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LANTBRUKSHÖGSKOLAN

DIRECT UPTAKE BY VEGETATION OF DEPOSITED MATERIALS.

I. RETENTION OF NUCLIDES AND SIMULATED FALLOUT PARTICLES IN PASTURE GRASS

Åke Eriksson

REPORT SLU-IRB-42
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Sammanfattning

Uppfångning och kvarhållning i betesgräs av nuklider i jonform och av märkta partiklar ur storleksfraktionerna 40-65, 65-100 och 100-200 µm studerades experimentellt 1968-1970. Erhållna data är jämförda med data från betesförsök 1970-72. Det visade sig att den relativa mängden av i vegetationen uppfångat material markerat avtog i följande ordning: Våtdeponerade nuklider > Våtdeponerade partiklar > Partiklar torrdeponerade på: Regnvått gräs > Ytligt fuktat gräs > Torrt gräs och Små partiklar > Större partiklar. Deposition vid hög luftfuktighet gav högre uppfångningsgrad än vid låg luftfuktighet. Materialets kvarhållning påverkades av dess art och av nederbördsförhållandena. Häftiga regn förkortade halveringstiden på vegetationen väsentligt. Markanta förluster av i vegetationen uppfångade torrdeponerade partiklar uppträdde under de första dagarna efter depositionen. Därefter inträdde en fas med längre halveringstid.

Summary

Interception and retention in pasture grass of nuclides in ionic form and of labelled particles (40-65, 65-100, 100-200 µm in size) were studied experimentally during 1968-70. The results obtained are compared with data from grazing experiments during 1970- . The data showed that the relative amount of material intercepted by the vegetation decreased markedly in the following order: wet-deposited nuclides > wet-deposited particles > particles dry-deposited on grass wet with rain > particles dry-deposited on grass superficially wet > particles dry-deposited on dry grass, and small particles > larger particles. At high relative humidity of the air much more of a deposition could be intercepted than at low relative humidity. The retention of intercepted material was influenced by type of material and by precipitation. Intense rains shortened the half residence time considerably. Dry-deposited materials intercepted in grass suffered marked losses by falloff during the first few days after deposition, which was followed by a phase with a longer half residence time.

Key words: Experimental deposition, pastures, nuclides, particles, interception, retention

Contents

1. Introduction

In a broad sense environmental contamination may take place in many ways and by many agents. Nuclear devices and nuclear facilities may give rise to radioactive fallout, and other industrial and domestic sources may contaminate the environments by unwanted stable and naturally occurring radioactive elements in smoke and dust emissions. If the environments contaminated include agricultural areas they are starting points for food chains and the hazard for man has to be considered.

The high interception by pasture grass has long been recognized as being important with regard to the direct uptake of contaminants which may rapidly reach man via dairy products etc. This transport is most efficient during the vegetation and grazing period, i.e. under short-term conditions. In the long-term situation, however, when the contaminants have been incorporated into the soil, the indirect uptake via plant roots may contribute to the contamination of the vegetation. In a situation of incessant fallouts and pollution during some decades, this indirect uptake may build up a lasting annual transport comparable to the direct one (cf. Eriksson, 1977).

The material deposited may reach the vegetation either in ionic form or bound to particles varying in size between one micron and a few millimeters. The ions and the small particles may have travelled long distances in the atmosphere while the larger particles mainly appear in near in fallouts.

The relative interception by the vegetation of nuclides in ionic form seems to be influenced by the valence. Morgan (1959) found the order $^{144}Ce^{+++} > ^{95}Zr^{+++} > ^{90}Sr^{++} > ^{137}Cs^{+}$. Also Kloke & Ludwig (1962) found a lower $^{137}Cs/^{90}Sr$ ratio in grass than in fallout. Two or three valent ions, however, show a slower penetration rate into plants and a slower redistribution rate within plants than univalent ions like Cs^{+}. The former rate is higher at high than at low humidity (cf. Middleton & Sanderson, 1965 and Ambler & Menzel, 1966).

The interception of particles by vegetation is influenced by many factors. Miller (1967) found that density and leaf area, the hairiness of the leaves and the relative humidity of the air were positively correlated with the absorption of particles in vegetation. A water film on the leaves should also increase the initial absorption of particles. On the other hand, the retention of particles is negatively correlated with factors like wind speed and amount and intensity of precipitation following the deposition. Generally, the smaller are intercepted to a higher extent than the larger ones. Grasses, however, may efficiently entrap also larger particles in leaf axils and basal tissues (Russell and Possingham, 1961, Russell, 1966 and Witherspoon & Tylor, 1970).

If deposition occurs under Swedish conditions the chain deposition - grass - grazing animals - milk - man as well as the fate of the grazing animals is of importance in the short-term situation. Consequently, extensive investigations into the transfer of nuclides and particles from grass to grazing animals have been carried out (Auraldsson et al., 1970, 1971, a, b, 1972, Ekman et al., 1973 a, b and Greitz et al., 1974). These grazing experiments were by nature of short endurance and finished within two days. To observe both the phase of interception and that of retainment and falloff for a longer period another series of experiments was devised and carried out. The results of these are reported below and to some extent compared with those of the grazing experiments, which are summarized in one section of the report.

As shown by Chamberlain (1970), different types of environmental depositions on vegetation behave in ways similar to that of fallout and to experimental depositions of radioactive nuclides and labelled particles. Information on the behaviour of the latter, as well as absorption and transport coefficients, retention, transport via grazing animals etc. may thus be useful for estimation of the effects of other environmental depositions on pasture lands.

2. Materials and methods

2.1. Weather conditions

The weather conditions differ considerably between years and also between different parts of the country during the vegetation period. Of importance for the retention of depositions in vegetation is humidity and precipitation. Table 1 gives the mean relative humidity and mean number of days with precipitation during the period June - September for five places in different regions of the country and for three years, 1964, 1965 and 1972. These years represent "normal", "wet" and "dry" years respectively. Table 1 shows that the mean precipitation may differ more between years than between individual regions while differences in the mean relative humidity is due to the season. However, the number of days per month with precipitation does not vary much and indicates that the time when precipitation occurs and when grass cover is wet with dew or rain should be about the same as when the grass cover is dry.

The experimental simulation was intended to cover these three cases, which were identified as:

1. Depositions during or with precipitation
2. Depositions when the vegetation was wet with dew or after a precipitation
3. Deposition on dry vegetation

In practice the experimental work at the start of the experiment was considerable and went on in the field for several hours. Thus the depositions took place when the humidity of the air was closer that recorded at 14 h:s than that recorded at 08 h:s in the morning (cf. Tables 2 and 3).

If half of the precipitation occurs during the night it can be estimated that the probability for a randomly generated deposition as well as a continous deposition to occur in the three cases is in the order Case 3 > Case 2 > Case 1.

2.2. Experimental

In 1968-1970, 8 field experiments, Nos. 1-8, were carried out on established pasture land at an experimental station of the Swedish University of Agricultural Sciences. The absorption and retention of wet-deposited nuclides and wet- as well as dry-deposited particles were studied. The pasture grass consisted of about one half timothy (Phleum pratense and Phleum nodosum) and the other half of meadow foxtail (Alopecurus pratensis), meadow grass (Poa pratensis and others) and meadow fescue (Festuca pratensis, Festuca rubra).

In each experiment the area used was divided into large main plots, 60-100 m^2, for the primary treatments, i.e. deposition of the different materials used.

The main plots were split into smaller subplots for secondary treatments (pretreatments) and for replicates. Shelter belts were used to avoid border effects.

The plots were sampled at intervals by stripping with a grass mower, cutting the grass 2-3 cm above the soil surface. The fresh material from each strip was placed into a plastic sample container (vol. 1.5 l.) and excessive amounts into plastic bags and weighed. The dry matter content was determined.

2.3. Material deposited

The wet material, ions and particles, was deposited with droplets of a simulated precipitation of 0.1 mm. The droplets were produced by injection of the solution or the suspension into the airstream of a sprayer device. The dry material was deposited in calm weather with a device for spreading powder. The particles were thrown out mechanically by a motor-driven rotating blade wheel carried repeatedly at even speed along the rectangular main plots and across the intended stripping direction.

The labels and particle fractions used in the experiments are given below:

Expt.	Labelling material		Labelled particles	
No.	Nuclide	State	Fraction	$g\ m^{-2}$
1	$^{85}Sr^{++}$	In solution	-	-
		Adsorbed	40-63	
2	$^{137}Cs^{+}$, $^{59}Fe^{+++}$	In solution	-	-
		Adsorbed	40-63	1.0
		"	100-200	1.0
3	$^{137}Cs^{+}$, $^{59}Fe^{+++}$	In solution	-	-
		Adsorbed	40-63	1.0
		"	100-200	1.0
4	$^{140}La^{+++}$	Adsorbed	100-200	0.8
5-8	$^{141}Ce^{+++}$	"	40-63	0.4
	$^{46}Sc^{+++}$	"	63-100	0.4
	$^{140}La^{+++}$	"	100-200	0.8

The labels were tightly sorbed by the sand particles. Shaking 1 part of the dried material in 10 parts of distilled water for 2 hours at 20°C removed only a few per cent of adsorbed ^{46}Sc, ^{59}Fe, ^{140}La and ^{141}Ce. However, ^{137}Cs was much less extractable, ^{85}Sr somewhat more, than the three valent ions of the nuclides used. The low extractability of the nuclides adsorbed to the particle material used indicates a satisfactory function as labels. Transfer of activity in ionic form from particles intercepted in the grass cover to the surface of the leaves could have taken place only to a negligible extent.

