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Report to RSPB

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BASE-LINE SOIL STUDIES OF THE HEATHLAND RESTORATION SCHEME AT MINSMERE

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1. INTRODUCTION

RSPB have bought 158 ha (11 fields) of arable land as an extension to their Minsmere reserve on the Suffolk coast. The ultimate aim for this area is to restore it to heathland, effectively creating a large extension to the Westleton-Dunwich heathland complex. One potential problem which may hinder heathland recreation is that of the high residual fertility on this arable land. Thus, a major objective of management for the first few years is to reduce soil fertility. The scheme that has been adopted was used by NCC at Roper's Heath in Breckland (reported in Marrs, 1985) where cereal cropping was used in an attempt to deplete nutrients. The first cereal crop under the scheme (Spring Barley) was sown in February 1990 and was fertilized only with inorganic nitrogen fertilizer (rate = 48 -64 kg N ha^{-1} as urea). The nitrogen fertilizer was added to increase crop production, therefore increasing the uptake of other elements, and hence increasing the nutrient offtake. Whilst, this scheme should work in practice, it must be viewed as experimental, and in particular we have very little information about the likely rates of depletion. Depletion rates are essential, because we need to be able to predict when it is realistic to stop the cereal cropping and start heathland restoration. If the soil fertility is too high, either vegetation communities dominated by ruderals and productive species will result, or there will be a rapid succession through heathland toward bracken or scrub dominated late-succesional communities.

Here we report the results of a base-line soil study aimed at determining initial soil chemical properties against which the success of the scheme can be assessed in future years.

2. METHODS

2.1 Study sites and soil sampling

Base-line soil sampling for the study was done on 1 May 1990; 3 types of area was sampled:

(a) Arable fields included in the 'Nutrient Depletion Scheme' - 12 fields.

(b) Areas of semi-natural Calluna heathland - 3 areas.

(c) Areas of old-field succession - 2 areas, one recent (1 year) and 1 older (n years).

The distribution of the individual fields sampled is shown in Fig. 1, and the types of vegetation in Fig. 2. The arable fields were for convenience considered as two separate blocks - north and south (Figs. 1,2; Table 1).

Sample numbers were weighted according to the area of the field (Table 1). At each field a random walk was done to locate sampling points; at each point a soil sample (0 - 10 cm) depth was taken with a trowel in a standard way. This procedure was used, because the soil was very dry as a result of the extended drought and the large number of stones in the surface layers, made the use of a soil auger very difficult.

2.2 Analysis

2.2.1

Soils were air-dried and sieved through a 2 mm mesh and the following measurements made using methods outlined in Allen et al. (1974):

(a) Soil pH in a 1:2.5 slurry of soil with distilled water.

(b) Air:oven dry weight ratio and the loss-on-ignition.

(c) Exchangeable cations (10 g extracted in 50 ml 1M ammonium acetate), with Ca and Mg determined by atomic absorption spectrophotometry and K by emission spectrophotometry.

(d) Extractable P (10 g extracted in 50 ml Truog's reagent) with P being determined colorimetrically using the ammonium molybdate-stannous chloride method.

(e) Extractable and mineralizable N (10 g extracted in 40 ml 2M KCl) both before and after a 14 day incubation. Total mineral N was determined in the extracts using standard distillation and titration techniques.

(f) Phosphorus adsorption maximum (sensu Chapman, Rose & Basanta, 1989) (1g in 20 ml of different aqueous P solutions ranging from 0.5 - 500 μg P ml^{-1}. This measure was done on pooled soil samples from each field.

All assessments of element concentrations were expressed on an oven dry weight basis.

Table 1. The number of soil samples taken from each field.

Field Number	Vegetation Description	Arable block	Number of samples
1	Heath	-	12
3	Heath	-	12
3b	Bracken on Heath	-	4
6	Old field (old)	North	12
9	Heath	-	12
21	Arable	North	8
51	Old field (new)	-	10
60	Arable	North	12
61	Arable	North	10
62	Arable	North	12
63	Arable	North	10
64	Arable	North	10
65	Arable	North	12
66	Arable	South	10
67	Arable	South	12
68	Arable	South	10
69	Arable	South	10

3. RESULTS

The results for the soil parameters can be divided into 3 broad categories:

(a) where values for arable soils were greater than heathland soils,

(b) where values for heathland soils were greater than arable soils, and

(c) where values did not differ between the two main soil types studied here.

Each of these categories will presented in turn:

3.1 Arable > Heathland

Soil pH was greater in all arable soils (pH 5-6) than in heathlands soil where values were between 3-3.5 (Fig. 3). The new old-field had a pH similar to the arable soils (pH = 4.8) but the older one was close to the heathland soils (pH = 3.5).

Exchangeable Ca, as expected, showed a close correlation with the pH values, with arable soils fluctuating between 350 - 700 µg Ca g^{-1} and the heathland soils being < 160 µg Ca g^{-1} (Fig. 4). There was some indication that the Ca levels were lower and less variable on the southern group of fields than the northern ones.

Extractable P was consistently higher in the arable fields ranging from 75 - 150 µg P g^{-1} compared to < 50 µg P g^{-1} in heathlands (Fig. 5). Three of the arable fields in the southern group had particularly high concentrations.

The newer old-field succession had values for pH, exchangeable Ca and extractable P in a similar range to the arable fields, and the older one was similar to the semi-natural heathlands (Figs. 3,4,5). There was no apparent difference in any of these three properties between the Calluna dominated heathlands and the one where bracken had invaded (Figs. 3,4,5).

3.2 Heathland > Arable

Loss-on-ignition (Fig. 6) and mineralizable N (Fig. 7) was greater in the heathland compared to arable soils.

All arable soils had LOI values < 5% whereas the heathland soils were in the range 8 - 17 %. Both old fields had intermediate values.

Mineralizable N values showed a great deal of variability in all soils but arable soils ranged from a negative value at one site (net N immobilization) to rates of c. 75 µg N g^{-1} $14d^{-1}$. Values for heathland soils were much more variable but ranged from low values (25 - 60 µg N g^{-1} $14d^{-1}$) at two fields to 300 µg N g^{-1} $14d^{-1}$ in field 3. The newer old-field had a negative mineralization rate but the older had rates similar to field 3 where the highest rates were found. The bracken patch on field 3 had a much lower mineralization rate than the heathland area sampled nearby.

3.3 Heathland ≈ Arable

Values for exchangeable K and Mg and extractable N showed differences between individual fields (Figs. 8, 9, 10), but no significant trend. Values for these elements were in the ranges 20 - 50 µg K g^{-1}, 9 - 40 µg Mg g^{-1} and 14 - 40 µg N g^{-1}.

