	**0.0408**
Mature	0.0104	0.0210	0.0124	0.0226	0.0397
Juveniles	0.0009	0.0010	0.0090	0.0042	0.0011
GASTROPODA					
Stylommatophora	0.0010	0.0008	0.0015	0.0029	0.0027
ARACHNIDA					
Acari (Sum)	**0.8082**	**1.4575**	**0.9894**	**0.4599**	**0.6487**
Prostigmata	0.4004	0.5146	0.6617	0.2278	0.2585
Mesostigmata	0.0283	0.3032	0.0905	0.0396	0.0647
Cryptostigmata	0.3675	0.6374	0.2336	0.1915	0.3255
Astigmata	0.0120	0.0023	0.0036	0.0010	-
Araneae (Sum)	**0.0024**	**0.0037**	**0.0052**	**0.0019**	**0.0133**
Lycosidae					
Pardosa spagnicola	0.0008	-	-	-	-
Linyphiidae					
Erigone atra	0.0014	0.0025	-	-	0.0039
Allomengea scopigera	-	-	0.0010	-	-
Agyneta decora	-	-	0.0009	-	0.0027
Lepthyphantes mengei	-	0.0002	0.0002	-	0.0020
Juveniles	0.0002	0.0010	0.0031	0.0019	0.0047
Ophiliones					
Phalangiidae					
Mitopus morio	0.0023	0.0009	0.0010	0.0010	0.0009
INSECTA					
Collembola (Sum)	**1.9722**	**2.8733**	**2.4279**	**0.7367**	**0.7613**
Hypogastruridae	1.4090	1.5668	1.3337	0.1900	0.1994
Onychiuridae	0.0009	0.0073	-	-	-
Isotomidae	0.3903	1.1165	0.7601	0.2904	0.3081
Entomobryidae	-	0.0010	0.0049	0.0029	0.0141
Sminthuridae	0.1720	0.1817	0.3292	0.2534	0.2397
Hemiptera (Sum)	**0.0085**	**0.0012**	**0.0080**	**0.0063**	**0.0126**
Miridae					
Teratocoris saundersi	-	-	0.0010	-	-
Cicadellidae					
Jassargus distinguendus	-	0.0002	-	-	0.0029
Macrosteles laevis	-	-	-	-	0.0009
Delphacidae					
Javesella pellucida	0.0010	-	-	-	-
Aphididae	0.0075	0.0010	0.0070	0.0063	0.0088
Thysanoptera					
Thripidae					
Aptinothrips rufus	0.0019	0.0018	-	-	0.0023

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CLASS Order Family Species	A No nitrogen	B Ammonium nitrate	C Ammonium sulphate	D Calcium nitrate	O No fertilizer
	Number of trapped specimens/day				
Coleoptera (Sum)	**0.0551**	**0.0722**	**0.0780**	**0.0415**	**0.0334**
Carabidae					
Notiophilus aquaticus	-	-	0.0010	-	-
Patrobus septentrionis	0.0010	-	-	-	-
Bembidion bipunctatum	0.0002	-	-	-	0.0011
Amara quenseli	0.0010	0.0010	0.0019	-	-
Staphylinidae					
Quedius boops	-	0.0011	0.0059	-	-
Othius angustus	-	-	0.0009	0.0010	-
Omalium rivulare	0.0010	-	-	-	-
Tachinus corticinus	0.0097	0.0017	0.0136	0.0022	0.0049
Oxypoda islandica	0.0010	-	-	-	-
Atheta melanocera	0.0010	-	0.0017	0.0005	-
A. fungi	0.0053	-	0.0068	0.0019	0.0026
A. islandica	-	0.0002	-	-	-
A. atramentaria	0.0217	0.0510	0.0370	0.0119	0.0140
A. excellens	0.0021	0.0111	0.0040	0.0220	0.0027
Stenus carbonarius	0.0010	0.0012	-	0.0009	0.0027
Elateridae					
Hypnoidus riparius	0.0011	-	0.0011	-	0.0029
Cryptophagidae					
Atomaria analis	0.0044	0.0011	0.0002	0.0002	0.0002
Curculionidae					
Otiorhynchus nodosus	0.0023	0.0038	0.0029	0.0009	0.0023
Tropiphorus obtusus	0.0023	-	0.0010	-	-
Hymenoptera (Sum)	**0.0372**	**0.0298**	**0.0802**	**0.0193**	**0.0190**
Ichneumonidae	-	-	-	-	0.0010
Gelis spp.	0.0010	-	0.0031	-	0.0009
Endasys varipes	0.0046	0.0018	-	0.0021	0.0035
Phygadeuon cylindraceus	-	-	-	-	0.0019
Ichneumon ligatorius	0.0019	-	-	-	-
Braconidae	0.0010	-	-	0.0010	-
Chasmodon apterus	-	-	-	0.0021	-
Dacnusa spp.	-	-	-	-	0.0010
Aphidiidae	0.0010	0.0027	0.0010	-	-
Cynipidae	0.0010	-	0.0010	-	-
Cynipidae, Eucoilidae	0.0010	-	-	-	-
Pteromalidae, Encyrtidae, Aphelinidae, Eulophidae, Mymaridae	0.0024	0.0019	0.0010	0.0018	0.0009
Diapriidae					
Trichopria aptera	0.0049	0.0022	0.0010	0.0028	0.0038
Platygastridae	0.0087	0.0117	0.0347	0.0041	0.0027
Platygaster spledidulus	0.0009	0.0019	0.0009	0.0009	0.0014
Megaspilidae					
Dendrocerus spp.	0.0088	0.0076	0.0375	0.0045	0.0019
Diptera (Sum)	**0.1510**	**0.1234**	**0.3162**	**0.0534**	**0.0944**
Mycetophilidae	0.0010	0.0010	-	-	-
Sciaridae	0.1312	0.1141	0.2776	0.0380	0.0707
Bradysia rufescens	0.0029	-	0.0049	0.0058	0.0057
Cecidomyiidae	-	0.0010	-	0.0019	-