2.4. Measurements

Depending on differences in water content the weight of the fresh grass samples in the plastic containers varied between 0.3 and 0.5 kg. For safe determination of the activity of the nuclides present in the samples, they were measured without delay with a duly calibrated 512 channel γ-spectrometer connected to a 4x4" NaI(Tl) crystal. To eliminate undue geometrical effects of activity unevenly distributed within the sample containers they were measured twice, once placed normally on the crystal and then again upside down. The mean of the two determinations was used as a representative value for the content of labels in the sample.

3. Results and discussion

3.1. Interception in the grass

Natural precipitation, depending on the amount, may more or less saturate the vegetation, i.e. wet the plant surfaces available.

After saturation continued precipitation results in a flow of water over the leaves. Due to ionic and adhesion forces, ions and particles in the rain water may be sorbed on the plant surfaces but afterwards are exposed to wash-off.

In experiments with artificial wet depositions the grass cover is seldom saturated with water because of the large amounts of water necessary. The representativity of the data obtained for the whole grass profile is therefore somewhat limited. Dry particles deposited in small amounts should be absorbed in proportion to the deposition, as they have only very small statistical chances to interfere with particles previously intercepted. Data obtained on the initial absorption of nuclides and particles that were wet-deposited (simulating Case a, cf. above) are given in Table 2 and that of particles deposited dry (simulating Case b and Case c) in Table 3. The absorption of deposited materials in the grass cover is given by $\underline{\mu}$ and $\underline{F}$-values. $\underline{\mu}$ denotes the absorption coefficient and $\underline{F}$ the fraction of deposited material found in the grass cover at the sampling operations.

$$F = \mu A$$

where $\underline{A}$ is the amount of grass dry matter per unit area in kg m^{-2}. μ is then expressed in m^{2}kg^{-1}.

3.1.1. Absorption of wet-deposited materials

As shown in Table 2, the absorption coefficients (μ-values) found varied between 1.9 and 3.4 for ionic nuclides, between 1.1 and 1.5 for the 40-63 μm and between 0.5 and 1.0 for the 100-200 μm particles. The recovery (F) varied within wider limits depending on the wide range in grass density. Grass density and humidity seem to have influenced the absorption coefficient. For the nuclides it was somewhat reduced with increased grass density in the same experiments. With increased relative mean humidity (cf. Expt. 2) there was a tendency towards increased absorption of all types of material deposited.

The effect of grass density on $\underline{\mu}$ for the nuclides may be a consequence of the fact that the artificial as well as natural precipitation of the size 0.1 mm is insufficient to saturate the whole grass cover. The effect of the grass density on $\underline{\mu}$ for the particle fractions was much less than for the nuclides. The range of $\underline{\mu}$ for each particle fraction was rather narrow. This indicates that $\underline{\mu}$ is a rather independant quality factor and that $\underline{F}$, the total retention of particles, mainly was a function of the plant leaf area as it could be observed by $\underline{A}$, the dry matter weight of grass per unit area ($F = \mu A$).

Regardless of humidity and grass density, the valence effect of the nuclides (cf. Morgan, 1959 and Kloke & Ludwig, 1962) in Expts. 2 and 3 became apparent. Thus $\underline{\mu}$ increased in the following order: $^{137}Cs^{+} < {}^{85}Sr^{++} < {}^{59}Fe^{+++}$, from 100 to 104-106 and to 109 respectively.

Expt. 4 was designed to be a link between wet and dry depositions of particles, 100-200 μm in size. The interception at wet deposition was somewhat higher than in Expts. 1 and 3, most probably due to the fact that dandelions (Taraxacum vulgare) covered 10-15 per cent of the area of the experimental field. The dandelions have largely horizontal leaves and if they dominate a pasture field (which may happen in the eastern part of the country during the early summer), a much higher interception and transport of deposited material might be expected than for a pure grass field.

In Expt. 4 wet-deposited particles were intercepted to a significantly higher degree by the grass than dry-deposited particles on wet grass. The latter were in turn significantly more retained than particles deposited dry on dry grass.

3.1.2. Absorption of dry-deposited particles

The initial absorption of dry-deposited particles by the pasture grass cover in Expts. 5-8 is given in Tab. 3. Three particle fractions, 40-63, 63-100 and 100-200 μm in size were deposited on wet grass, representing Case b, and on dry grass, representing Case c (cf. above). Deposition and 1st sampling took place between 9 and 11 o´clock in the morning, when the relative humidity was intermediary to the values for 08 and 14 hours, i.e. under rather dry weather conditions.

As expected, the absorption coefficient tended to be less the larger the particles were. The absorption of the middle fraction, 63-100 μm, when the grass cover was thoroughly wetted prior to deposition (by rain in Expt. 7) was similar to that of the 40-63 μm fraction. At superficial wetting (Expts. 5, 6 and 8) corresponding to dew, fog, etc. prior to deposition the absorption of the 63-100 μm fraction was about the same as that of the larger particles, 100-200 μm. Thorough wetting gave higher absorption coefficients as shown by Expt. 7. The absorption of 40-63 μm particles was significantly higher than that of 100-200 μm particles in both situations (cf. below).

Range and level for the absorption coefficients in Expts. 5-8.

Particle fraction, μm	μ, $m^2 kg^{-1}$		
	Dep. on wetted grass		Dep. on dry grass
	Expts. 5, 6 and 8	Expt. 7	Expts. 5, 6 and 8
40-63	0.61-0.85	1.03	0.31-0.57
63-100	0.42-0.65	1.00	0.15-0.28
100-200	0.39-0.56	0.65	0.16-0.26

However, the absorption of wet-deposited particles was still somewhat higher (cf. Table 2) than that found in Expt. 7 when the weather conditions were about the same.

Data from Expts. 5-8 thus indicate that for interception of an environmental dry deposition of particles during the daytime the absorption coefficient may show the ranges 0.3-1.0 for 40-63 µm, 0.2-1.0 for 63-100 µm and 0.2-0.7 for 100-200 µm particles. Giving the coefficient a relative value of 1.0 for depositions on grass wetted by rain it might be around 0.7 for depositions on grass wetted by dew or by fog and around 0.4 for depositions on dry grass.

Depositions at high humidity in the air during the night or early in the morning, etc. can be expected to give higher interception of particles than those experienced above under comparatively dry weather conditions.

3.2. Retention in the grass

3.2.1. Wet-deposited material

The weather conditions, growth of grass and the trends in retention of initially absorbed simulated fallout in Expts. 1 and 2 are given in Figs. 1-8.

In Expt. 1, carried out in the autumn, the growth showed a nearly linear function of time (Fig. 1). Also there was a clear decrease with time in ^{85}Sr activity and in particles found in the grass cover (Fig. 2). The absorption coefficient decreased almost exponentially, partly because of dilution by growth and partly because of a real loss of absorbed material from the grass cover. This loss was mainly caused by rains during a period of rich precipitation in the middle of August (cf. Fig. 1). Thus, the initial rapid decrease after deposition in retained material had been levelled out when 40 mm rain between the 3rd and 4th samplings reduced the amounts of retained ^{85}Sr by one-third and 40-63 µm particles by 40 per cent. The material initially absorbed thus obtained a half residence halftime of about 2.5 weeks.

In Expt. 2 the fate of a single deposition in spring was recorded up to the beginning of July (Figs. 5-8). Due to the growth of the grass a decrease with time in μ took place. The trend was the same for both low and high productive areas. Neither was the retention of ^{137}Cs much different from that of ^{59}Fe nor the 100-200 µm particles much different from 40-63 µm particles. The trend in Expt. 2 was different from that in Expt. 1, however. No rain showers washed the grass and for nearly one month there seemed to be no appreciable reduction in the fraction of nuclides retained (Fig. 7). On the contrary, between the 2nd and 3rd sampling there seemed to be a general rise in the fraction retained of both nuclides and particles. This, however, may be due either to the fact that material intercepted by the plant base tissues by growth was lifted above the cutting level in the grass profile or to comparatively small losses at the 3rd sampling. Thus the relative humidity was higher at the 3rd than for the 2nd sampling. Fig. 7 shows that the half residence time for the nuclides absorbed in the grass cover was longer than one month when there were no heavy rains and that ^{137}Cs seemed to be somewhat more resistant to falloff than ^{59}Fe. Wet-deposited particles (cf. Fig. 8), obtained under the same conditions a half residence time of at least three weeks.

3.2.2. Dry-deposited particles

The main events during the experimental periods of Expts. 5-8 are given in Figs. 9 and 10. Grass density and humidity are given in the upper sections of the figures, precipitation and absorption coefficient, m^2kg^{-1}, in the middle ones and the fraction of the deposit retained in the grass cover in the lower sections. In Expts. 5 and 6 the trend in $\underline{\mu}$ is very similar although there were differences in grass quality and density and in weather conditions. In both experiments the μ-value decreased between the 1st and 2nd sampling.

The moisture regime during the deposition determined the retention level during the observation period. It was consistently higher when deposition took place on grass thoroughly wetted by rain (Expt. 7), the absorption coefficient was kept on a higher level than in the others for all particle sizes during the observation periods. Miller (1967) obtained similar results and concluded that density of vegetation, leaf area, the hairiness of the leaves and the relative humidity were positively correlated with the amount of particles absorbed.