P adsorption showed no difference between soils and all came into the > 700 µg P g^{-1} class of Chapman, Rose & Basanta (1989). Chapman, Rose & Basanta (1989) classified heathland soils into three categories on the basis of their maximum phosphorus adsorption; < 70 µg P g^{-1}; 70 - 700 µg P g^{-1}; > 700 µg P g^{-1}. Basically, the higher the class the greater the probability that succession to woodland will occur.

3.4 Relationship between Minsmere 1990 data and other East Anglian Heaths

The results obtained for heathland soils in this study are higher than values obtained for heathland soils in Breckland, but are similar to values supporting semi-natural heathland vegetation (Table 2).

Table 2. A comparison of selected at Minsmere with other values for heathland/moorland soils; Breckland data from Marrs et al. (in press) and North York Moors from Allen et al. (1974).

Soil property	Minsmere	Breckland	North York Moors
pH	3.2	3.6	34.7
Exchangeable K	36	25	40
Exchangeable Ca	128	48	140
Exchangeable Mg	17	6	40
Extractable P	29	8	20

Data for soil P adsorption maxima are available from Chapman, Rose & Basanta (1989), where they classified Westleton Heath, adjacent to the Minsmere complex within their 70 - 700 µg P g^{-1} category. In this study the Minsmere complex had much greater P sorption maxima. This difference may have been the brought about by the use of a simpler technique than that used by Chapman et al (1989) or there may be genuine differences across the area.

4. DISCUSSION

These data were collected during the first year of the RSPB heathland restoration project, and forms a base-line which allows us to (1) determine the size of the fertility problem, (2) isolate the key problem elements for future intensive study, and (3) gives us the base-line against which future progress can be measured. As the scheme progresses we should be able to calculate rates of decline more accurately, and thus be able to predict when soil fertility will no longer be a problem.

There are clear and consistent differences between the heathland and arable soils, and these can in the main be accounted for by past fertilizer use, for example:

(1) The higher pH and exchangeable calcium is almost certainly the result of past liming.

(2) The higher extractable phosphorus is the result of residues of phosphate fertilizer additions.

(3) The low soil organic matter (estimated by LOI values) and mineralizable nitrogen levels result the effects of continuous arable cultivation (Jenkinson, 1988).

These results are similar to those in other studies where the chemical properties of soil under arable cultivation and semi-natural grasslands have been compared (Gough & Marrs, 1990a,b). As heathlands develop there is likely to an increase in soil organic matter (loss-on-ignition), which may sequester some of the available calcium and phosphorus.

The main fertility problems in the arable soils for heathland restoration at Minsmere are the high levels of (1) exchangeable calcium and its associated effect on pH, and (2) extractable phosphorus. Mean values for the main vegetation types are shown in Table 3 along with the values that need to be removed in order to achieve heathland levels. There are few published data on soil chemistry depletion rates, but Gough & Marrs (1990b) estimate that for extractable phosphorus concentrations depletion rates range between 1 -3 μg P g^{-1} yr^{-1}. If these rates are accurate then it will take a minimum of 18 years for phosphorus levels to fall to heathland levels. The soils at Minsmere are, however, very sandy, and the high exchangeable calcium concentration may help to reduce the phosphorus supply through the formation of insoluble phosphate complexes. Thus, there may be a more rapid reduction in phosphorus supply than suggested by these literature values for depletion rate. The older of the old-field successions has shown a decline in soil phosphorus to near heathland levels. However, the soil phosphorus is still greater than heathland values and some of the phosphorus must have been sequestered in developing soil organic matter and heath and scrub biomass at this site.

Table 3. Mean values ± standard errors of soil pH, exchangeable calcium and extractable phosphorus (both $\mu g\ g^{-1}$) in soils from the main vegetation sites samples (3a), with differences between soils under arable or arable to heath succession and heathland soils (3b).

Soil chemical property	Heath	Old-Field		Arable	
		Old	New	North	South
(3a)					
Soil pH	3.2 ±0.1	3.5 ±0.1	4.8 ±0.2	5.2 ±0.04	5.5 ±0.05
Exchangeable Ca	128±16	208±42	527±78	452±15	522±20
Extractable P	29±3	41±3	79±9	132±5	85±3
(3b)					
Soil pH	-	0.3	1.6	2.0	2.3
Exchangeable Ca	-	80	399	324	394
Extractable P	-	12	50	103	56

It may be possible to increase nutrient offtake in the crop and help to reduce soil pH if an ammonium-based nitrogen fertilizer was applied instead of urea. MAFF/ADAS (1981) consider that ammonium based fertilizers require 1.4 - 3.9 kg $CaCO_3$ to neutralize 1 kg of fertilizer, although from theoretical considerations NH_4SO_4 requires 7.2 and NH_4NO_3 requires 3.6 kg $CaCO_3$ (Rowell, 1988). Urea has half the acidifying effect of ammonium-based fertilizers (Rowell, 1988). As exchangeable potassium concentrations are no higher in the arable soils than the heathlands it may be worth considering applying these to effect a reduction in pH (1 kg potassium fertilizers (SO_4 or Cl) requires 1.1 kg $CaCO_3$ to neutralize its effect). These changes to current fertilizing practice may be worth including in the last year of the scheme, when a reduction in pH may be more desirable. A rapid reduction in pH may be counter-productive in the early stages, if a low soil pH, and its associated effects through increased levels of toxic elements such as aluminium, interfere with crop production.

5. SUGGESTIONS FOR FUTURE WORK

Cropping he arable land at Minsmere is projected to continue for at least 3 years, and it is important that soil chemistry is monitored in each year. We suggest that these studies should concentrate on the three measures, which have been shown to be greater on arable soils, viz: soil pH, exchangeable calcium and extractable phosphorus. The rates of decline can then be calculated, and predictions made about the time required to reach the target heathland values.

In order that the desired type of heathland communities can be established quickly after the cereal cropping is stopped, an experimental program should be started to develop methods which can be used realistically on the scale required for restoring this large heathland complex.

The limited data on soil phosphate adsorption curve suggests that vegetation on these soils will change rapidly to birch woodland unless maintenance management is implemented. The observed succession on the older old-field confirms this view. A long-term management plan, therefore, must be developed to include management prescriptions to maintain heathland.

