WORKING PAPER

ASSESSMENT OF THE FINNISH AGRICULTURE 2000 PROGRAM: EFFECTS ON NUTRIENT LOSSES

Seppo Rekolainen
Lea Kauppi

November 1988
WP-88-103

PUBLICATION NUMBER 81 of the project:
Ecologically Sustainable Development of the Biosphere

IIASA
International Institute
for Applied Systems Analysis

ASSESSMENT OF THE FINNISH AGRICULTURE 2000 PROGRAM: EFFECTS ON NUTRIENT LOSSES

Seppo Rekolainen
Lea Kauppi

November 1988
WP-88-103

PUBLICATION NUMBER 81 of the project:
Ecologically Sustainable Development of the Biosphere

INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS
A-2361 Laxenburg, Austria

ABOUT THE AUTHORS

Mr. Seppo Rekolainen and Dr. Lea Kauppi worked in the Biosphere Project at IIASA as Research Scholars. Their current address is:

National Board of Waters and the Environment
Water and Environment Research Institute
P.O.Box 250
SF-00101 Helsinki
Finland

FOREWORD

One of the important functions which IIASA can fulfill for its member nations is to serve as a scientific resource. In this role, IIASA provides the physical, electronic, and intellectual setting required to approach a task of importance to a member nation. The report which follows represents an excellent example of successful implementation of IIASA's catalyst role. The Finnish Agriculture 2000 program, complementing similar work in other Nordic countries, has generated a superb assessment of the role of governmental policy in defining environmental quality. To do so, the authors took advantage of a mathematical model from another member nation, the USA, in order to define nutrient loads. The model was implemented at IIASA by those who were responsible for its presence at IIASA. In addition, IIASA staff members from Finland, who have the best understanding of the Finnish national needs, were the primary producers of the report. However, the writers were able to utilize the intellectual resources of IIASA during all stages of the study development, and to apply the unique combination of facilities and intellect at IIASA to produce the high quality document which follows. It is our hope that the value of this kind of support for member nations will continue to be provided in future initiatives as well.

Allen M. Solomon
Project Leader
Ecologically Sustainable Development of the Biosphere

ACKNOWLEDGEMENTS

This study was funded by the Finnish Ministry of Agriculture and Forestry, and carried out in collaboration with the International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria, and the Finnish National Board of Waters and the Environment, Helsinki. The authors are grateful to Dr. Jouko Sippola (Agricultural Research Centre, Finland) and to Dr. Walter J. Knisel (USDA, Agricultural Research Service) for their valuable help in the application of the CREAMS model. Ms. Aino-Maija Niemelä revised the English text.

ABSTRACT

A governmental committee has prepared a long-term programme (Agriculture 2000) concerning future agricultural policy in Finland. The purpose of this study was to assess the effects of these measures, mainly fallowing and reforestation, on nonpoint nutrient loads to watercourses. The work was mainly based on the use of a continuous simulation model, CREAMS. Using this model we estimated the relative effect of different management practices. Depending on the fallowing practice, the total amount of agricultural nonpoint nutrient load can increase by 15% or more, if fallowing is carried out by bare soil practices. If only green fallow is used, the nutrient load remains approximately at the level of normal cereal cultivation. It is recommended that fallowed fields not be located on permeable soils because of the risk of N leaching and not on steep slopes because of the high erosion and P losses. A reforestation programme planned in Finland could reduce the nutrient loads by 5-10%.

Key words: nonpoint load, nutrients, fallow, reforestation, CREAMS.

TABLE OF CONTENTS

ASSESSMENT OF THE FINNISH AGRICULTURE 2000 PROGRAM: EFFECTS ON NUTRIENT LOSSES

Seppo Rekolainen and Lea Kauppi

1. INTRODUCTION

A continuous increase in productivity in agriculture and the coincident decrease or only a slight increase in consumption of the most important agricultural products have caused agricultural overproduction in Finland as well as in many other developed countries. The improved agricultural technology in countries previously importing agricultural products has caused them to become exporters. The export of overproduction needs considerable governmental support to maintain the income level of farmers.

In 1985 the Finnish government set up a committee called Agriculture 2000, the task of which was to prepare a long-term programme for agricultural policy. The committee defined the objectives of agricultural policy and proposed measures to achieve these (Ministry of Agriculture and Forestry 1987). The measures proposed concern agricultural production, structure and income policy as well as marketing of agricultural products. As a means of reducing overproduction in Finland, the Committee proposed a decrease in the area of land under cultivation rather than less intensive farming, which in many other countries is proposed for the same effect.

The measures aiming at reducing overproduction may have direct effects on nutrient loadings to watercourses. The aim of the present paper was to evaluate what effects the proposals of the Committee Agriculture 2000 would have on the nutrient load of the watercourses.

2. MEASURES PROPOSED BY THE COMMITTEE

The agricultural land in Finland totals 2,400,000 ha, i.e. approximately 9% of the total land area. Agriculture is concentrated in southern Finland, where the proportion of agricultural land exceeds 30% in many river basins. The specializing process has decreased the number of milk and meat producers. The proportion of agricultural land used for ley cultivation (alternation of crop production and grazing) has decreased from 54% to 33% in 25 years. This change is particularly true in southern Finland, where most of the agricultural land at present is under cereal production.

The surplus area of agricultural land is estimated by the Committee to be 510,000-750,000 ha depending on the self-sufficiency level wanted. The main measures to reduce this surplus area are:

- to increase fallowing so that the area annually under fallow would be 200,000 ha or more
- to increase reforestation to an annual level of 10,000 ha. By the year 2000 a total of 100,000-150,000 ha of agricultural land would be reforested.

In addition to the proposed measures, the use of agricultural land for purposes other than reforestation, as well as total cession of production, have been examined to reduce the area of agricultural land.

The use of artificial fertilizers in Finland increased very rapidly during the 1960s until the middle of the 1970s. After that it levelled off for several years (Figure 1). In 1985 the average amount applied was 90 kg ha^{-1} of nitrogen and 31 kg ha^{-1} of phosphorus. In the most intensively cultivated areas in southwestern Finland the amounts applied were 95 kg ha^{-1} of nitrogen and 37 kg ha^{-1} of phosphorus. The usage of nitrogen per ha is of the same order of magnitude or lower than in the other Nordic countries, whereas the use of phosphorus per ha is quite high, e.g. twice as much as in Sweden (Table 1).

Table 1. The use of commercial fertilizers per hectare of agricultural land in some countries in 1982 (FAO 1983).

	N kg ha^{-1}	P kg ha^{-1}
Finland	92	30
Sweden	84	17
Denmark	148	19
Norway	92	30
France	118	38
Italy	78	23
Netherlands	530	39
Great Britain	224	29
FRG	196	43
USA	44	9
Soviet Union	39	11

The committee proposed that the effects and possibilities of moving to a less intensive agricultural practice should be studied, but did not suggest the extent to which the use of fertilizers and pesticides could be reduced.

3. ESTIMATION OF THE EFFECT OF FALLOWING ON NUTRIENT LOSSES

The evaluation of the effects of fallowing on nutrient losses was mainly based on the simulations made by the CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems) model (Knisel 1980). The results obtained by modelling were compared to the few experimental observations on the effects of fallowing (Jaakkola 1979, Uhlen 1986).

3.1. Brief Description of the CREAMS Model

CREAMS is a continuous computer simulation model that can be used to estimate field-edge losses of sediment, the surface-runoff losses of nitrogen and phosphorus, and also the nitrate leached out of the root zone (Knisel 1980). CREAMS was developed by the Agricultural Research Service, United States Department of Agriculture, to compare relative field losses of soil nutrients and pesticides under different management practices. CREAMS has been widely applied for these purposes (see, e.g. de Mare 1983, Crowder et al. 1985, Young et al. 1985, Heatwole et al. 1986, Crowder and Young 1987). One of the disadvantages of CREAMS is that it is strictly a field scale model, which cannot be directly applied to larger drainage basins.

The CREAMS model includes components for hydrology, erosion and sediment yield, as well as chemical transport. The hydrology component allows two types of rainfall data to be used, daily or breakpoint data. The daily values were used in this application. This means that the calculation of the runoff is based on the Soil Conservation Service curve number method (U.S. Department of Agriculture, Soil Conservation Service 1972). The output of the hydrology component consists of surface runoff, percolation, and evapotranspiration. Overland and channel flow, and also the flow from an impoundment can be included, but in this study only overland flow option was used. Estimation of erosion and sediment yield is based on the Universal Soil Loss Equation (USLE) (Wischmeier & Smith 1978) and on the Yalin equation (Yalin 1963). In the erosion output the total soil loss is available by storm, or on a monthly or yearly basis. The particle size distribution and the organic matter load are included in the output. Nitrogen and phosphorus runoff losses are modelled as soluble and sediment-bound.