The particles initially absorbed suffered some falloff losses during the first days after deposition (cf. Figs. 9 and 10). However, then a stabilization took place. Both the μ-value as well as the amount recovered levelled out for at least up to the sixth day and in some cases, Expts. 5-7, up to the tenth or twelfth day after deposition.

During the observation periods in Expts. 5 and 6 several precipitations were registered (Fig. 9). None of them, however, seems to have had any appreciable effect after the 2nd sampling. This indicates that after a few days dry-deposited particles reach a "residual level" in the grass with most of the retained particles entrapped in leaf axils, where the half residence time may be comparatively long (cf. Russell & Possingham, 1961 and Witherspoon & Taylor, 1970). The "residual level" reached in Expts. 5 and 6 was characterized by the low retention, 0.4 m^2kg^{-1}. In Expt. 7 this level was higher and in Expt. 8 an increase in $\underline{\mu}$, parallel to the growth of the grass was observed.

3.3. Grazing experiments

The grazing experiments have been reported (Auraldsson et al., 1972; Ekman et al., 1973, a, 1973 b; Ekman et al., 1974; Greitz et al., 1974). Some of the data, however, can be analyzed statistically and used for elucidation of interception of particles in grass under different weather conditions, generally more favourable for retention than in the experiments above. The data are outlined in Tables 3 and 4 and represent experiments carried out in 1970-72 with four different types of depositions simulating long range and near in fallouts.

a. wet deposition of ~1 μm labelled particles
b. "- 40-63 "-
c. "- 100-200 "-
d. dry deposition of 100-200 "-

Half an hour after deposition early in the morning the field was sampled for estimation of grass yield and the interception of particles in the grass. The herd grazed from 9 o'clock for 6-7 hours. Then the field was sampled again for estimation of grass and particles left for the next days' grazing.

The experimental conditions varied considerably (cf. Tables 4 and 5) and so a statistical analysis was applied to study the influence of parameters identified above on the interception and transport of the particles in a-d (Tables 6 and 7). The analysis (Table 6) showed that the absorption coefficient, the fraction of deposition intercepted in the experimental grass field, as well as that ingested by the grazing herd, were correlated negatively with the temperature and positively with the relative humidity. In addition the fraction ingested was negatively influenced by wind speed. According to radiometry of the faeces the fraction of the intercepted material that was ingested by the grazing herd was positively correlated with the estimates of grass consumed and negatively with the wind speed.

Fig. 11, based on the regression analyses (Table 7), shows how the percentage of material retained in grass at sampling depends on grass density and on humidity at deposition. The retention as well as the regression coefficients are smaller the larger the particles are. Also the absorption coefficient, which describes the retention, depends on the humidity but not on other parameters observed. This dependancy (Fig. 12) implies that the interception and retention of deposited particles may differ by a factor of 2-3 between occasions during days and nights and between dry and wet weather conditions as was the case in the experiments described in Section 3.1. above. The percentage of deposition ingested by the grazing herd is strongly correlated with the percentage intercepted by the grass cover, and to some extent the fraction of particles lost during grazing seems to be strongly correlated with grazing intensity and wind speed (Table 7). The size of the losses of particles from grass to the ground during a day of grazing are indicated by the ratio between the absorption coefficients obtained from the samplings after and before the start of grazing. The mean values and the standard error for each group of experiments were:

a. 0.58 ± 0.17 (n = 6)
b. 0.53 ± 0.18 (n = 7)
c. 0.46 ± 0.21 (n = 17)
d. 0.38 ± 0.20 (n = 7)

The ratios indicate that the grazing and other factors together reduced the retention in the remaining grass by 40-60 per cent. Consequently the grass consumed by the cows during the day could contain, per unit weight, from about 40±20 up to 100 per cent of the deposition retained in grass per unit area according to the absorption coefficient found in the morning. As the humidity changes gradually a fair estimate of the mean absorption coefficient for the grass consumed would be 70-80 per cent of that in the morning.

In some of the grazing experiments a higher interception of particles in the grass cover and a higher absorption coefficient were obtained than in Expts. 1-8. The difference is understood when the considerable difference in the relative humidity of the air is considered. In several of the grazing experiments the depositions took place in high humidity conditions, which represent conditions during nights and early mornings. In Expts. 1-8 the depositions took place during the day, in Expts. 1-6, and 8 in dry, stabilized, weather conditions when the relative humidity of the air was low, around 40 per cent. Thus, when the deposition takes place during the night, or when the relative humidity is high (~100 per cent), the interception and the μ-value may be considerably higher than under dry weather conditions.

The ingestion of contaminants by grazing animals seems to be strongly correlated with the amount intercepted by the grass (cf. Tables 6 and 7) while losses and falloff of particles from the grass cover depends on grazing intensity and wind speed. A reasonable mean retention on the grass consumed during the day should be ~75 per cent of that in the morning. However, that fraction of the deposition, which is ingested by the grazing herd depends both on the fraction retained and on the fraction of the grass cover consumed as shown by Fig. 13.

4. Conclusions

Interception of deposited material in grass covers may be described by the formula $F = \mu A$, where F is the fraction retained per unit area, μ is the absorption coefficient, $m^2 kg^{-1}$, and A is the amount of grass dry matter per unit area, kg m^{-2}, and an expression also for the grass leaf area. Within rather narrow limits μ depends on the quality of the grass and on the weather conditions.

Experimentally (Expts. 1-8), μ was found to be significantly higher for wet than for dry material deposited during daytime. In the former case the ranges found were 1.9-3.4 for ionic nuclides, 1.1-1.5 for 40-63 μm and 0.5-1.0 for 100-200 μm particles. In the latter case the ranges were 0.3-0.6 for 40-63 μm and 0.15-0.3 for 100-200 μm particles when deposited on dry grass but 0.6-1.0 and 0.4-0.7 respectively when deposited on grass wetted by rain or simulated precipitations.

Depending on the weather conditions the half residence time for initially intercepted wet deposits varied between 2.5 and 5 weeks. The lower figure may be valid for rainy periods, the higher for periods with little or no precipitation. Corresponding half residence time for dry deposited material may be 1-3 weeks.

After a period of more or less intense falloff the particles reach a "residence level" in the grass characterized by low μ-values (0.1-0.5 m^2kg^{-1}). The particles seem resistant to continued falloff.

Consequently, when single depositions of particles have occurred the length of the time period needed for a considerable reduction of particles retained in the grass depends on the moisture conditions at and after deposition. The hazard of the "residual level" has to be considered before allowing contaminated pasture land to be grazed.