6. REFERENCES

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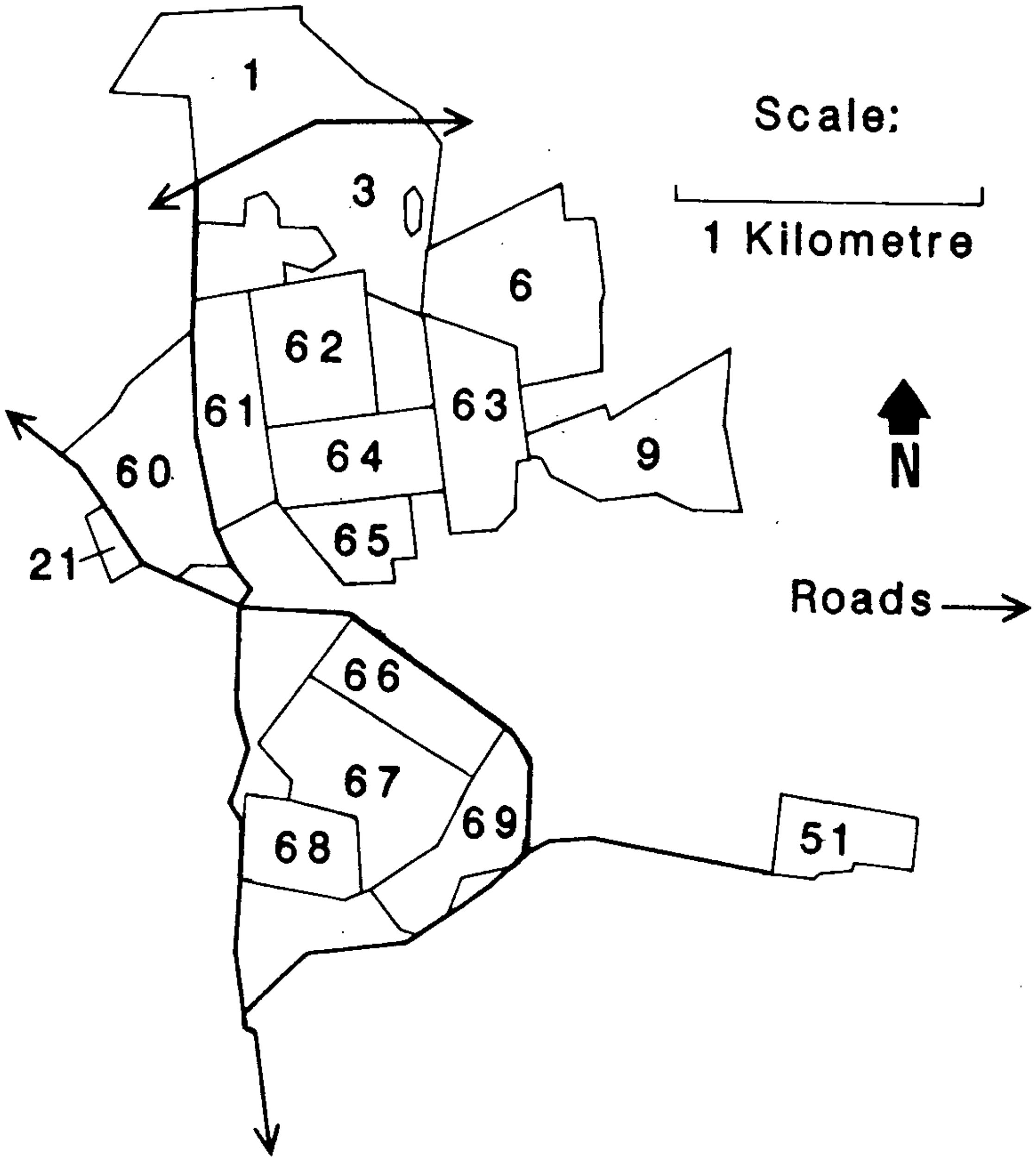

Figure 1. Map showing the distribution of individual fields at Minsmere.

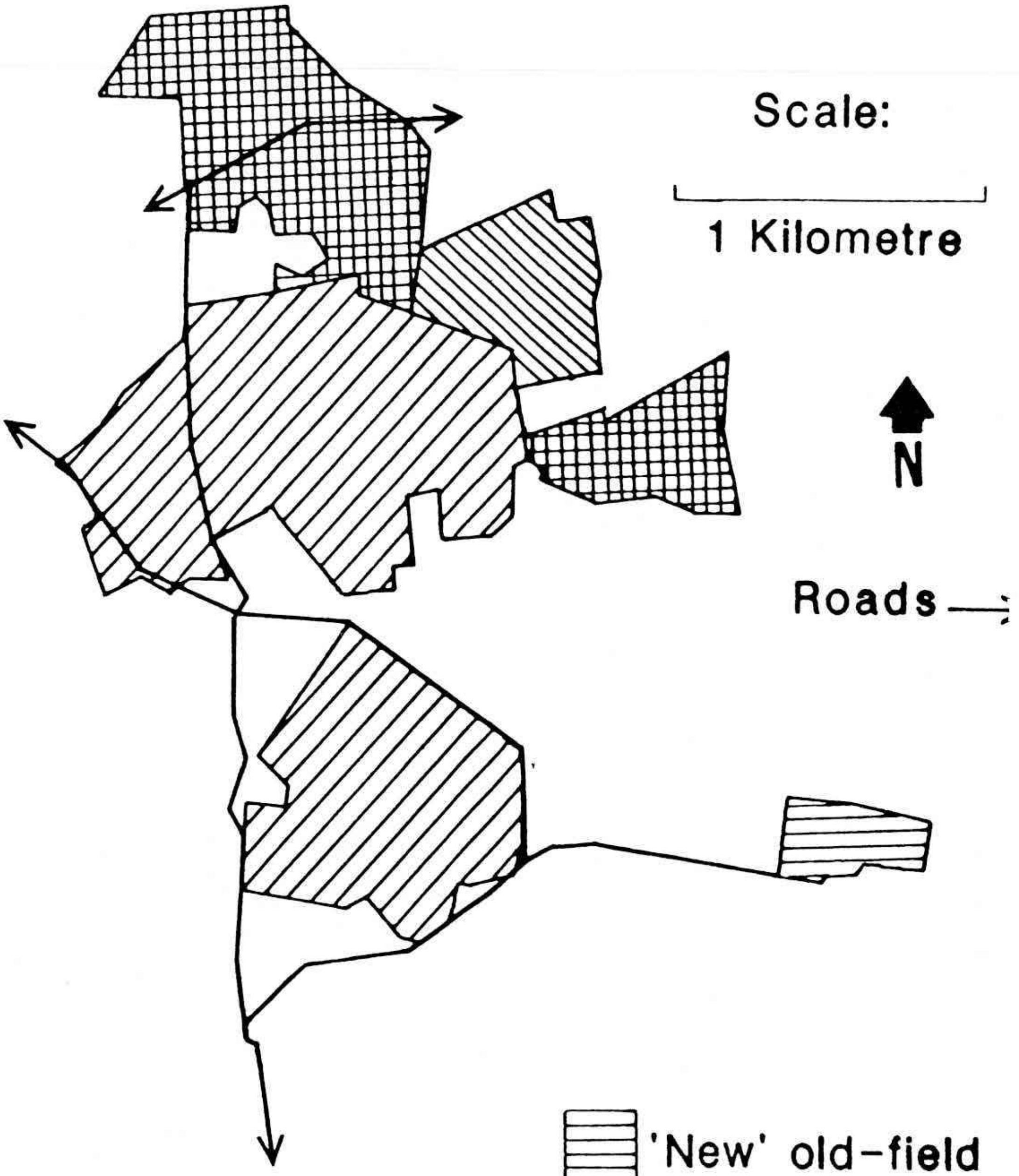

Figure 2. The distribution of different vegetation types at Minsmere in 1990.