Both sediment-bound N and P have an enrichment ratio included. The only nutrient leaching component is NO_3-N. The model also estimates nitrogen uptake, mineralization, and denitrication losses.

3.2. Input Data and the Management Practices Tested by the Model

The field area simulated in this application was hypothetical but typical of southern Finland. The area of the hypothetical field was 2 ha, the length 200 m and the width 100 m. The effects of different management practices were tested on varying soil types (Table 2). As the clay soils are usually flatter than silty and sandy soils, the slopes used were 1%, 3% and 6% for clay soil and 3.6% and 12% for silt and fine sand soil. The most distinctive differences between the soil types were those concerning infiltration of water and erosivity of the soils. Sandy soils are more permeable than silty and clayey soils, and silty soils more erodible than sandy and clayey soils.

Table 2. The percentage of clay, silt, sand, and organic matter in the simulated hypothetical fields.

	clay field	silt field	sand field
clay %	65	25	20
silt %	20	55	25
sand %	15	20	55
organic matter %	7	6	5

Although several row crops (e.g. potato, sugar beet, cabbage, carrot) are cultivated in Finland, different fallowing practices were compared only with barley and ley cultivation. Spring-sown barley is the most common cereal crop in Finland, also rye (winter), wheat (winter and spring-sown) and oats are cultivated. Ley cultivation must be rotated so that after 3-4 years of ley, the field is used for cereal cultivation for 2-3 years before sowing ley again.

The input data used in this application was collected from the meteorological observations in Jokioinen, southwestern Finland (The Meteorological Yearbooks 1983, 1984, 1985, 1986, 1987, and monthly reports of the Finnish Meteorological Institute). The years chosen in the application were 1982-1987 and the following input files were used:

- daily precipitation
- monthly mean temperatures
- monthly mean radiation.

In 1982-1987 the precipitation varied considerably. The average precipitation of these years exceeded the average of the years 1961-1980 (Table 3).

Table 3. Annual precipitation of the years 1982-1987.

Year	Precipitation mm
1982	650.0
1983	606.1
1984	776.3
1985	573.2
1986	672.3
1987	572.4
1982-1987	641.7
1961-1980	545.0

Management practices

Fallowing previously belonged to the normal crop rotation of the farmland. In the present paper, a six-year rotation was chosen for comparison. A six-year continuous barley cultivation was chosen for the basic level. The ley rotation consisted of three year ley - three year barley cultivation and for each fallowing practice the six year period contained only one year fallow. A more detailed description of the rotations as well as the timing of sowing, fertilization and ploughing is presented in Figure 2.

Three fallowing practices were chosen for the simulations:

- Fallow 1. After ploughing in autumn, the field area is harrowed in spring or early summer and kept free of vegetation by repeated harrowing. In late August winter rye is sown.
- Fallow 2. As fallow 1, but the soil is left bare also for the next winter and barley is sown only next spring.
- Green fallow (fallow g). Ley is established by sowing it together with barley during the previous year and by ploughing it in the following August. After that winter rye is sown.

In fallowing practices where the soil is kept bare, either 1983 or 1984 was chosen for the fallow year to find out if different amounts of yearly precipitation affected the nutrient losses.

The fertilizers applied to spring-sown cereals are almost exclusively incorporated into the soil. Surface application is used only for leys and winter cereals in spring. The fertilization rates used in the simulations are presented in Table 4.

Table 4. Fertilization rates used in the simulation.

	N kg ha^{-1}	P kg ha^{-1}
Barley, simultaneously with sowing	90	38
Ley, after first harvest	110	20
after second harvest	90	10
after third harvest	60	10
Winter rye, with sowing	30	
next spring	90	25

3.3. Results of the Simulations

Results are presented as relative differences compared to nutrient losses from continuous barley cultivation done separately for each soil type. The differences in the fallowing year, the succeeding year (Figures 3-8 and Table 5) and the average differences during the whole six-year rotation period (Figures 9-14 and Table 6) are presented.

Table 5. The relative differences in total phosphorus and nitrogen losses in the fallow year (1984) and the succeeding year (1985). The continuous barley cultivation with medium slope in 1984 (3% for clay soil, 6% for silt and fine sand) was chosen as the base (100%) level. For a more detailed explanation of the crop rotations, see Figure 2.

			PHOSPHORUS					NITROGEN				
	slope %	year	B	L	F_1	F_2	F_g	B	L	F_1	F_2	F_g
CLAY	1	84	20	12	25	27	4	91	56	178	161	84
	1	85	31	8	48	120	50	33	25	58	50	39
	3	84	100	12	126	130	5	100	56	188	172	77
	3	85	140	134	231	508	237	45	26	78	92	59
	6	84	200	61	266	276	53	110	61	203	312	82
	6	85	313	67	589	1457	609	63	32	117	194	99
SILT	3	84	41	13	42	42	12	93	54	190	171	81
	3	85	67	13	125	349	128	30	17	62	70	43
	6	84	100	52	104	104	51	100	58	197	178	86
	6	85	150	46	280	730	286	40	21	79	112	60
	12	84	243	154	252	252	153	59	30	113	192	95
	12	85	325	123	586	1458	598	59	30	113	192	95
FINE	3	84	36	6	36	36	6	95	47	162	150	77
SAND	3	85	58	9	101	282	144	31	17	62	55	42
	6	84	100	26	100	100	26	100	51	175	156	81
	6	85	146	30	259	724	259	39	19	76	95	56
	12	84	222	115	222	222	115	111	59	184	166	89
	12	85	317	101	582	1491	582	53	24	99	159	83

Table 6. The relative six-year average difference in total phosphorus and nitrogen losses. The continuous barley cultivation with medium slope (3% for clay soil, 6% for silt and fine sand) was chosen as the base (100%) level. For a more detailed explanation of the crop rotations, see Figure 2.

	slope %	PHOSPHORUS B	L	F_1	F_2	F_g	NITROGEN B	L	F_1	F_2	F_g
CLAY	1	21	16	26	37	22	86	57	103	101	83
	3	100	56	122	169	100	100	64	120	124	96
	6	223	146	290	433	243	122	80	149	17	122
SILT	3	42	27	53	89	46	89	57	107	105	88
	6	100	73	126	197	112	100	66	120	128	99
	12	230	178	283	419	254	124	85	149	169	126
FINE	3	38	23	46	75	40	92	57	105	101	90
SAND	6	100	64	123	197	106	100	63	115	117	98
	12	222	138	278	422	245	115	75	134	145	116

*3.3.1. **Phosphorus Losses***

Phosphorus losses estimated by CREAMS consist of a sediment-bound and dissolved fraction of phosphorus in surface runoff water. The proportion of the sediment-bound phosphorus was usually very high (more than 95% of the total phosphorus loss). Only in flat clayey soils (slope 1%-3%) was the proportion of phosphorus loss in surface runoff low: approximately 10% in barley cultivation and approximately 40% in ley cultivation. Variations in the dissolved fraction of P were not very large. Erosion was the most important factor affecting P losses.

The total phosphorus losses from barley cultivation were simulated to be 40% to 60% higher in 1985 than in 1984, although the total precipitation was lower in 1985. This was due to the heavy rainfall events in the springtime, when most of the erosion took place.

The P losses from ley were much lower (70%-90%) than from barley (Figures 3-5). The six-year averages of ley rotation (three years ley and three years barley) were 20% to 40% lower than those of continuous barley cultivation (Figures 9-11). The highest relative reduction in P losses was in clay and fine sand soil with 3% slope, but the absolute losses were naturally higher with steeper slopes.