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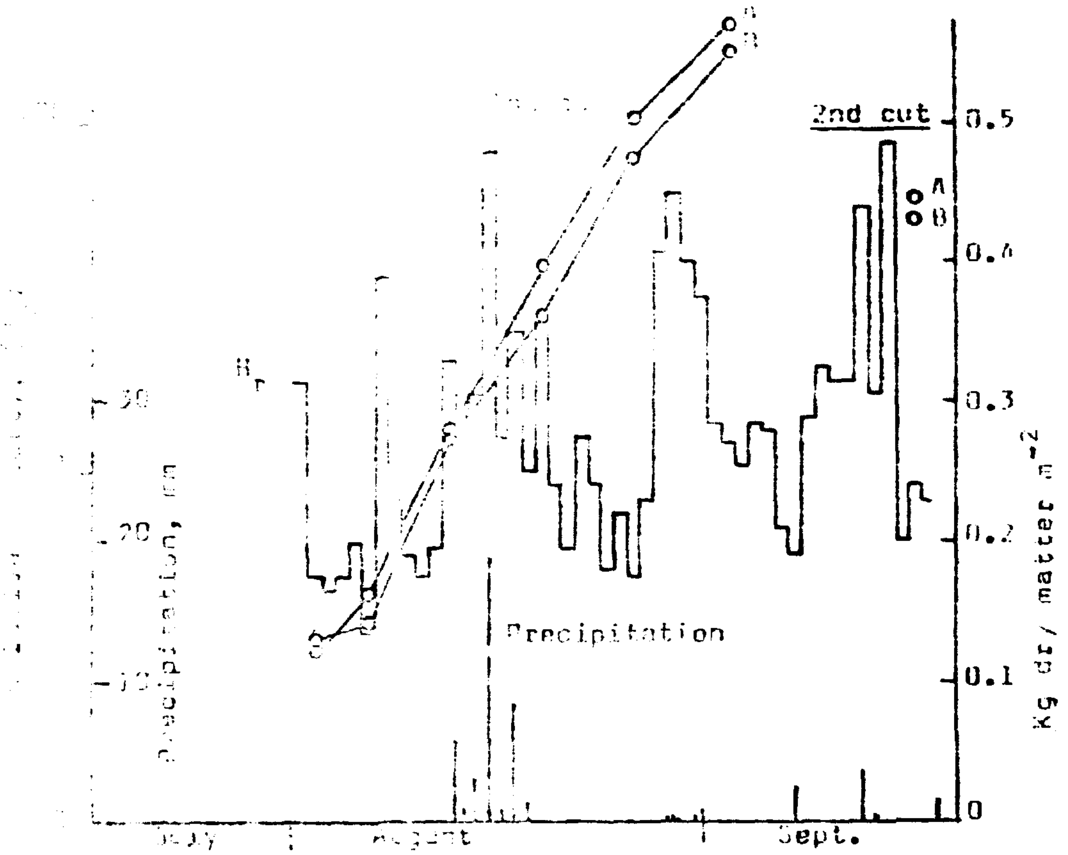
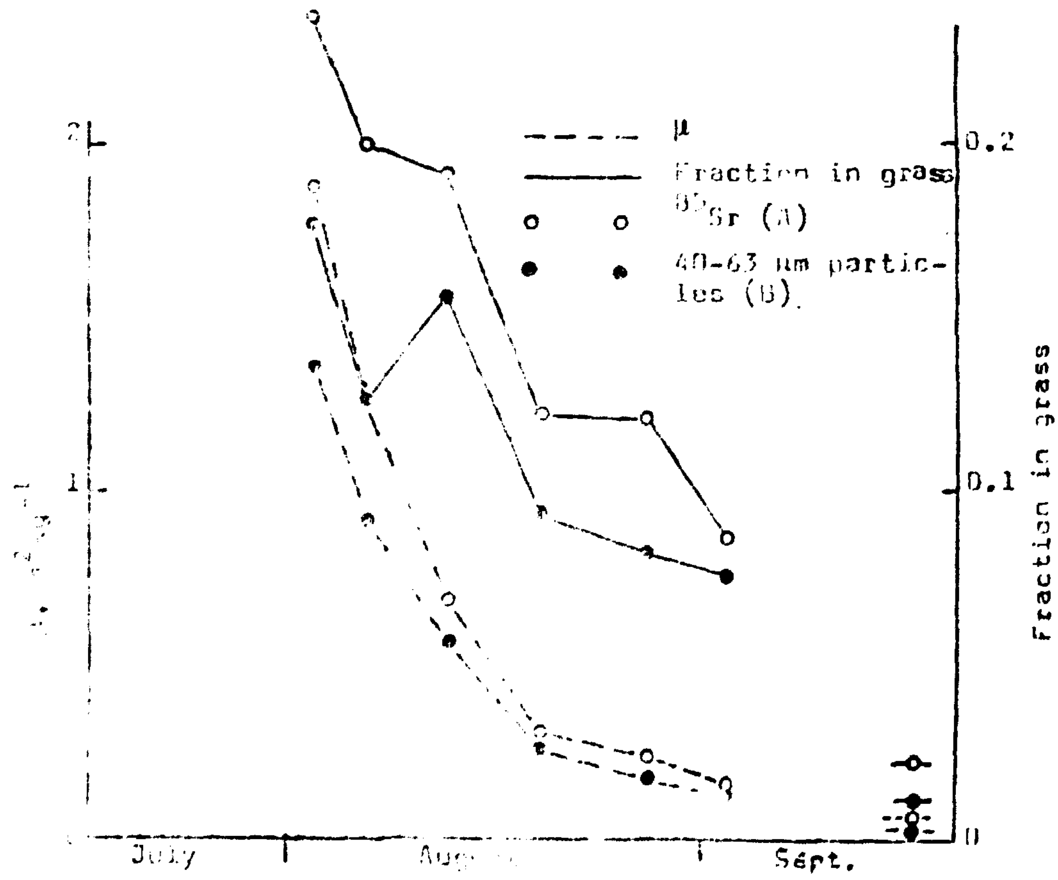


Fig. 1. Development of pasture grass, relative humidity at 14 hour and precipitation in Expt. 1.



[illegible] and [illegible] in retention of ^{85}Sr and 40-63 µm particles [illegible] in Expt. 1.

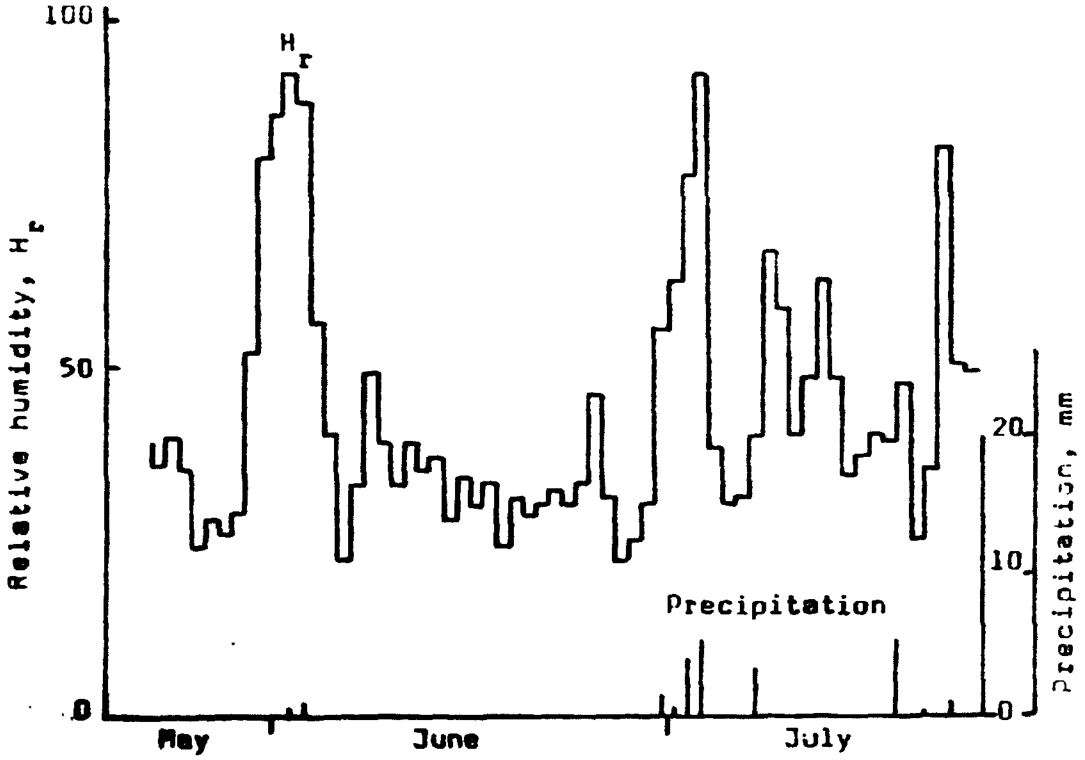


Fig. 3. Relative humidity at 14 hour, and precipitation during the experimental period in 1969.

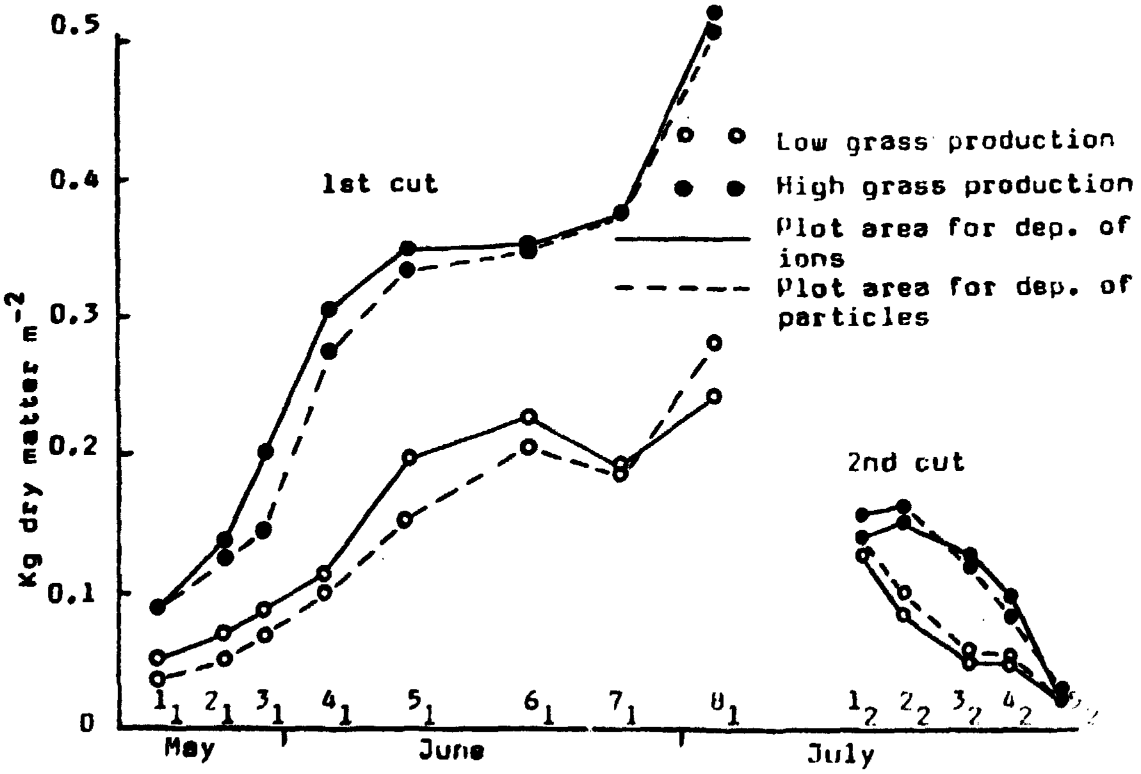


Fig. 4. Development of the pasture grass in Expt. 2. 1969.