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CLASS Order Family Species	Number of trapped specimens/day				
	A No nitrogen	B Ammonium nitrate	C Ammonium sulphate	D Calcium nitrate	O No fertilizer
Bibionidae					
Bibio pomonae	-	-	-	-	0.0008
Dilophus femoratus	0.0043	-	0.0185	0.0010	0.0067
Dolichopodidae					
Dolichopus plumipes	0.0029	-	0.0019	0.0019	0.0019
Lonchopteridae					
Lonchoptera furcata	-	0.0008	-	-	-
Syrphidae					
Melanostoma mellinum	-	0.0010	-	-	-
Sphaeroceridae	-	-	0.0010	0.0010	0.0010
Copromyza similis	-	0.0010	-	-	0.0019
Minilimosina vitripennis	-	-	-	-	0.0010
Spelobia luteilabris	0.0010	-	0.0010	-	-
Kimosina empirica	-	-	-	-	0.0010
Chloropidae					
Oscinella hortensis	0.0009	0.0018	0.0103	0.0008	0.0010
Scathophagidae					
Chaetosa punctipes	-	-	-	0.0010	-
Anthomyiidae					
Pegoplata infirma	-	0.0010	-	0.0010	-
Botanophila betarum	-	0.0017	-	-	-
B. fugax	-	-	-	-	0.0027
Zaphne ambigua	0.0010	-	-	-	-
Delia echinata	0.0029	-	0.0010	-	-
Muscidae					
Thricops cunctans	0.0010	-	-	-	-
Spilogona contractifrons	0.0010	-	-	0.0010	-
Coenosia pumila	0.0009	-	-	-	-
Larvae	0.0020	0.0040	0.0038	0.0012	0.0019

springtails indicates good soil conditions for these invertebrates, which are not only living on the soil surface, but may also travel into the soil pores.

On plots fertilized with ammonium sulphate (C), the Acari family Prostigmata, the Collembola family Sminthuridae, Coleoptera, Hymenoptera and Diptera were most numerous.

In plots fertilized with calcium nitrate (D), slugs and earthworms were most frequently collected, probably because these invertebrates seek to the tall grass growth where humidity is higher. On the other hand few specimens of Acari (mainly Prostigmata and Cryptostigmata), Araneae, Collembola family Poduridae, Diptera and larvae were collected in these plots.