The two fallowing practices, in which the soil is kept free from vegetation (fallow 1 and fallow 2), did not increase the P losses very much during the fallowing year. This was particularly true for permeable silt and fine sand soils. Most of the surface runoff (and erosion) took place in spring with snowmelt, and at that time the fallow fields were ploughed, but not yet harrowed. The most distinctive effects of the bare fallowing practices could be seen in the year after fallowing, when in both cases the P losses were much higher than from the barley field. In case of fallow 1 (fallow followed by winter rye), the high P loss was based on the assumption that the harrowed field with a young crop during snowmelt is more sensitive to erosion than a ploughed field. Information on erosion processes under Finnish conditions is poor, but the harrowed soil probably is more erodible than ploughed and rye vegetation probably is not dense enough to slow down the surface runoff during snowmelt. This is also the reason for the high P losses in case of fallow 2 but only if it is left harrowed during winter and spring snowmelt period. If it were ploughed in autumn, the P losses would stay on the same level as under continuous barley cultivation. Reduced erosion from a rough soil surface (ploughed) compared to a smooth surface (harrowed) may be a consequence of either reduced surface runoff or of a greater resistance of the soil to detachment (Cooke 1985). Calculated on a six year basis the total P losses from fallow 1 practice were 20% to 30% higher and from fallow 2 practice 75% to 110% higher than from the continuous barley.

The effect of green fallow (fallow g) on the P losses during the six year rotation is quite minimal, the average losses being of the same order of magnitude as from barley cultivation (Figures 9-11). The P loss during the fallow year was lower than from the barley field, because of the grass sown simultaneously with barley in the previous spring. Similarly, the P loss was higher the next year, because the green fallow was ploughed in summer and after that winter rye was sown (Figures 3-5).

The most distinctive differences in the P losses were caused by the slope, because the P losses were controlled by erosion. Soil type had only a minor effect on the P losses. Silty and sandy soils are more sensitive to erosion than clay soils, but on the other hand they are more permeable and the proportion of surface runoff is lower than on clay soils.

3.3.2. Nitrogen Losses

Nitrogen losses estimated by the CREAMS model consist of a sediment-bound and dissolved fraction of nitrogen in surface runoff water at the edge of the field and of nitrate leaching from the root-zone. As was the case with P losses, the dissolved fraction in surface runoff contributed only slightly to the total N losses.

The leaching of NO_3-N formed the largest proportion of the total N losses. The proportion and also the total amount of percolated water was the most important factor determining the total N losses. Only in clay soil, where the proportion of the surface runoff was higher, were the N losses during fallowing periods slightly increased by an increased amount of sediment-bound nitrogen. In silt and fine sand soils percolation was high, and the total N losses were strictly dependent on leached nitrogen.

The total N losses in 1985 (dry year) were 40% to 70% lower than in 1984 (wet year). The highest relative difference was found in flat fields in all of the simulated soil types (Figures 6-8). The fact that most N loss was caused by leaching accounted for the minor N loss on slopes where runoff rather than percolation predominates.

The total N loss from the ley field was about half of that from the barley field (Figures 6-8). The six year average N losses from ley rotation (3 years ley and 3 years barley) were 30% to 35% lower than from the continuous barley cultivation. Because the absolute amounts of N losses were somewhat higher from sandy soils than from clay soil, the ley rotation decreased N losses more in more permeable soils.

No remarkable differences in N losses were found between fallow 1 and fallow 2 practices. In both cases N losses were about twice as high as from the barley field during the fallowing year as well as the year after (Figures 6-8). The increased N loss in the year after fallowing was caused by the increased nitrate concentration in the soil. In fallow 2 practice (fallow followed by spring-sown barley), the N losses were to some extent dependent on the slope because of the high erosion during the snowmelt period from the harrowed field.

During the six year rotation period the total N losses were about 20% higher from the fallow fields than from fields under continuous barley cultivation (Figures 12-14). Fallowing practice had only a slight effect on the N losses. Some years after the fallowing the N loss was in certain cases even lower from the fallowed field than from the barley field because of the increased uptake of nitrogen. Because the uptake of nitrogen by ley is much higher than that of barley, the N losses from the green fallow rotation were not higher than from the barley cultivation on a six-year basis (Figures 12-14).

Based on the simulations the nitrogen losses were only slightly affected by slope. Because the permeability of the soil determines the proportion of water and dissolved nutrients leaching out of the root zone, the soil type has some influence on nitrogen losses. Particularly when sandy soil was fallowed, the nitrate leached out was calculated to be higher than in clay or silt soil.

4. DISCUSSION

There are only a few experimental studies on the effects of fallowing on the nutrient losses under circumstances comparable to Finnish conditions. In Norway the effects of fallowing were studied on a silty clay field with 4.5% slope (Uhlen 1986). The results from this study show that both P and N losses from fallow were 2-3 times as high as losses from spring-sown cereals. Finnish observations on fallowing (Jaakkola 1979) suggest that the amount of N leached from fallowed fields was approximately 5 times as high as from barley fields. Because nutrient losses are highly dependent on the amount of runoff, the results obtained by the model calculations can be considered comparable to these field observations.

The nutrient losses estimated by the CREAMS model are expressed only as relative changes compared to the barley cultivation. The model estimates the nutrient losses at field edge and from the root zone. Thus the values do not necessarily represent the loads discharged into watercourses. However, the relative changes in field-scale losses can be considered comparable to changes in actual agricultural nonpoint loading as well. Based on the simulations, agricultural land lying fallow once in six years contributes 25% more to the P load and 20% more to the N load than continuous cereal cultivation, when traditional fallowing practice (bare soil) is applied.

It can be assumed that farmers do not let every field lie fallow in every sixth year, but rather keep some (usually the most productive) fields under continuous cultivation. The total area of agricultural land in Finland is 2,400,000 ha and the annual amount of fallow should be 200,000-250,000 ha according to the report of the Agriculture 2000 Committee. Thus it can be estimated that about 1,400,000 ha of the total agricultural land is in crop rotation, i.e. lies fallowed once in six years. Assuming that the nutrient load from the continuous crop cultivation does not change, the total agricultural nonpoint P load increases by 15% and the nitrogen load by 12%, if only traditional fallowing practice is used. If fallowing is carried out partly by fallow 2 practice (barley sown the following spring), the nutrient loads can increase even more. If only green fallowing were used, the nutrient loads would not increase.

If no measures towards more extensive agricultural practices are introduced, it can be assumed that farmers will cultivate the non-fallow land even more intensively than at present. The increased use of fertilizers can increase the nitrogen load to surface as well as to ground waters, and the increasing phosphorus content of surface soil layers can increase phosphorus losses in the long run.

The total load of nutrients from agriculture into watercourses in Finland has been estimated to be 1,400 t for phosphorus and 31,000 t for nitrogen (Kauppi 1979). The estimates were based on the observations in small agricultural basins in the years 1965-1976. In the 1980s precipitation and runoff have been higher than in those years. A shift towards more specialized and intensive agriculture has also taken place in the recent 10-15 years. These factors can be assumed to increase nutrient loads. If P and N losses are increased due to fallowing by 15% and 12% respectively, it means that annually 200-300 t more of phosphorus and 4,000-6,000 t more of nitrogen is transported from agricultural land to watercourses in Finland.

The slope of the field has a distinctive effect on phosphorus loads. By locating the fallowed field areas mostly in flat lands, the absolute P losses would not increase as much as in sloping areas. Similarly, location of leys and also green fallow fields (especially if perennial) onto steep slopes would decrease phosphorus losses.

5. EFFECTS OF REFORESTATION ON NUTRIENT LOADS

In forests both nitrogen and phosphorus inputs are much lower than in agricultural land. The growing period is also longer in forests and the uptake of nitrogen is higher. Usually in forests the soil is totally covered by vegetation, and erosion is minimal compared to agricultural land. In many studies (e.g. Kauppi 1979, Brink 1983) it has been observed that both N and P losses from forest land are one-tenth or less than that from agricultural land.

Within two years after the reforestation of agricultural land, the soil is covered by thick grass vegetation. Erosion probably decreases to a very low level within 2-3 years. This should result in remarkable reduction in phosphorus losses. Because the soils, which were previously in agriculture, were the most fertile soils, it can be assumed that when these soils are reforested, the nutrient losses never reach such a low level as is observed in old forest soils. However, the reduction of P loads is considerable within a few years due to minimal erosion.

Nitrogen uptake by recently planted forests is not as efficient as that by agricultural plants and, because of the high nitrogen status of the fields, the N decrease more slowly than the P. However, when the canopy cover of the new forest becomes closed (in about 15-20 years in southern Finland), the N is probably close to the level of N in soils of old forests.

If 200,000 ha of agricultural land is reforested by the year 2000, the total nonpoint N and P load from agricultural land would be 5% to 10% lower than at present. For phosphorus the absolute reduction would be approximately 100 t and for nitrogen 2,000 t. If the reforestation areas are located along the steep river banks and other areas with high erosion potential, reduction in nutrient loads can be even higher.