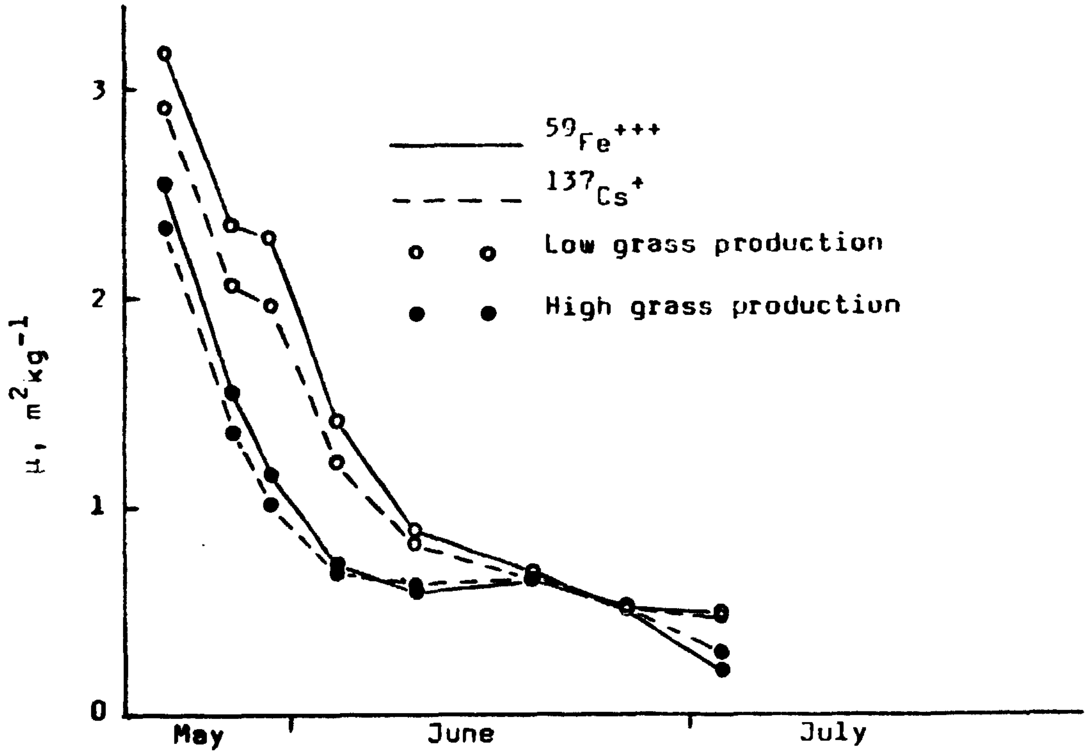


Fig. 5. Change in the concentration of absorbed nuclides by growth and fall off in Expt. 2.

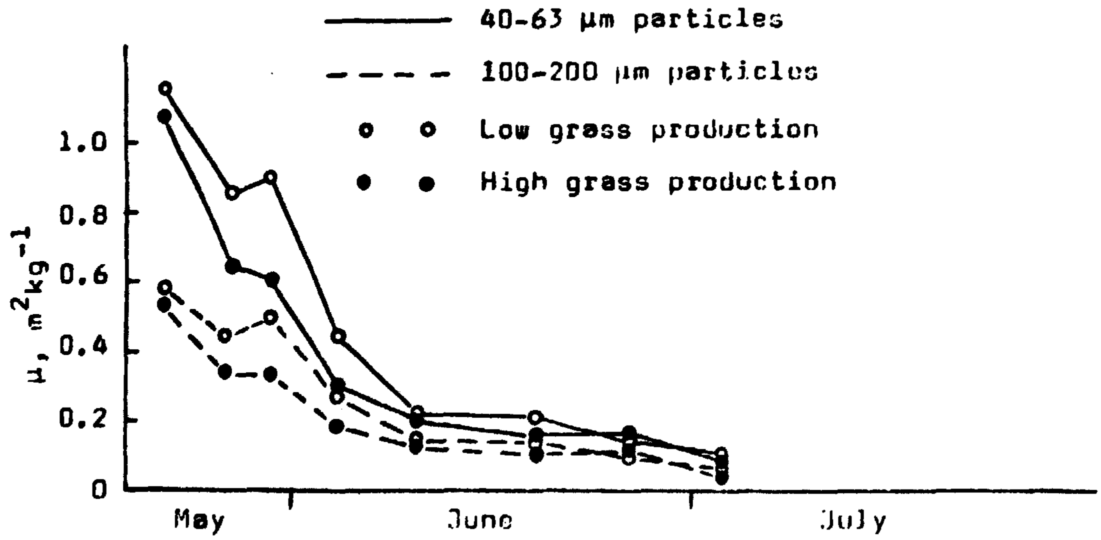


Fig. 6. Change in the concentration of absorbed particles by growth and fall off in Expt. 2.

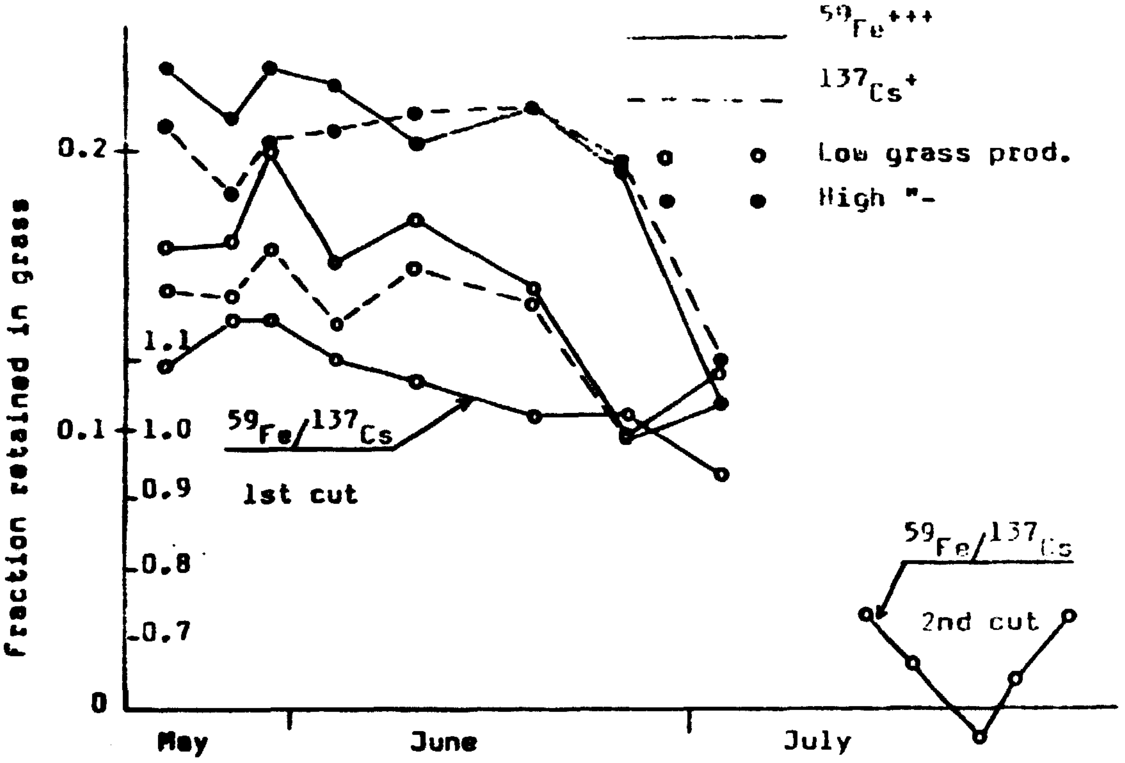


Fig. 7. Retention in grass of absorbed nuclides in Expt. 2.

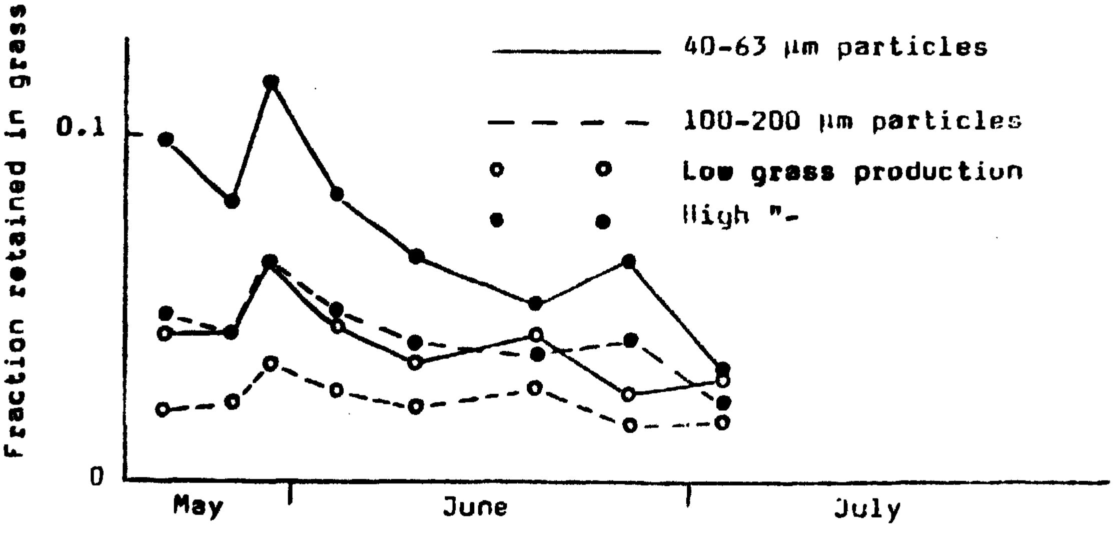


Fig. 8. Retention in grass of absorbed particles in Expt. 2.