The total number of collected specimens/day and number of species identified in each plot may be compiled from Table 5. Number of specimens collected/day is dominated by the number of Acari and Collembola, which are at lowest numbers outside the experiment and in plot fertilized with calcium nitrate and most numerous in plot fertilized with ammonium nitrate (Table 6). This indicates that these groups increase with fertilization, but decrease where very high amounts of fertilizer are used as in plots fertilized with calcium nitrate. On the other hand the number of identified species is highest in plot with no nitrogen fertilizer or no fertilizer at all, indicating that fertilizing decreases the diversity of insect species (Table 6).

This sampling offers the possibility to see at which time of the growing season the differ-

Table 6. Number of collected specimens/day and number of species of invertebrates identified in each plot in experiment number 5-45 June 4th to October 29th 1996.
6. tafla. Einstaklings- og tegundafjöldi hryggleysingja sem söfnuðust í hverjum reit í tilraun 5-45 á Akureyri frá 4. júní til 29. október 1996.

	Treatment				
	A No nitrogen	B Ammonium nitrate	C Ammonium sulphate	D Calcium nitrate	O No fertilizer
Number of collected specimens/day	3.1	5.6	3.9	1.3	1.6
Number of identified species	37	26	29	24	31

ent groups of invertebrates are most active at soil surface level. Following comparison (mean of all plots), is performed presuming that the activity represents managed permanent grasslands with different vegetation and soil. Also many species of the same family, which may culminate at different times, are put in one group. The most frequently trapped species therefore will dominate the picture. The number of specimens collected throughout the summer within different groups is presented in Figures 1–4, where mean air temperature at Möðruvellir is also inserted. Very few specimens were trapped of Enchytraeidae, Gastropoda, Opiliones and Thysanoptera along with the Collembola groups Entomobryidae and Onychiuridae and the Acari group Astigmata, so they are not included in the figures. Of these Opiliones and Thysanoptera were mainly collected in June, Gastropoda, and Astigmata in July, Onychiuridae and Entomobryidae in August and Enchytraeidae in September.

The Collembola family Poduridae is the most numerous of all invertebrates collected and has three distinct peaks (Figure 1), in early and late June and late July. Sminthuridae has lower peaks at the same time. These peaks correspond to peaks in air temperature. Isotomidae has four peaks, one in late July, two in August, and a very distinct one in September–October.

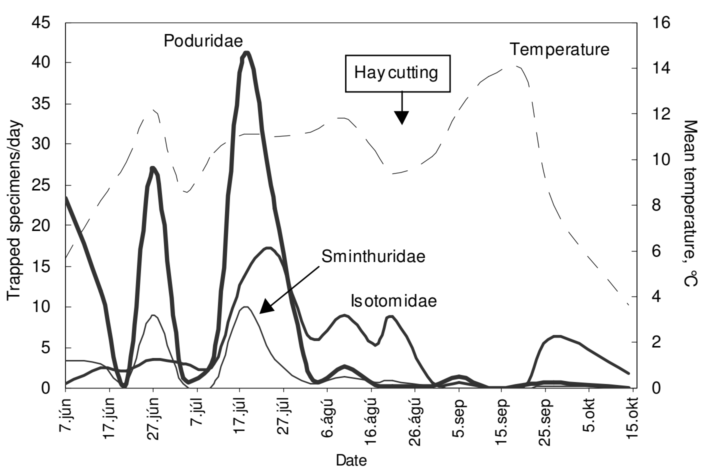

Figure 1. Number of Collembola collected throughout the summer, mean of all plots.
1. mynd. Fjöldi mordýra sem söfnuðust yfir sumarið, meðaltal allra liða.

The Acari group Prostigmata has three peaks (Figure 2), in early and late June and a high one in July (as Poduridae and Sminthuridae in Figure 1), while Cryptostigmata is numerous in June and July with small peaks in August and September. Mesostigmata has a distinct peak in end of July and a small one in late August. Diptera, dominated by Sciaridae, is very numerous in early June with lover peaks in late June and early July.