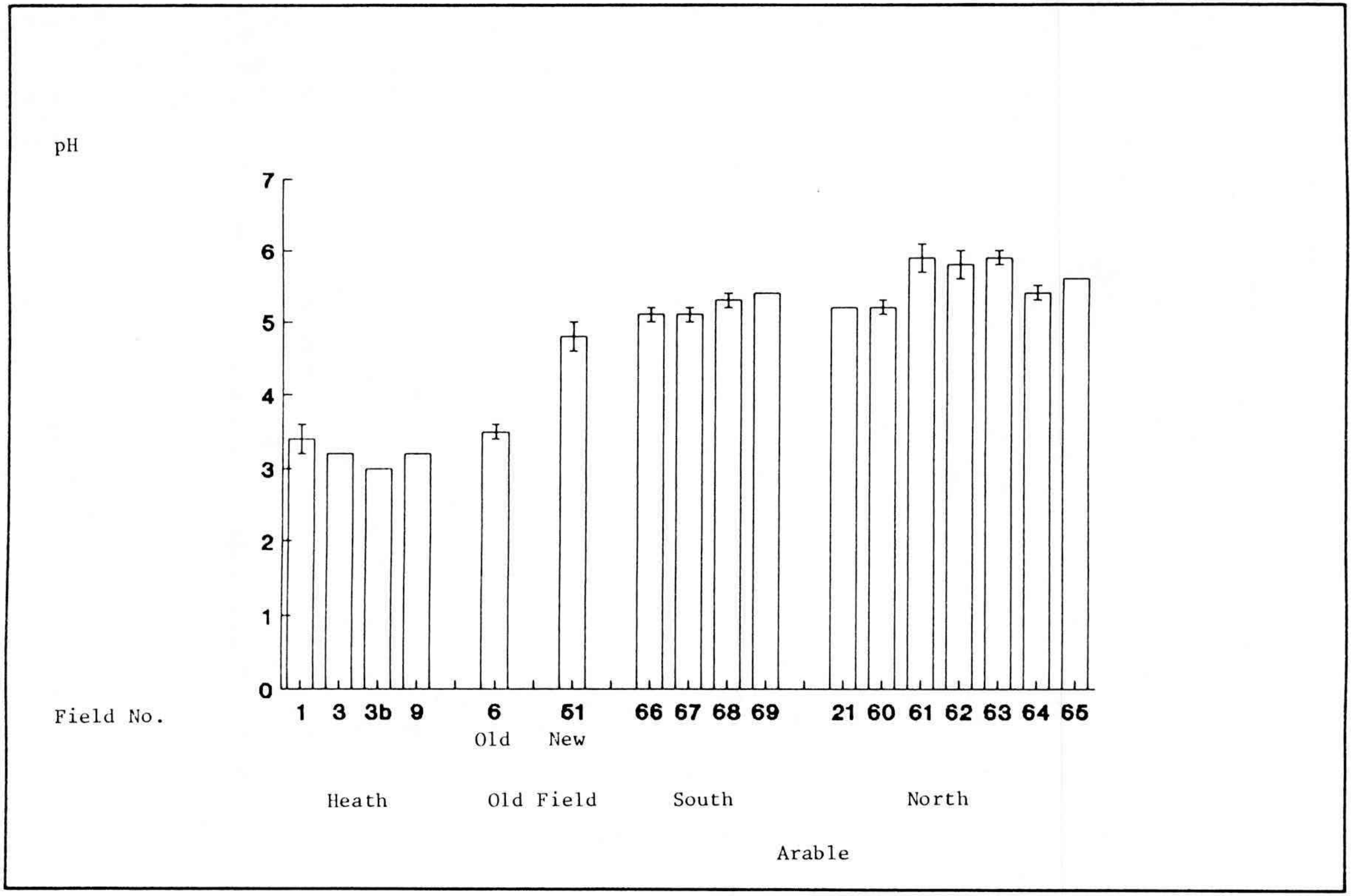

Figure 3. Soil pH in different vegetation types at Minsmere in 1990; mean values ± standard errors are presented. Where no vertical line is present the standard error was too low to illustrate graphically.