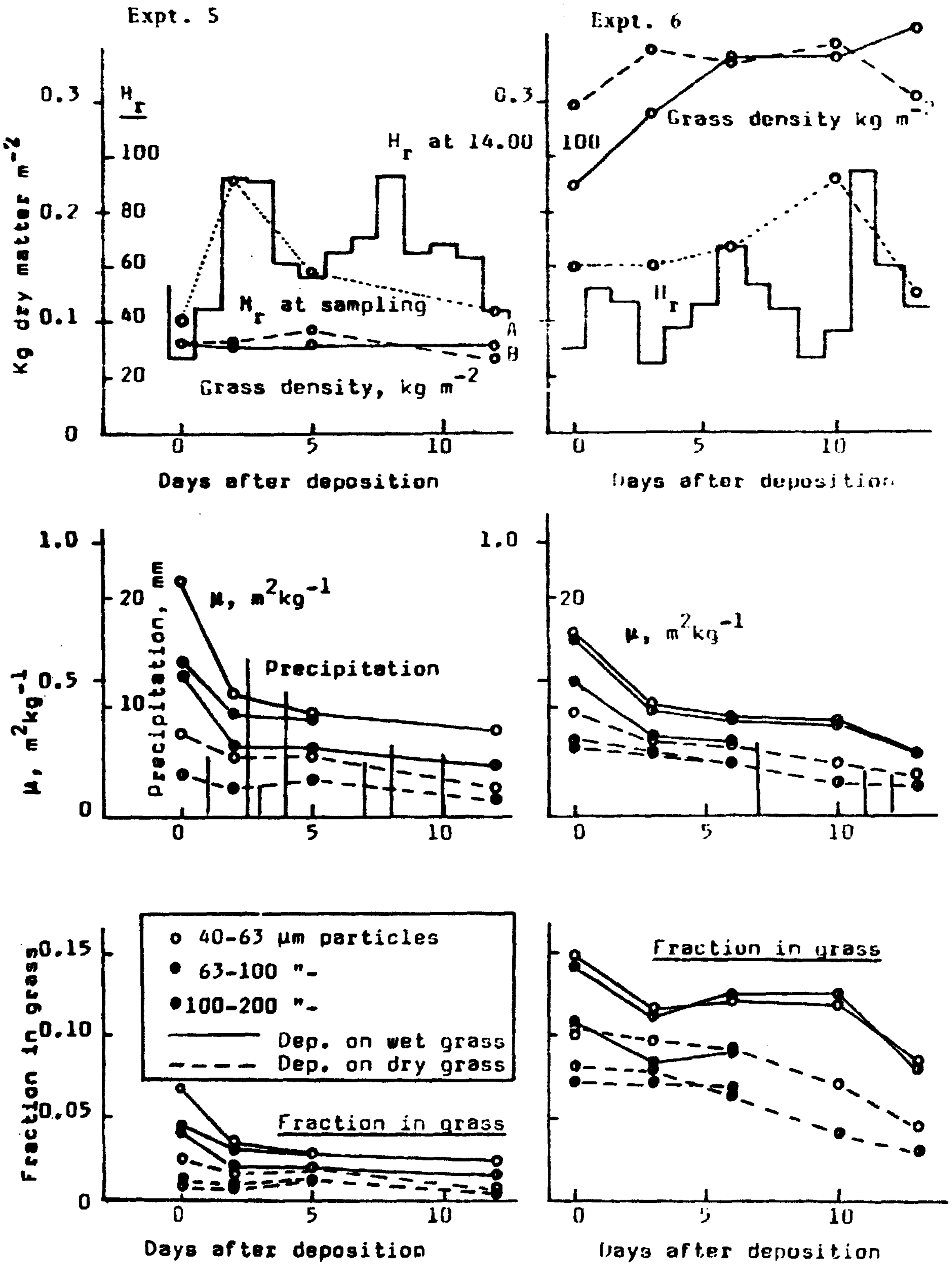


Fig. 9. Grass density, humidity, precipitation and trend in retention of particles deposited in Expts. 5 and 6.

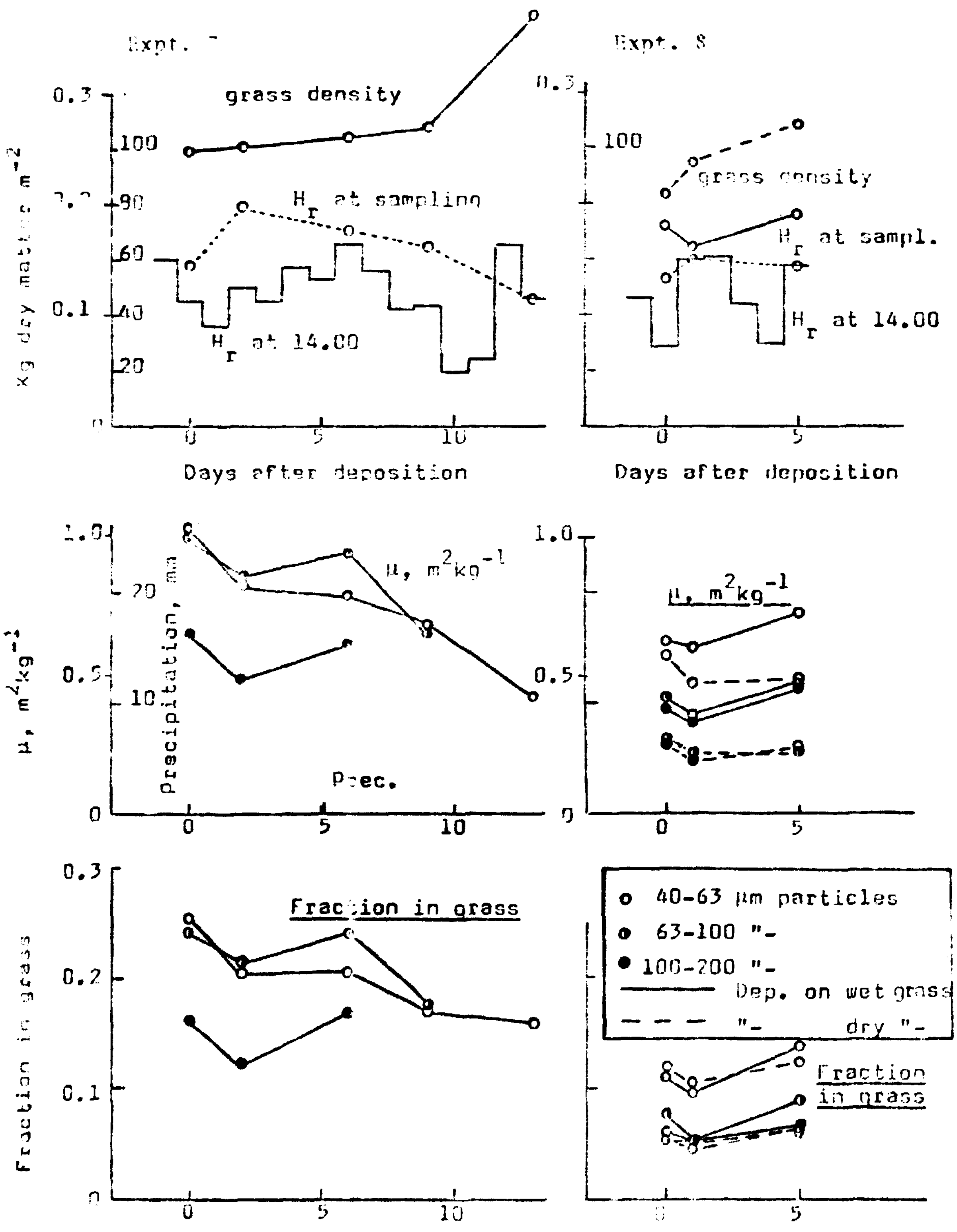


Fig. 10. Grass density, humidity, precipitation and trend in retention of particles deposited in Expts. 7 and 8.