6. CONCLUSIONS AND RECOMMENDATIONS

- Increased fallowing of agricultural land increases the nutrient load to water courses.

- If fallowing is carried out by keeping the soil bare of vegetation, but followed in the same year by planting winter cereals, the total loads of N and P from agricultural land will be 12% and 15% higher than from normal crop cultivation. The estimate for phosphorus is based on the assumption that during the snowmelt period erosion from a field under winter cereals is higher than from a ploughed field. However there are no observations of erosion from fields of this kind in Finland. Further studies are needed.

- If the fallow field is left harrowed until the following spring the P losses can be further increased.

- If only green fallowing were used, the nutrient load would not increase.

- In permeable soils the fallowing especially increases the N losses through percolation. There is also a risk for increased nitrate leaching into ground waters. Therefore, it is preferable not to let sandy soils lie fallow to any considerable extent.

- The loss of phosphorus increases rapidly with increasing slope. Therefore, the fallowing fields should not be located on sloping fields. With less than 3% slope the absolute P losses from fallowed fields are not very much higher than from fields under continuous cereal cultivation.

- If leys and also perennial green fallows were located in fields with steep slopes, the total agricultural load to water courses could be reduced. Theoretically, if all the agricultural land in Finland were under 3-year ley - 3-year cereal cultivation, the total non-point load of agriculture could be 30%-50% lower than at present.

- If farmers intensify the cultivation of non-fallowed land, the total nutrient losses will increase.

- The proposed reforestation would reduce the total nutrient load to water courses by 5%-10%. It would be beneficial to locate the reforested areas in fields with high slopes and in steep river and channel banks.

REFERENCES

Brink, N. 1983. Närsalter och organiska ämnen från åker och skog. (Nutrients and organic matter from farmland and woodland.) Division of Water Management, Swedish University of Agricultural Sciences. Ekohydrologi 14:21-30.

Cooke, J.W. 1985. Effect of fallowing practices on runoff and soil erosion in southeastern Australia. Aust. J. Exp. Agric. 25:628-635.

Crowder, B.M. and C.E. Young. 1987. Soil conservation practices and water quality: Is erosion control the answer? Wat. Res. Bull. 23:897-902.

Crowder, B.M., H.B. Pionke, D.J. Epp and C.E. Young. 1985. Using CREAMS and economic modeling to evaluate conservation practices: An application. J. Environ. Qual. 14:428-433.

De Mare, L. 1983. Management of crop nutrient leaching with CREAMS: Nitrate leaching from agricultural fields in Skåne, Sweden. Vatten 39:69-77.

FAO Fertilizer Yearbook. 1983. Volume 33. FAO Statistics Series 56. 143 pp.

Heatwole, C.D., A.B. Bottcher and L.B. Boldwin. 1986. Basin scale model for evaluating best management practice implementation programs. Trans. of the Am. Soc. of Agric. Engin. 29:439-444.

Jaakkola, A. 1979. Ravinteiden huuhtoutumistutkimus käynnistynyt. (The study on nutrient leaching has started). Koetoiminta ja käytäntö 24.4.1979.

Kauppi, L. 1979. Phosphorus and nitrogen input from rural population, agriculture, and forest fertilization to watercourses. Publ. of the Wat. Res. Inst. 34:35-46.

Kemira. 1986. Lannoitteiden myynnin jakautuminen maatalous-keskusalueittain lannoitusvuonna 1985/86. (The sale of fertilizers by regions in Finland in the fertilizer year 1985/86.) Helsinki.

Knisel, W.G. (ed) 1980. A field-scale model for chemicals, runoff, and erosion from agricultural management systems. U.S. Dept. of Agric., Conserv. Res. Rep. No. 26, 640 pp.

Ministry of Agriculture and Forestry, Finland. 1987. Agriculture 2000. Committee Report 1987:24. 192 pp.

Uhlen, G. 1986. Avrenningstap av N og P ved olika vekstsystemer. (Leaching losses of N and P from different cultivation practices.) Nordisk Jordbrugsforskares Forening. Plantenäringsstoffer og vandmiljö. Seminarrapport.

U.S. Department of Agriculture, Soil Conservation Service. 1972. National Engineering Handbook, Hydrology, Section 4. 548 pp.

Wischmeier, W.H. and D.D. Smith. 1978. Predicting rainfall erosion losses. U.S. Department of Agriculture, Agriculture Handbook No. 537, 58 pp.

Yalin, Y.S. 1963. An expression for bedload transportation. J. of the Hydraul. Div., Proc. Am. Soc. of Civil Engin. 89(443):221-250.

Young, C.E., B.M. Crowder, J.S. Shortle and J.R. Alwong. 1985. Nutrient management on dairy farms in southeastern Pennsylvania. J. Soil Water Conserv. 40:443-445.

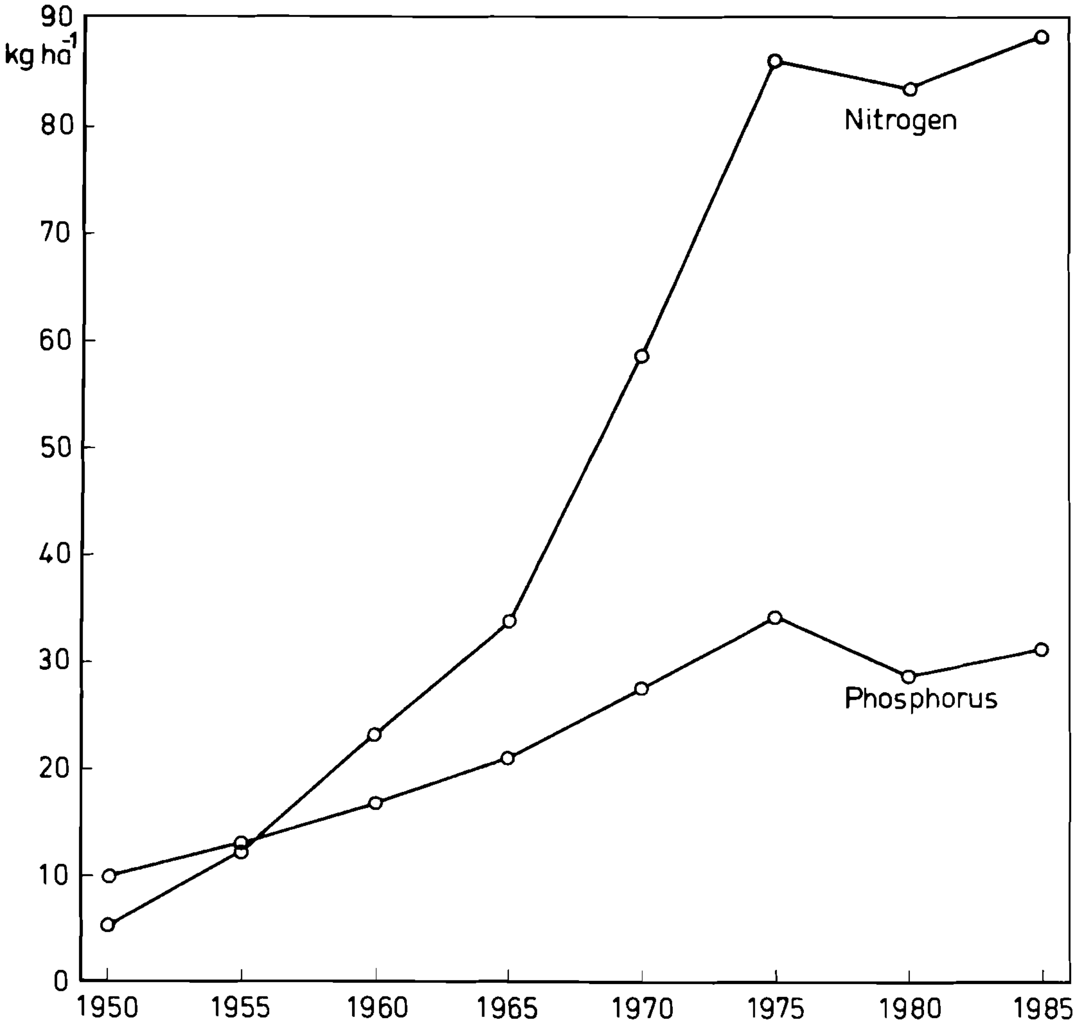

Figure 1. The use of artificial fertilizers in Finland. (Source: Kemira 1986)