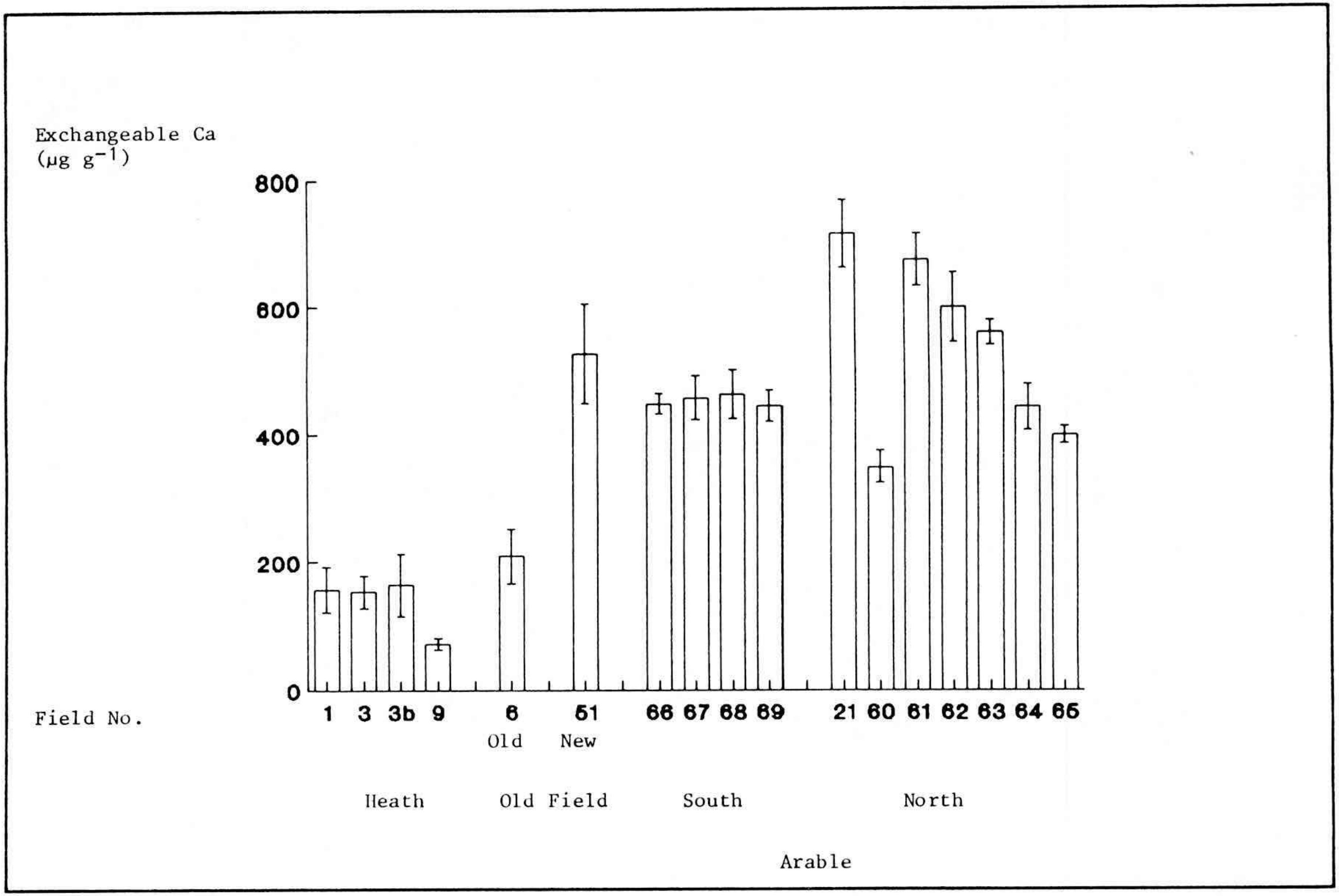

Figure 4. Soil exchangeable calcium in different vegetation types at Minsmere in 1990; mean values ± standard errors are presented.

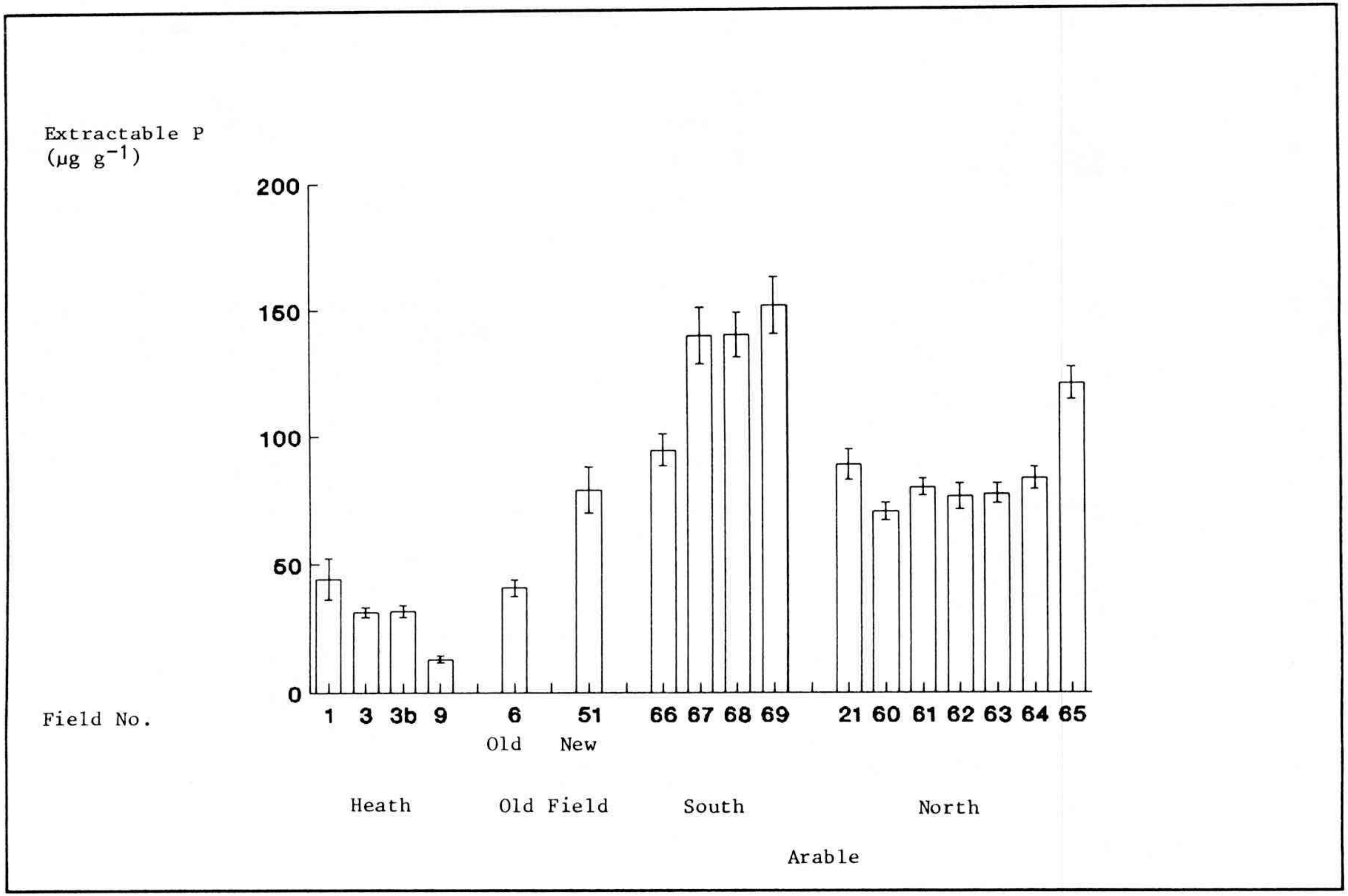

Figure 5. Soil extractable phosphorus in different vegetation types at Minsmere in 1990; mean values ± standard errors are presented.