The number of Lumbricidae trapped in pitfall traps probably depends on the humidity at the soil surface level and

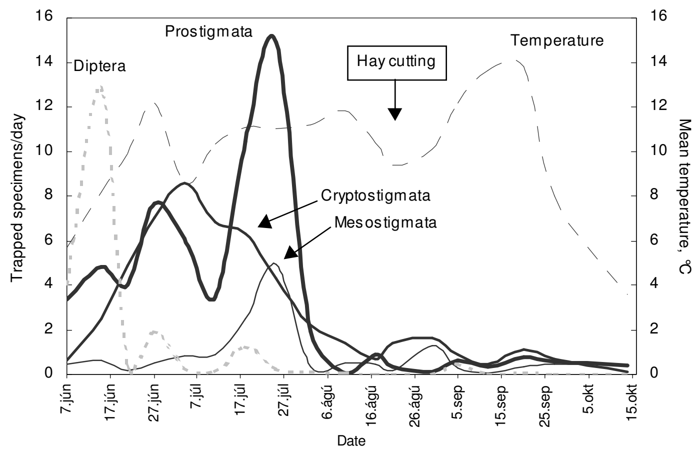

Figure 2. Number of specimens of Acari and Diptera collected throughout the summer, mean of all plots.
2. mynd. Fjöldi mítla og tvívængja sem söfnuðust yfir sumarið, meðaltal allra liða.

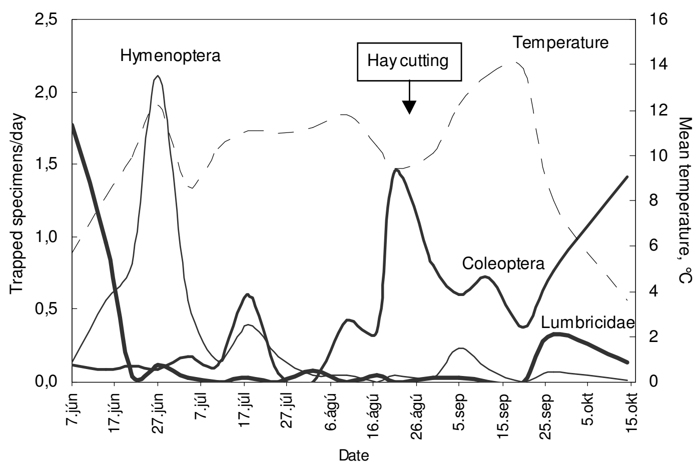

Figure 3. Number of Hymenoptera, Coleoptera and Lumbricidae collected throughout the summer, mean of all plots.
3. mynd. Fjöldi æðvængja, bjallna og ánamaðka sem söfnuðust yfir sumarið, meðaltal allra liða.

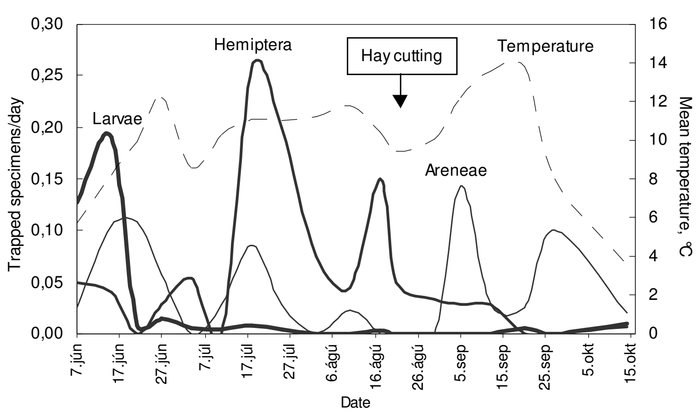

Figure 4. Number of larvae, Hemiptera and Araneae collected throughout the summer, mean of all plots.
4. mynd. Fjöldi lirfa, skortítna og köngulóa sem söfnuðust yfir sumarið, meðaltal allra liða.

they are mainly collected in early and late summer in connection with heavy rainfall (Figure 3). These specimens were collected after two heavy rainfalls in June 11th and 17th (7.1 mm/day) and again after heavy rain in October 21st (18.4 mm/day). Coleoptera, composed of many species and dominated by staphylinids, have many peaks throughout the summer. The first peak is in July (dominated by *Amara quenseli*, *Hypnoidus riparius*, *Otiorhynchus nodosus* and *Tropiphorus obtusus*). The highest peak is in late August around cutting (dominated by *Atheta atramentaria*, *A. excellens*, and *A. fungi*) another peak in September (dominated by *Tachinus corticinus*, *A. excellens* and *A. fungi*) and the last one in October before the onset of winter (also dominated by *A. atramentaria*, *A. melanocera*, *T. corticinus* and *Atomaria analis*). Hymenoptera has the highest peak in late June (composed of many species) with a smaller one in middle of July (dominated by Platigastridae), both related to temperature peaks, and a third one in early September, shortly after hay cutting.