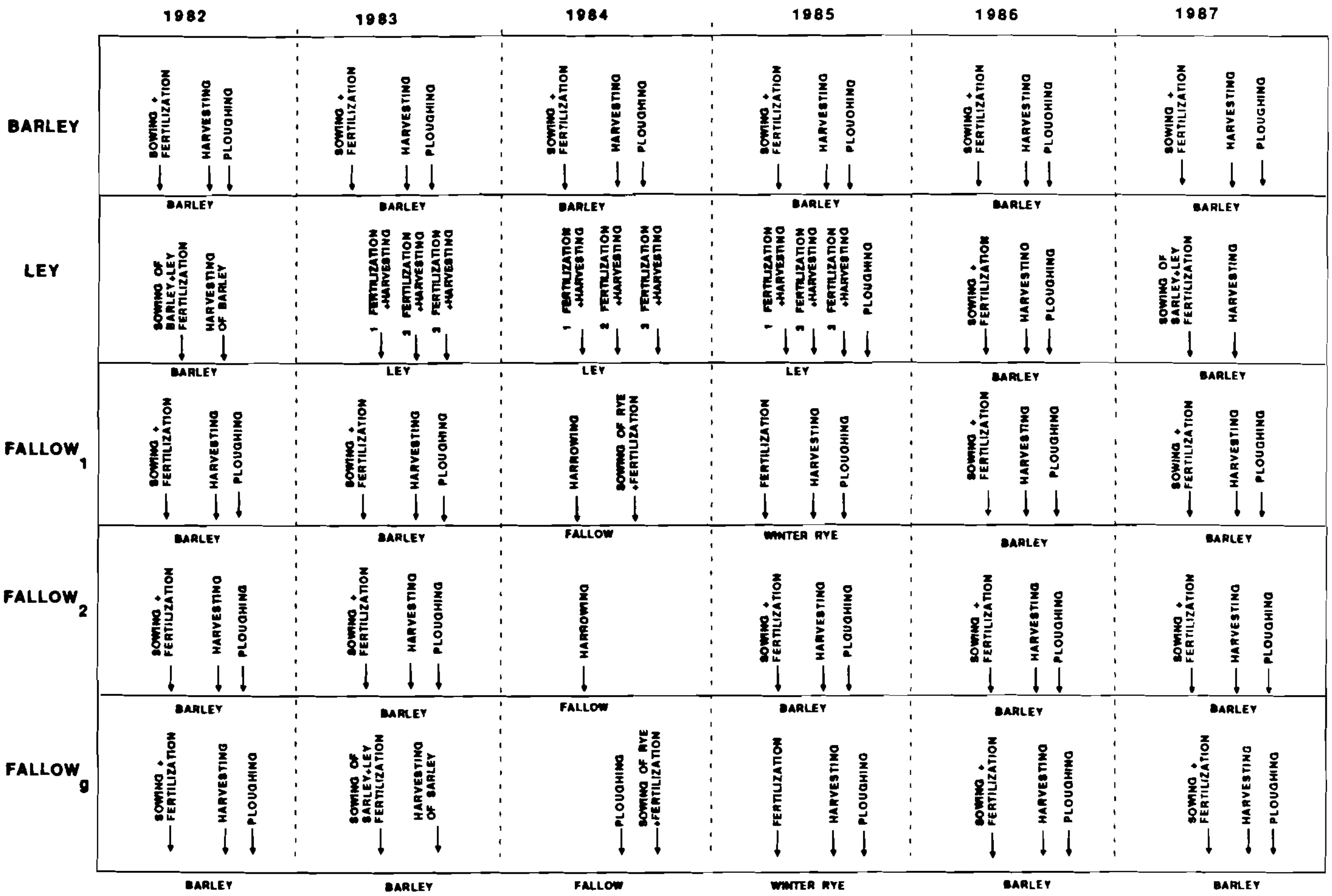

Figure 2. The crop rotation as well as the timing of sowing, fertilization, harvesting, and ploughing of the compared management practices.

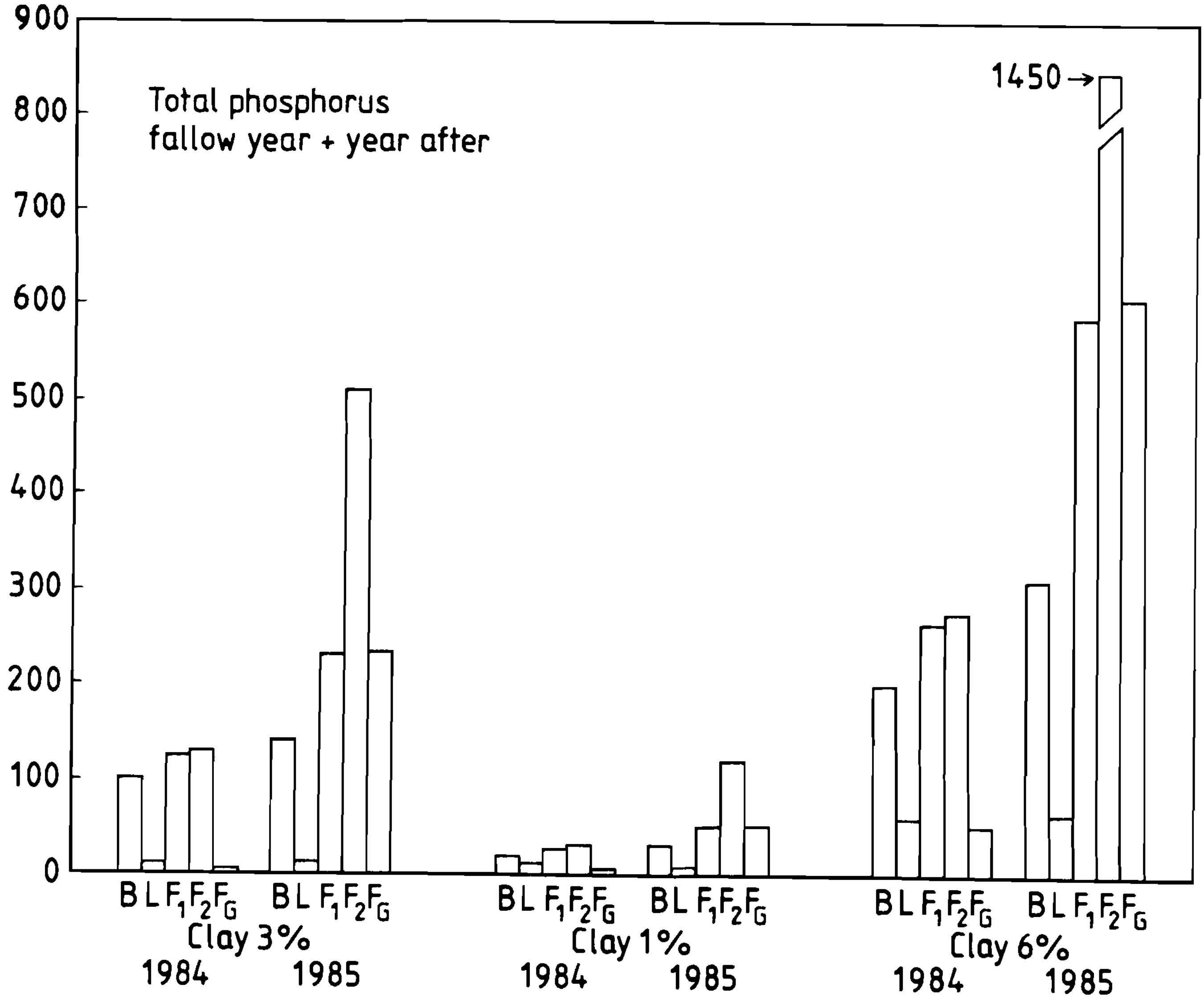

Figure 3. The relative differences in total phosphorus losses from different management practices in the fallow year (1984) and year after (1985) in clay soil with varying slope.

Legend:

B = continuous barley
L = 3 year ley + 3 year barley
F_1 = fallow followed by winter rye
F_2 = fallow followed by spring-sown barley
F_g = green fallow followed by winter rye

For a more detailed explanation, see Figure 2.