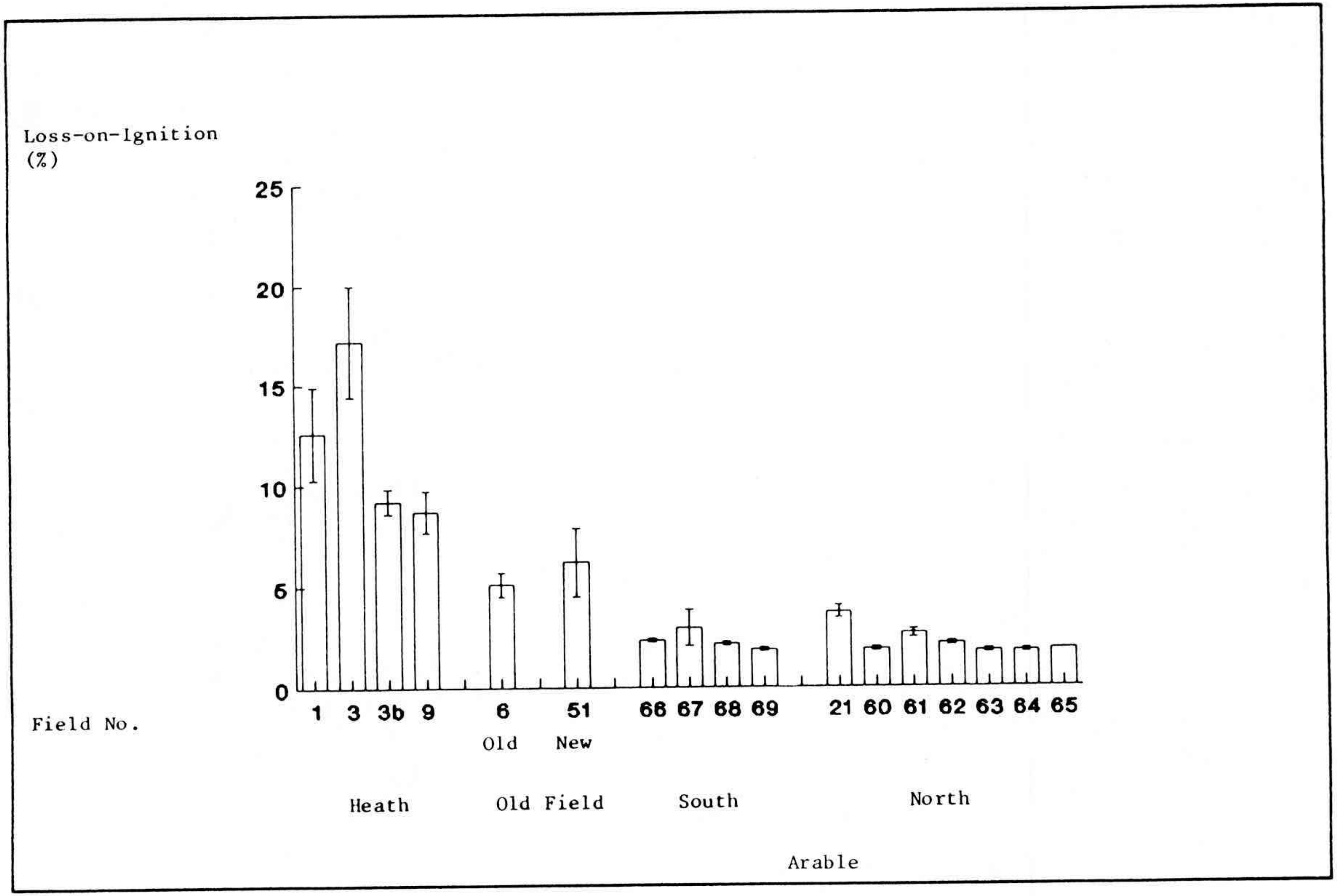

Figure 6. Loss-on-ignition in soils from different vegetation types at Minsmere in 1990; mean values ± standard errors are presented.