The larvae are most active in early June before temperature peaks (Figure 4). Hemiptera (dominated by Aphididae) has four peaks, one in June, two in July and one in August. Araneae, has 5 peaks throughout the season, the first one in June is dominated by *Agineta decora* and *Erigone atra*, while juveniles compose the peak in July and *Pardosa spagnicola* in August. The peak in September is dominated by *Allomengea scopigera* and the last one by *A. scopigera* and *Lepthyphantes mengei*.

In Figures 1–4 the mean temperature is inserted indicating peaks in end of June, middle of July, middle of August and end of September. Most families of Collembola (Figure 1) and Acari (Figure 2) have peaks corresponding to the temperature peaks in June, July and August. The Collembola family Isotomidae has a peak at hay cutting in late August, and another in September, which are not related to temperature peaks. The number of Diptera (Figure 2) peaks in early spring and is not related to temperature, while number of trapped Hymenoptera (Figure 3) is related to temperature peaks in June and July. The number of Coleoptera (Figure 3) at hay cutting is not related to temperature peaks, and larvae (Figure 4) have a distinct peak in early spring and then small peaks corresponding to the four temperature peaks. Besides Isotomidae and Coleoptera, the number of Hymenoptera and Araneae increases markedly after hay cutting (Figure 3 and 4).

DISCUSSION

Collection of invertebrates in pitfall traps is not a reliable tool for giving information on the activity of all groups of invertebrates (Adis, 1979), but taken into account the possibility of migration between plots, the method should in this study give a reasonable estimate of differences between treatments. The distance from the trap to the edge of the neighboring plot is about 3.5 m. Migration between plots mainly applies to invertebrates actively traveling around in the sward, like earthworms, spiders and beetles, or flying invertebrates such as dipterans and hymenopterans. Mites and springtails are more confined to the soil and are smaller and less likely to travel long distances.

Long-term use of ammonium sulphate decreases soil pH considerably (Table 2). Decreased pH results in accumulation of soil organic matter as a result of decreased microbial activity and reduced breakdown of plant and animal residues. Changes in soil pH also reflect the vegetation where *Agrostis capillaris* dominates at lower pH (Table 3). Also the largest invertebrates, earthworms, which are important in breakdown of organic matter, are totally missing at the low pH (Table 4), although few specimens were collected in the pitfall traps in these plots (Table 5). These earthworms, collected in pitfall traps in plots with low pH, might be earthworms migrating from neighboring plots in heavy rain. Overall only three species of earthworms were identified out of the 11 species known in Iceland and one species of slugs out of the 41 known, and these species were most frequent at high pH.

One of the reasons for lower activity of some invertebrate groups in plots fertilized with calcium nitrate compared to ammonium nitrate might be the amount of fertilizer used annually. To supply the same amount of nitrogen, 82 kgN/ha as in the experiment, 592 kg/ha of calcium nitrate are needed but only 245 kg/ha of ammonium nitrate. This might be the explanation of surprisingly few earthworms in plots fertilized with calcium nitrate (Figure 4). The abundance of mites and springtails in plots fertilized with ammonium nitrate is therefore a result of low amount of nitrogen fertilizer applied.

The high number of dipterans and hymenopterans in plots fertilized with ammonium sulphate and dominated by the grass species *Agrostis capillaris*, indicates that flying insects have better access to the ground surface where the short growing grass species *Agrostis capillaris* is dominating. The high frequency of slugs and earthworms and also the low levels of dipterans in plots with high pH (plot D) is related to the dominance of the grass species *Alopecurus pratensis* (Table 3), which has tall and dense growth and may keep the soil surface moist and suitable for travel of slugs and earthworms, and on the other hand is not easily accessible for flying insects. In general, fertilizer seems to decrease the number of slugs and earthworms.

Number of mites collected is lowest outside the experiment and surprisingly also in the plot with highest pH. Prostigmata dominate in plots fertilized with ammonium and Mesostigmata and Cryptostigmata in ammonium nitrate plots. As mites partly live in the soil this might be explained by higher organic matter content and pore volume in plots fertilized with ammonium fertilizer (Table 2).