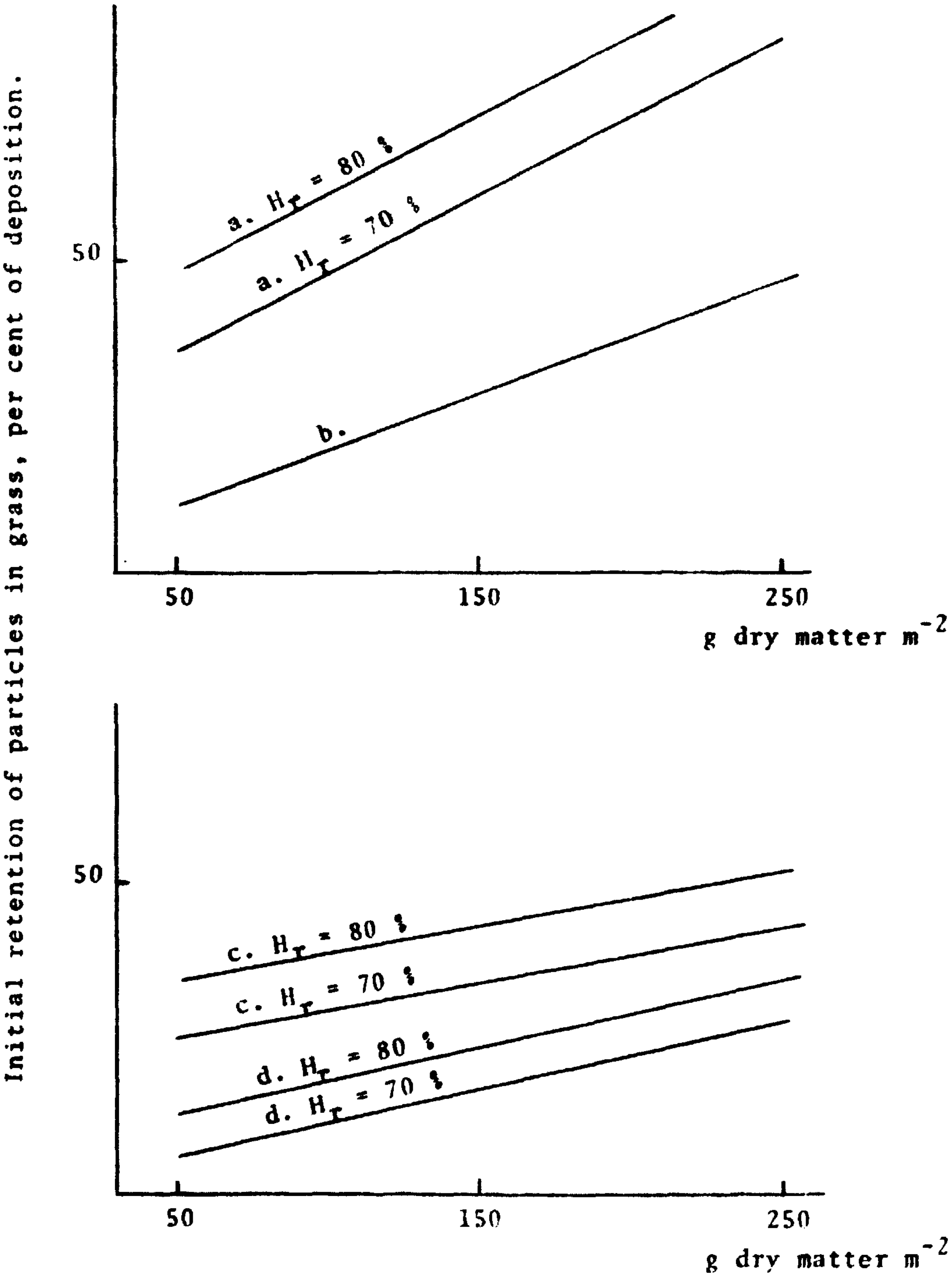


Fig. 11. Influence of grass density (X_1) at different relative humidity on the initial retention of particles in the grass cover (cf. Table 7).

a = Wet deposited ~1 µm particles
b = "- -40-63 "-
c = "- 100-200 "-
d = Dry deposited 100-200 "-

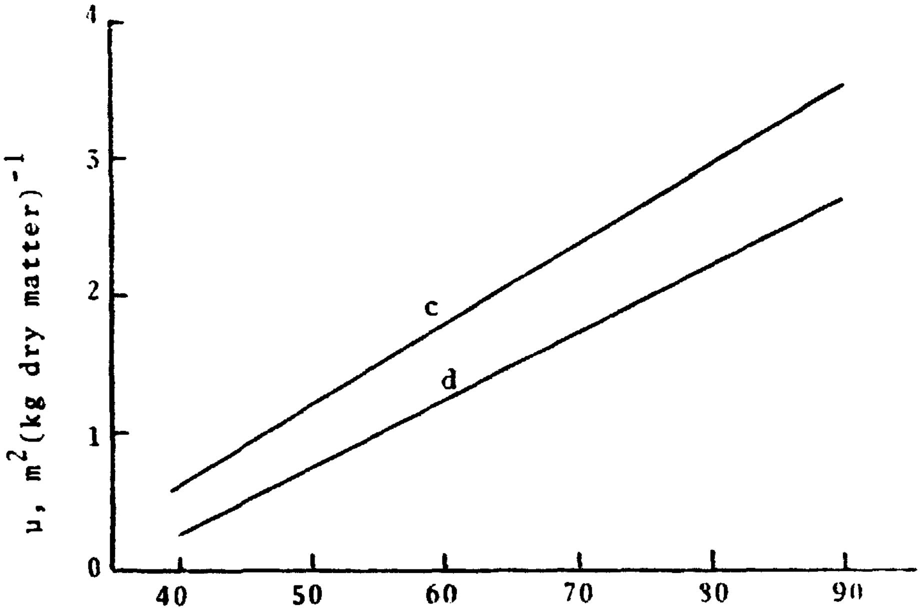


Fig. 12. Influence of relative humidity on the absorption coeff. μ ($m^2 kg^{-1}$) for wet (c) and dry (d) deposited 100-200 μm particles (cf. Table 7).

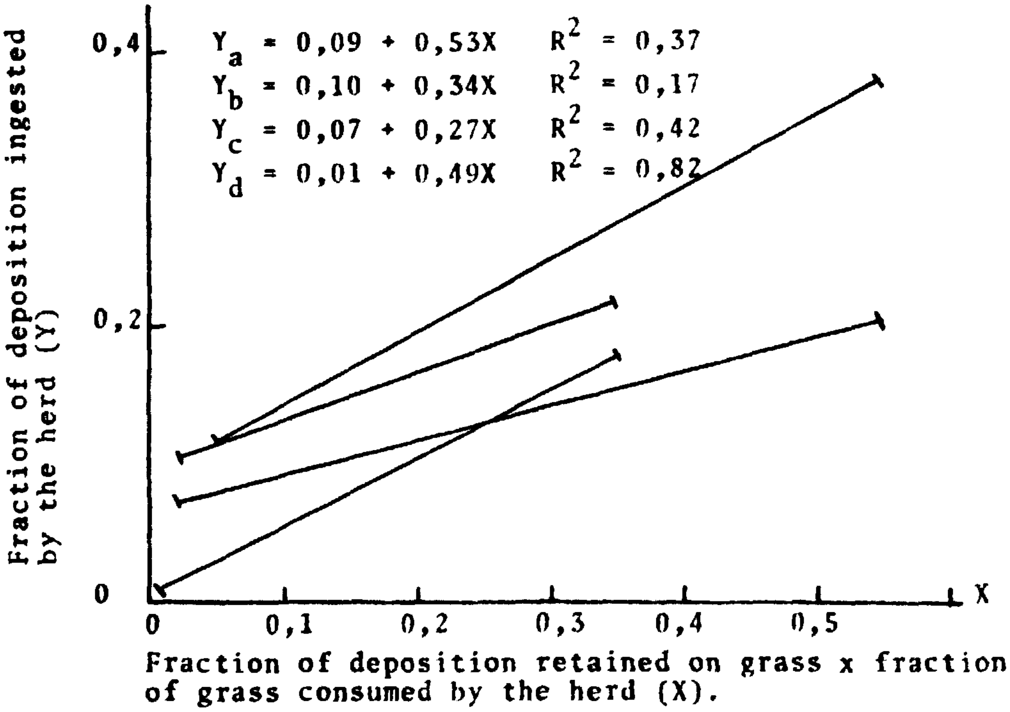


Fig. 13. Ingestion of particles by the grazing herd as explained by data for the fraction of deposition available for ingestion in grass consumed. Losses during grazing should explain a recovery, Y/X, lower than 1 (a, b, c, d refer to type of expt. cf. Fig. 11).

Table 1. Mean humidity and mean number of precipitation days per month in June - September at five places in three years. (Based on data from SMHI, 1966, 1968, 1973).

		Mean relative humidity at			Number of days per month with precipitations		
Place	Year	07	13	19	≥ 0.1 mm	≥ 1 mm	≥ 5 mm
Lund	1964	87	62	67	15	12	4
	1965	89	63	70	13	10	5
	1972	85	62	68	11	8	3
Gothenburg	1964	82	65	68	14	11	5
	1965	86	71	73	17	14	5
	1972	81	61	65	14	10	4
Stockholm	1964	80	61	65	16	7	3
	1965	83	63	72	19	11	6
	1972	78	58	67	12	7	2
Örebro	1964	83	62	69	15	11	3
	1965	82	62	71	18	13	5
	1972	81	59	66	11	8	3
Härnösand	1964	80	61	67	15	10	5
	1965	85	67	73	14	9	5
	1972	87	69	74	12	7	4
Mean over seasons and places	1964	82	62	67	15	10	4
	1965	85	65	72	16	11	5
	1972	82	62	68	12	8	3
Mean over years and places	June	79	60	64	13	9	4
	July	80	63	67	15	11	5
	Aug.	84	62	68	13	9	3
	Sept.	88	67	76	15	9	4

Table 2. Initial absorption of wet deposited nuclides and silica sand particles by the pasture grass in Expts. 1 (1968) and 2-4 (1969).