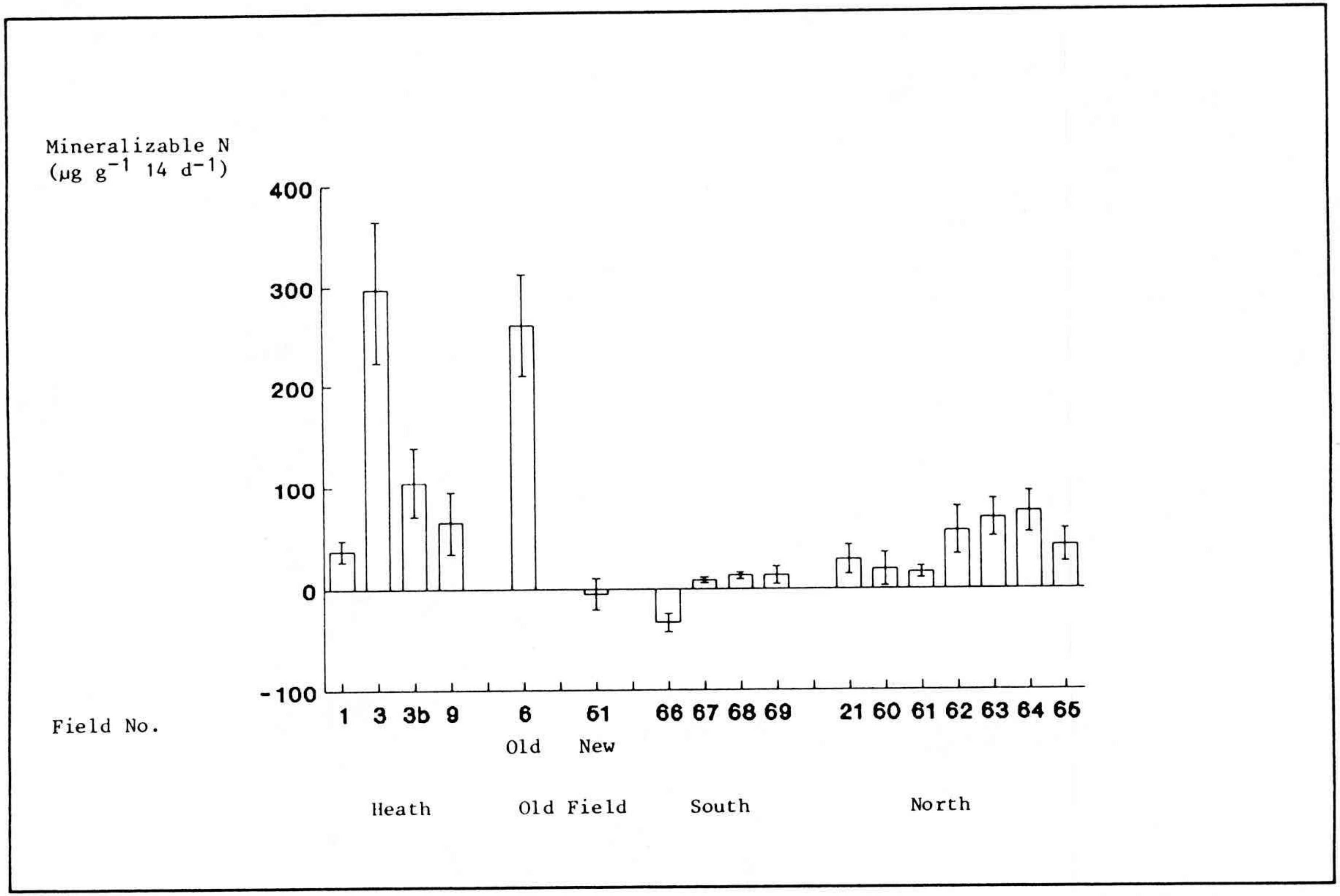

Figure 7. Soil mineralizable nitrogen in different vegetation types at Minsmere in 1990; mean values ± standard errors are presented.

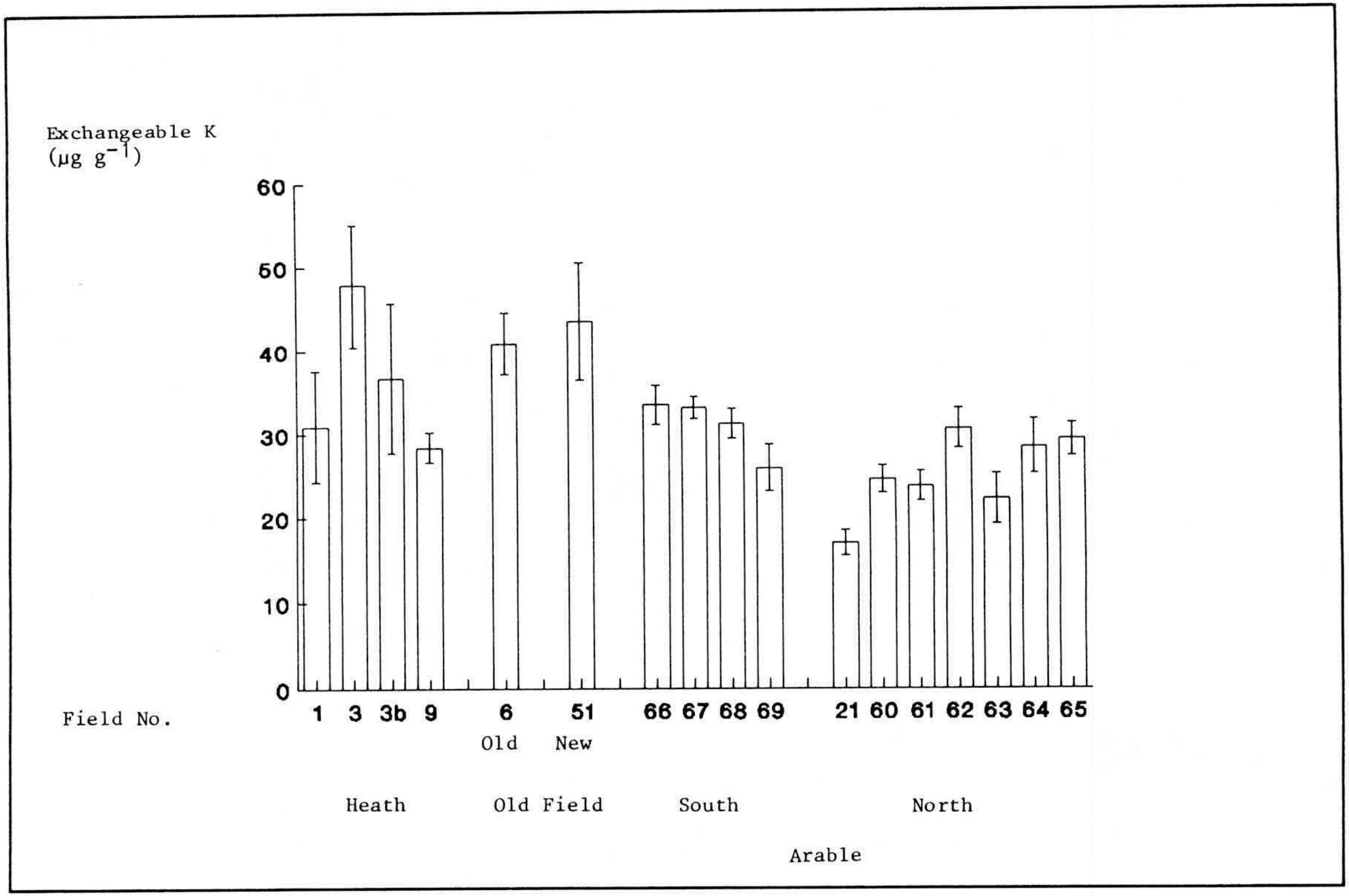

Figure 8. Soil exchangeable potassium in different vegetation types at Minsmere in 1990; mean values ± standard errors are presented.