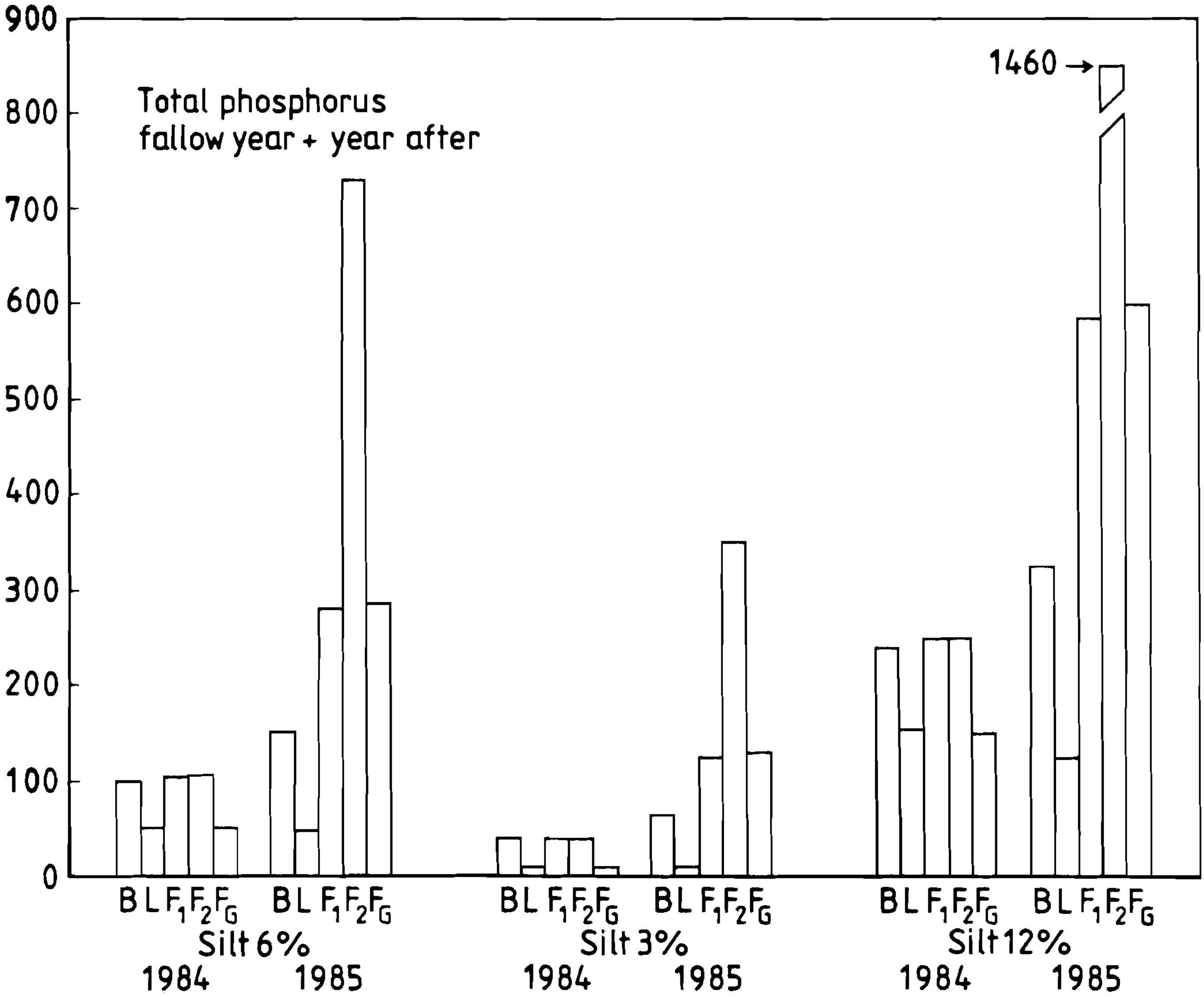

Figure 4. The relative differences in total phosphorus losses from different management practices in the fallow year (1984) and year after (1985) in silt soil with varying slope.

Legend:
B = continuous barley
L = 3 year ley + 3 year barley
F_1 = fallow followed by winter rye
F_2 = fallow followed by spring-sown barley
F_g = green fallow followed by winter rye

For a more detailed explanation, see Figure 2.

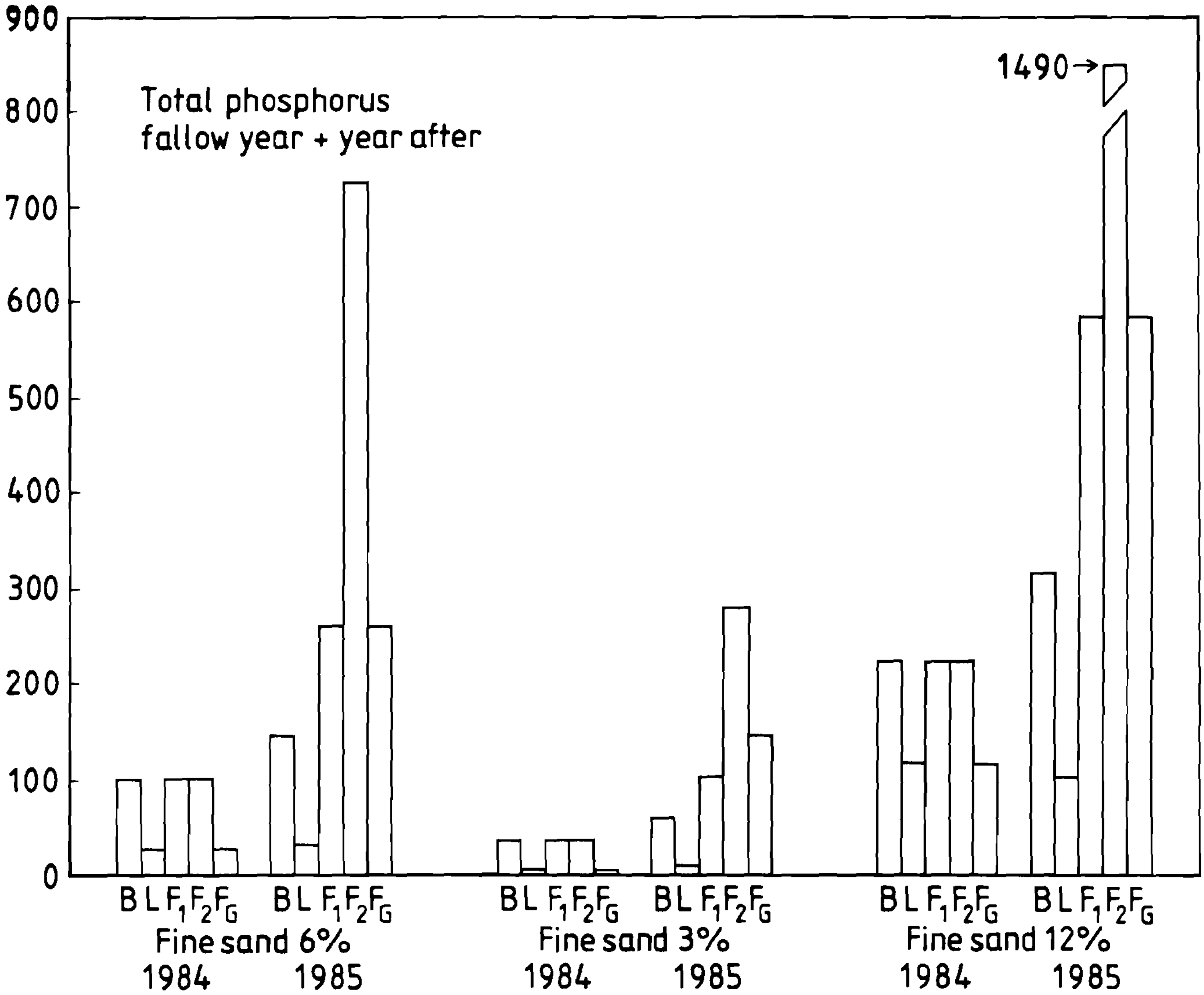

Figure 5. The relative differences in total phosphorus losses from different management practices in the fallow year (1984) and year after (1985) in fine sand soil with varying slope.

Legend:
- B = continuous barley
- L = 3 year ley + 3 year barley
- F_1 = fallow followed by winter rye
- F_2 = fallow followed by spring-sown barley
- F_g = green fallow followed by winter rye

For a more detailed explanation, see Figure 2.