Date of dep. and 1st sampl.	Humidity, (H_r)		Grass dry matter, kg m^{-2}	Material deposited		μ, m^{2}kg^{-1}	Fraction of dep. recovered
	Hour	%		Solution, nuclide	Suspension, particle size: µm		
0802	08	60	0.126	^{85}Sr	-	1.88	0.24
(Expt. 1)	14	35	0.130	-	40-63	1.36	0.18
0522	08	44	0.051	^{59}Fe	-	3.17	0.16
(Expt. 2)	14	39	(LP_A)	^{137}Cs	-	2.91	0.15
			0.089	^{59}Fe	-	2.57	0.23
			(HP_A)	^{137}Cs	-	2.35	0.21
			0.036	-	40-63	1.17	0.04
			(LP_B)	-	100-200	0.58	0.02
			0.090	-	40-63	1.08	0.10
			(HP_B)		100-200	0.54	0.05
0710	08	60	0.138	^{85}Sr	-	3.36	0.46
	14	40	(LP_A)	^{137}Cs	-	3.16	0.43
(Expt. 3)			0.193	^{85}Sr	-	2.50	0.48
			(HP_A)	^{137}Cs	-	2.41	0.47
			0.178		40-63	1.52	0.27
			(LP_B)		100-200	1.01	0.18
			0.186		40-63	1.46	0.27
			(HP_B)		100-200	0.91	0.17
0812	08	69	0.164 d)		100-200 a)	1.66	0.27
(Expt. 4)	14	37	0.159 d)		"- b)	0.95	0.15
			0.162 d)		"- c)	0.58	0.09
Range	08	44-69	0.05-0.19	Nuclides	-	1.9-3.4	0.15-0.46
(Expts. 1-3)	14	35-40	0.04-0.19		40-63	1.1-1.5	0.04-0.27
					100-200	0.5-1.0	0.02-0.18

a) Wet deposition

b) Dry deposition on wet grass

c) Dry deposition on dry grass

d) The grass cover was mixed up with 10-20 % dandelions (Taraxacum vulgare) so the result may not be representative for 100 % grass

LP = Low Production HP = High Production due to N-fertilization

Table 3. Initial absorption of experimentally dry deposited particles by prewetted (wet) and dry pasture grass, Expts. 5-8. 1970.

Date of dep. and 1st sampl.	Relative humidity		Grass conditions		Absorption of particles		
	Hour	%	Dry m, kg m^{-2}	Treatment	Size, μm	μ, m^{2}kg^{-1}	Fraction retained
0718	08	51	0.081	wet	40-63	0.85	0.068
(Expt. 5)	14	27			63-100	0.52	0.042
					100-200	0.56	0.045
			0.080	dry	40-63	0.31	0.025
					63-100	0.15	0.011
					100-200	0.16	0.012
0730	08	78	0.222	wet	40-63	0.67	0.148
(Expt. 6)	14	44			63-100	0.65	0.143
					100-200	0.49	0.108
			0.321		40-63	0.66	0.212
					100-200	0.47	0.149
			0.295	dry	40-63	0.38	0.112
					63-100	0.28	0.082
					100-200	0.26	0.076
			0.188		40-63	0.37	0.070
					100-200	0.22	0.042
0812	08	71	0.249	wet	40-63	1.03	0.256
(Expt.7)	14	45		by rain	63-100	1.00	0.249
					100-200	0.65	0.162
0826	08	76	0.181	wet	40-63	0.61	0.110
(Expt. 8)	14	29			63-100	0.42	0.075
					100-200	0.39	0.070
			0.209	dry	40-63	0.57	0.119
					63-100	0.27	0.056
					100-200	0.26	0.055
Expts. 5, 6, 8				wet	40-63	0.70	
					63-100	0.53	
					100-200	0.48	
				dry	40-63	0.41	
					63-100	0.23	
					100-200	0.23	

Table 4. Weather conditions during the field experiments in 1970-72. Range and mean for temperature, T°C, relative humidity, H_r, and wind speed, m s^{-1}.

Expt. code	Hour	T, °C		H_r, %		Wind speed, m s^{-1}	
		Range	**Mean**	**Range**	**Mean**	**Range**	**Mean**
a	08	10,4-23,0	16,2	59-92	72	0 - 4,3	3,2
	14	13,1-28,0	22,1	37-75	50	1,2- 6,3	4,2
b	08	10,7-18,1	14,8	46,99	68	1,3- 7,3	3,2
	14	15,3-22,7	19,3	26-74	35	2,9- 6,6	4,8
c	08	10,4-23,0	14,5	46-99	73	0 - 7,3	3,5
	14	13,1-28,0	21,1	26-75	47	1,2-11,4	5,3
d	08	5,3-21,4	14,3	53-94	75	1,7- 6,0	3,7
	14	10,7-26,6	19,8	24-67	50	1,0-11,4	6,2

Table 5, Grass yields, initial retention by the grass and ingestion of particles by the grazing herd in the field experiments, range and mean values.

Expt. code	**Type of data**	**Grass yield, g m^{-2}**	Initial retention		Ingested by cows, per cent of	
			% of deposition	$m^2 kg^{-1}$	deposition	retention
a	Range	31-249	11,5-93,9	2,7-6,9	10,1-48,0	24,9-100
n=10	Mean	136	60,3	4,9	24,8	44,6
b	Range	72-246	9,7-50,1	1,[illegible]-2,4	4,1-30,2	14,1-100
n=7	Mean	177	33,6	1,9	14,2	44,6
c	Range	55-249	6,8-77,6	1,0-5,3	2,8-24,5	16,1-100
n=22	Mean	142	36,2	2,7	11,7	29,3
d	Range	46-317	0,4-57,9	0,1-3,6	0,8-18,0	7,1-100
n=10	Mean	156	23,1	1,7	6,7	39,6

Table 6. Correlation between deposition retained in grass, μ, deposition ingested by the herd and characteristics for weather conditions on the first grazing day.

Dependant variable	Expt. code	n	Correlation coeff. for independant variables Humidity (r) at 08.00	 mean a)	 Temperature, °C at 08.00	 mean a)	 Wind speed, mean a)	 Grass yield
Y_1, per cent of	a	10	-		-0,67	-0,53		0,77
deposition	b	7	0,57	0,53	-	-0,28		0,77
retained in	c	22	0,54	0,44	-0,55	-0,54		0,33
grass	d	10	0,58	0,64	-0,46	-0,39		0,55
Y_2, μ,	a	10	0,47	0,29		-		-0,52
m^2kg^{-1}	b	7	0,30	0,12		-		-0,15
	c	22	0,52	0,46		-0,44		-0,16
	d	10	0,72	0,76		-0,26		-0,20
								Y_1
Y_3, per cent of	a	10	-	-	-0,64	-0,50	-0,75	0,74
deposition	b	7	-	0,84	-	-	-0,66	0,28
ingested	c	22	-	0,50	-0,55	-0,56	-	0,65
with grass	d	10	-	0,70	-0,39	0,31	-	0,74
				Removal of grass				
Y_4, fraction of Y_1	a	10		0,61			-	
ingested	b	7		0,48			-0,93	
with grass	c	22		0,59			-0,68	
	d	10		0,79			-0,44	

a) Mean value of the records obtained at 08 and 14 hours

Table 7. Linear regression of grass yield, g d.m.m^{-2}, X_1, per cent relative humidity at 08 hour (H_{r08}) X_2, and H_r mean (H_{r08} + H_{r14})/2, X_3, fraction of available grass ingested, X_4, and mean wind speed during grazing, X_5, on the dependant variables Y_1-Y_4.

Dependant variable	Expt. code	Intercept	Indep. variable	Regr. coeff.	T-value	Partial corr. coeff.	R^2
Y_1, (per cent of dep. retained in grass)	a	-62,5	X_1	0,25	4,79	0,88	
			X_2	1,22	2,51	0,69	0,78
	b	1,6	X_1	0,18	2,74	0,77	0,60
	c	-40,3	X_1	0,09	1,63	0,35	
			X_2	0,87	2,89	0,55	0,38
	d	-45,2	X_1	0,11	2,12	0,62	
			X_2	0,65	2,22	0,64	0,59
Y_2, (µ, m^2kg^{-1})	c	-1,70	X_2	0,058	2,73	0,52	0,27
	d	-2,09	X_3	0,053	3,28	0,76	0,57
Y_3(per cent of dep. ingested at grazing No. 1)	a	-14,9	Y_1	0,46	3,93	0,83	
			X_4	21,41	1,86	0,58	0,69
	b	-14,4	Y_1	-0,23	-2,08	-0,76	
			X_4	19,58	3,18	0,88	
			X_3	0,55	6,18	0,96	0,94
	c	-2,52	Y_1	0,17	3,18	0,60	
			X_4	5,14	1,25	0,28	
			X_3	0,10	1,10	0,25	0,52
	d	-12,55	Y_1	0,18	2,56	0,72	
			X_4	7,58	2,35	0,69	
			X_3	0,20	1,91	0,62	0,81
Y_4, (fall-off during the first day of grazing)	a	0,04	X_4	0,44	4,04	0,82	0,67
	b	-0,26	X_4	0,98	10,18	0,98	
			X_5	0,10	7,67	0,98	0,97
	c	0,23	X_4	0,41	3,67	0,64	
			X_5	0,05	2,35	0,47	0,43

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33	1976	Eriksson, Ake, Studies on the transport of fission products through food chains. IV. On the relationship between ^{137}Cs in fallout and ^{137}Cs in grass and milk.
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