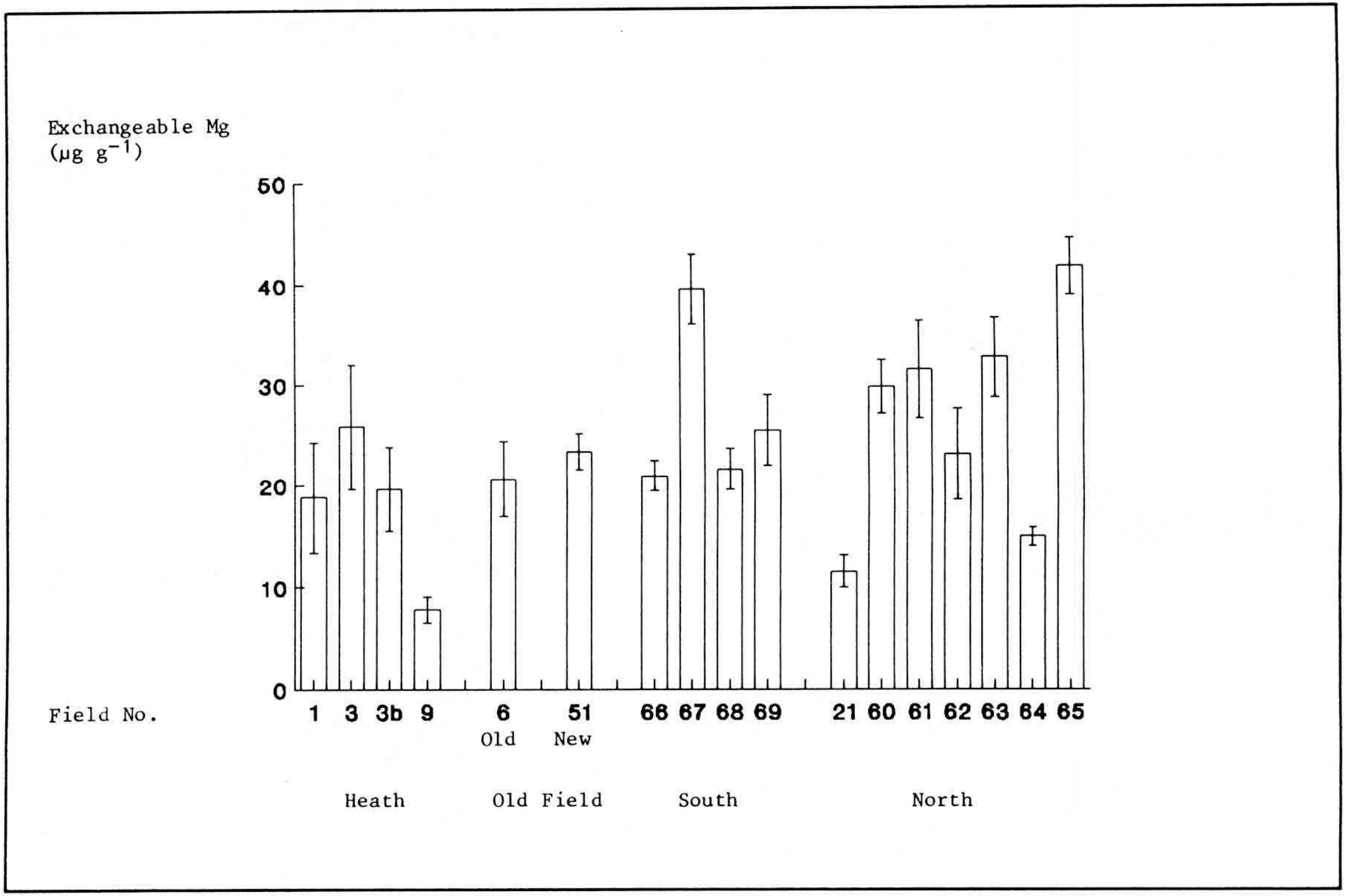

Figure 9. Soil exchangeable magnesium in different vegetation types at Minsmere in 1990; mean values ± standard errors are presented.

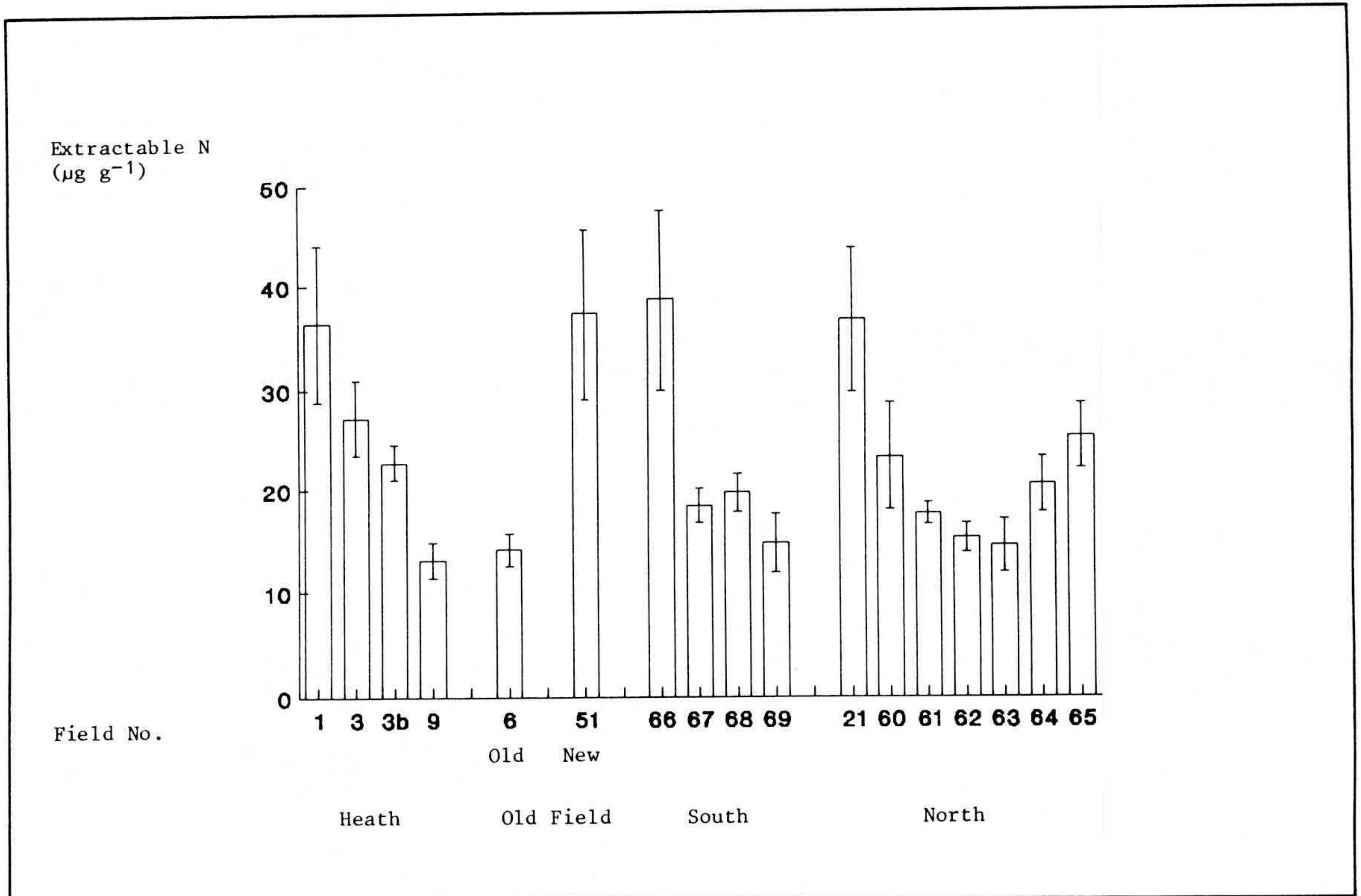

Figure 10. Soil extractable nitrogen in different vegetation types at Minsmere in 1990; mean values ± standard errors are presented.

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