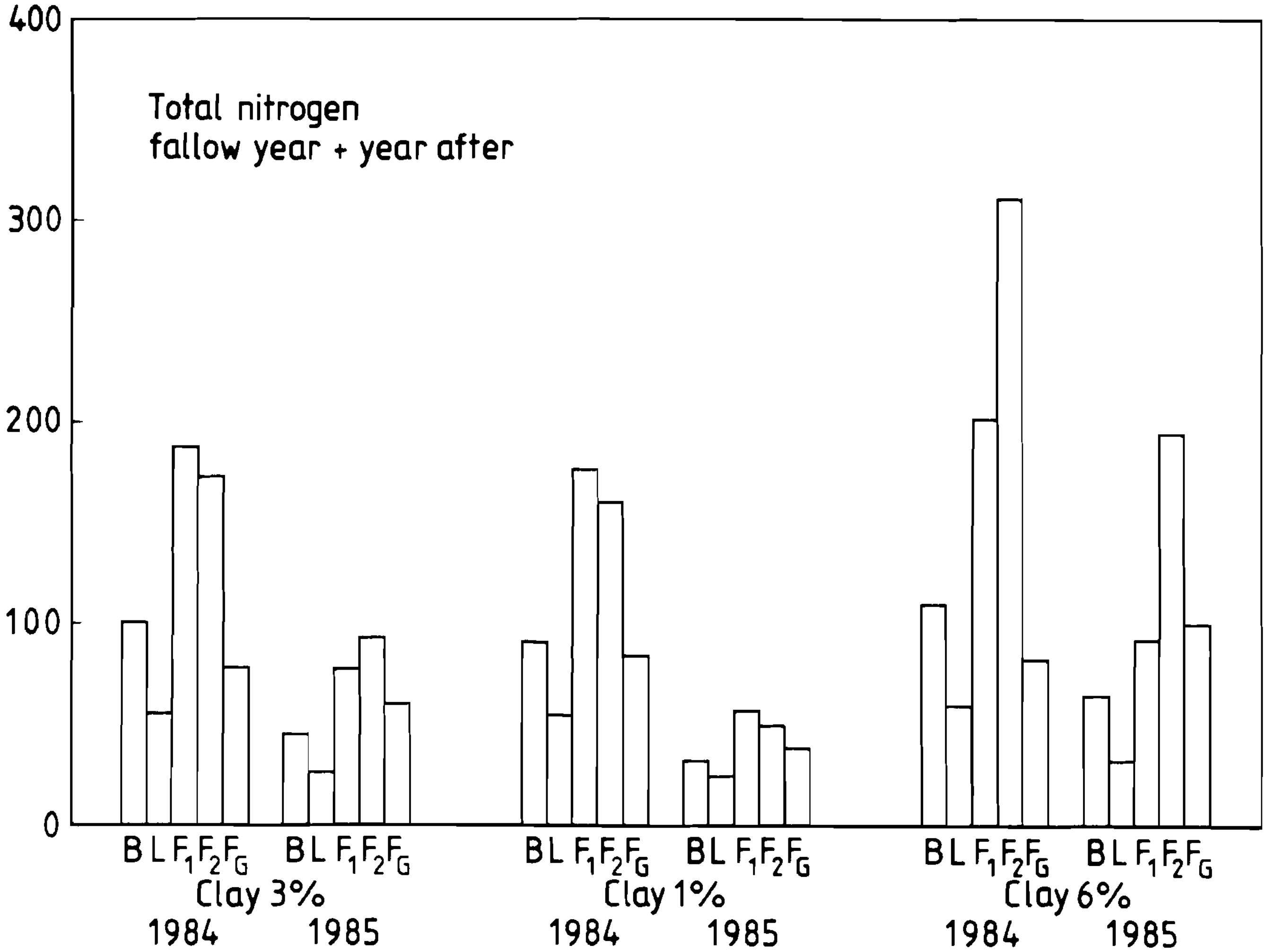

Figure 6. The relative differences in total nitrogen losses from different management practices in the fallow year (1984) and year after (1985) in clay soil with varying slope.

Legend:

- B = continuous barley
- L = 3 year ley + 3 year barley
- F_1 = fallow followed by winter rye
- F_2 = fallow followed by spring-sown barley
- F_g = green fallow followed by winter rye

For a more detailed explanation, see Figure 2.

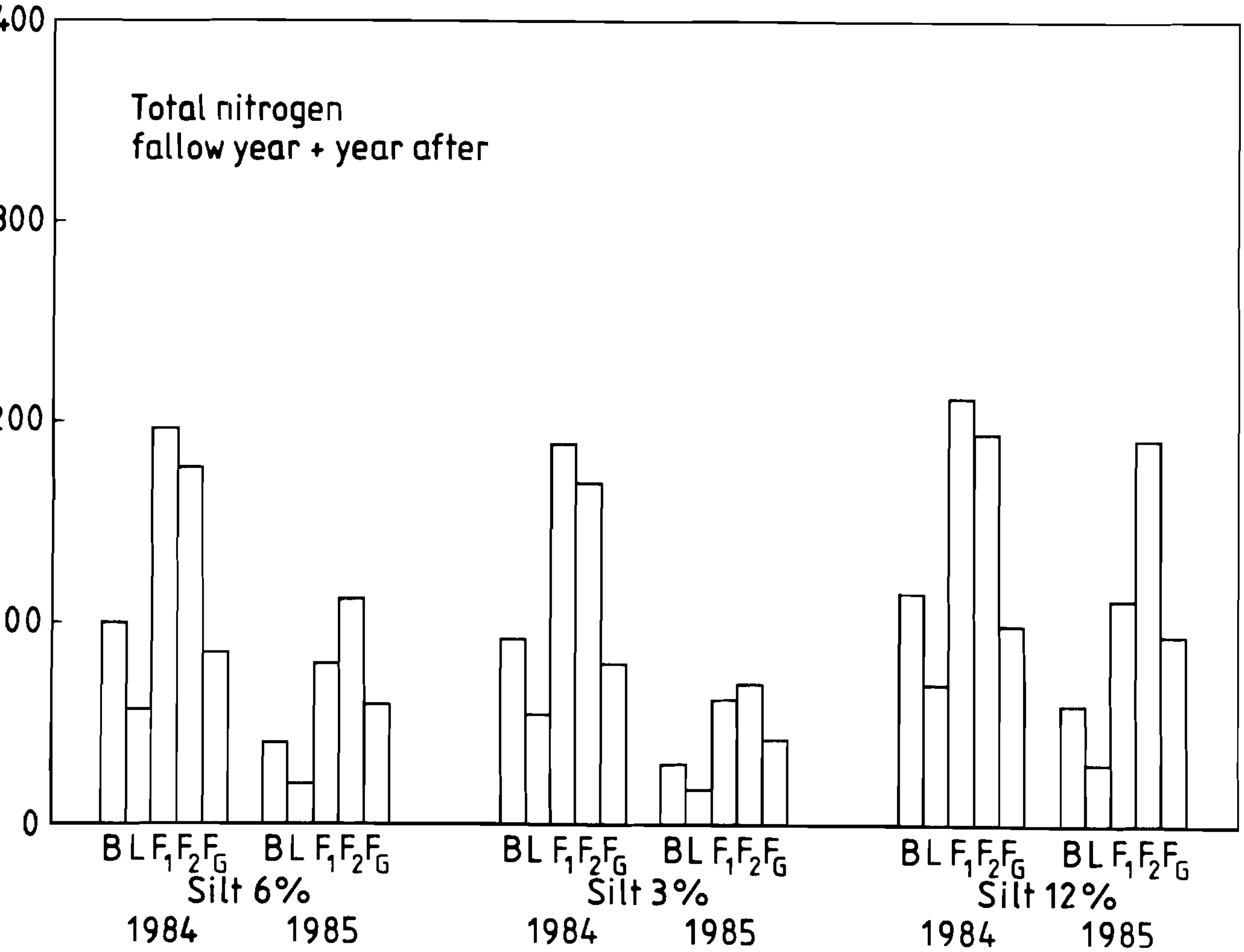

Figure 7. The relative differences in total nitrogen losses from different management practices in the fallow year (1984) and year after (1985) in silt soil with varying slope.

Legend: B = continuous barley
F_1 = fallow followed by winter rye
F_2 = fallow followed by spring-sown barley
F_g = green fallow followed by winter rye

For a more detailed explanation, see Figure 2.