Number of springtails is higher than number of mites, and they were also more numerous in the fertilized plots than outside the experiment. Ranking of plots is the same as for mites, collected specimens are lowest where pH is highest. In a study of surface fauna of the old Park Grass Plots at Rothamsted (Edwards *et al.*, 1975), the lowest number of Collembola was also detected at the highest pH. In Akureyri this was not the case with Sminthuridae. Isotomidae dominates in plots fertilized with ammonium (as Prostigmata), whereas the number of Poduridae and Isotomidae is highest in plot fertilized with ammonium nitrate (as Mesostigmata and Cryptostigmata). As assumed for mites, the increased yield and soil organic matter content (Table 1 and 2) seem to attract springtails. Sminthuridae is the only springtail family preferring high pH, and this is in accordance with the results obtained in Rothamsted Grass plots, where Sminthuridae prefers high pH soil (Edwards *et al.*, 1975). In a study in Northern-Iceland, where soil dwelling invertebrates were extracted in Tullgren funnel, Collembola (but not Acari) were more numerous in cultivated hayfields than uncultivated (Hallgrímsson and Sigvaldason, 1974).

Sigvaldason (1973) measured in 1970 the number of springtails and mites in the same experiment, 5-45. Invertebrates were counted from soil samples collected July 27th down to 7.5 cm and extracted in Tullgren funnel. The highest number of both groups of invertebrates was observed in plot without N-fertilizer. This applies to invertebrates in the soil. In the present study, where invertebrates were collected on the soil surface, this was only the case with Astigmata, although the number of Prostigmata and Poduridae were also high in plots with no N-fertilizer. Sigvaldason (1973) found highest number of springtails in fertilized plots with highest pH. In the present study this was not the case, none of the mite families and only the springtail family Sminthuridae was most numerous in high pH plot. This indicates that surface and soil dwelling fauna might respond differently to fertilization.

Number of spiders and hemipterans is generally low in the test plots but highest outside the experiment, indicating that fertilization decreases these populations. Inside the experiment these groups of invertebrates are highest in the plots fertilized with ammonium sulphate with low pH, probably because *Agrostis capillaris* is dominating in these plots, which is shorter than the grass dominating in the other plots. The same trend was detected in the Rothamsted plots for hemipterans but not for the spiders (Edwards *et al.*, 1975).

Beetles, hymenopterans and dipterans are on the other hand more numerous inside the experiment indicating that they are attracted to the grasses growing there, especially the low growing *Agrostis* in plots fertilized with ammonium sulphate and with low pH. This was also the case in the Rothamsted plots for hymenopterans and dipterans, not for beetles (Edwards *et al.*, 1975). It is also worth noting that number of trapped specimens of beetles is highest around cutting (Figure 3) and number of trapped spiders culminates just after cutting (Figure 4). This indicates that cutting increases activity and migration of these two surface invertebrates.

Most of the surface invertebrates have highest activity when temperature peaks (Figures 1–4). In some cases the number of collected invertebrates culminates in early spring before the temperature has increased substantially. This is the case with the springtail family Poduridae (Figure 1), dipterans, dominated by Sciaridae (Figure 2), earthworms (Figure 3) and larvae (Figure 4). Some groups also have an activity peak in late fall, when temperature is dropping, such as the springtail family Isotomidae (Figure 1), beetles and earthworms (Figure 3) and spiders (Figure 4). These peaks are related to the physiology of some species of these invertebrates.

Relatively few species were collected in this experiment compared to invertebrates collected the same year in Möðruvellir Experimental Farm only 15 km away (Guðleifsson, 1998). As an example 22 species of spiders were collected in Möðruvellir, whereas only 5 species were collected in the present study in Akureyri. In the plot with no N-fertilizer where highest number of species was identified, 37 and 31 outside the experiment, whereas 24 species were identified in plot fertilized with calcium nitrate with highest pH. Thus fertilization seems to decrease the number of insect species, whereas number of specimens, especially mites and springtails, increases (Table 6).

No comparable results are available on number of surface invertebrates in hayfields in Iceland, but several studies on surface fauna in meadows have been presented. Compared to results from Hestur, West-Iceland, 40 m above sea level (Friðriksson *et al.*, 1977) and from the highland, 600 m above sea level (Gíslason, 1977; Ólafsson, 1988, 2000), the test plots have less spiders, harvestmen and hemipterans and more springtails, hymenopterans and dipterans.

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