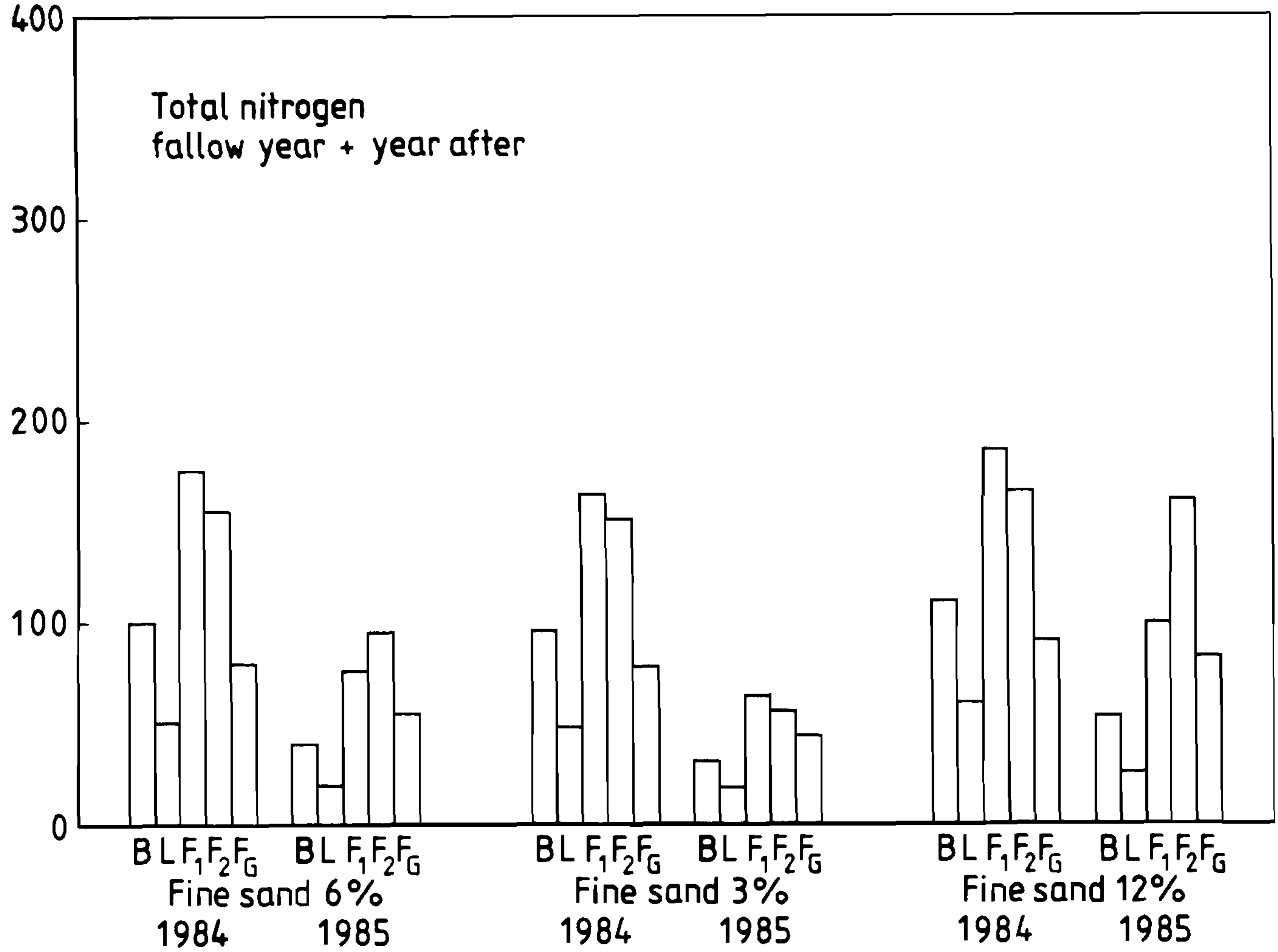

Figure 8. The relative differences in total nitrogen losses from different management practices in the fallow year (1984) and year after (1985) in fine sand soil with varying slope.

Legend:
- B = continuous barley
- L = 3 year ley + 3 year barley
- F_1 = fallow followed by winter rye
- F_2 = fallow followed by spring-sown barley
- F_g = green fallow followed by winter rye

For a more detailed explanation, see Figure 2.

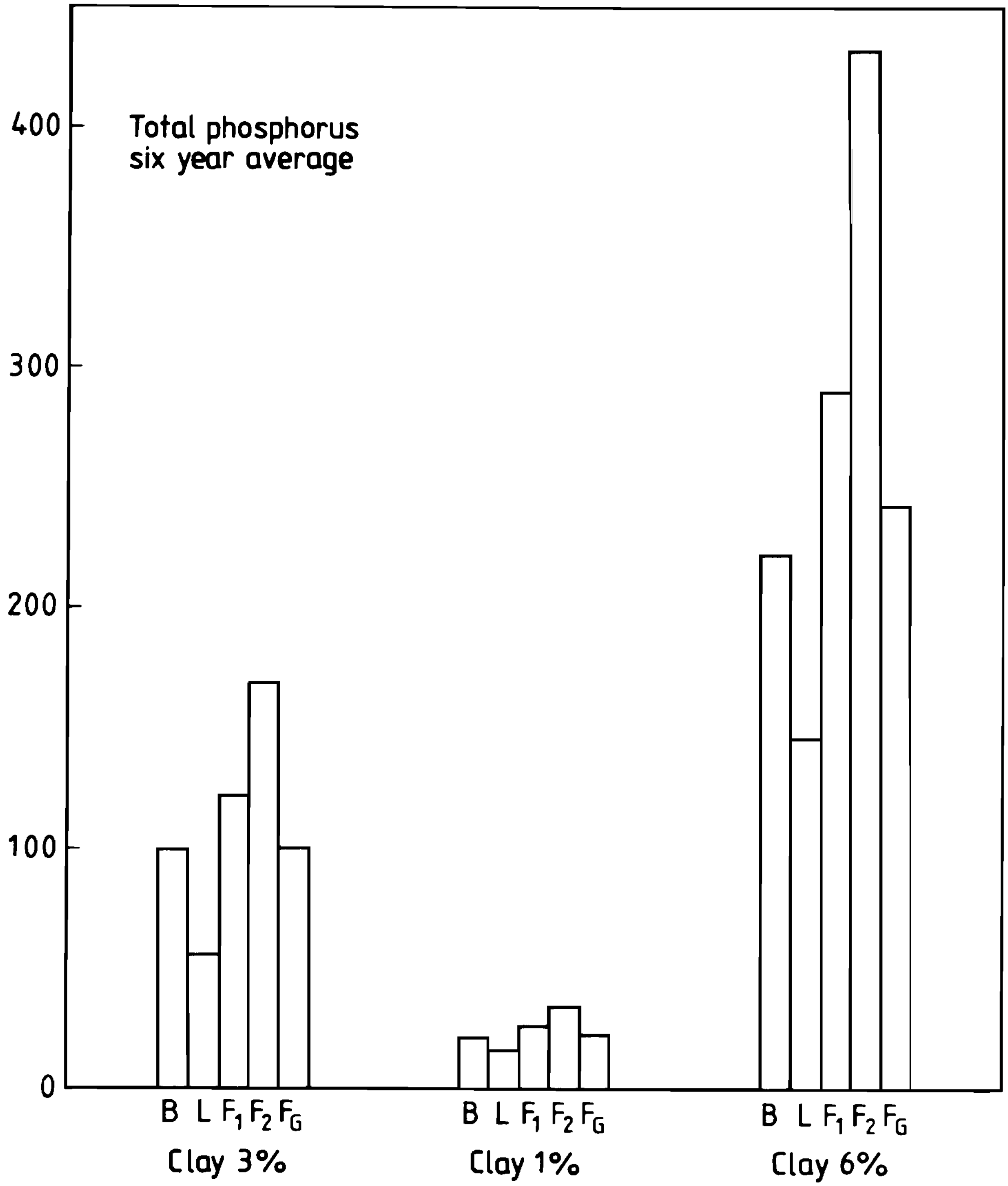

Figure 9. The relative average differences in total phosphorus losses from different management practices in clay soils with varying slope. Calculations are based on six year rotation period.

Legend:
B = continuous barley cultivation
L = 3 year ley + 3 year barley
F_1 = barley + 1 year fallow followed by winter rye
F_2 = barley + 1 year fallow followed by spring-sown barley
F_g = barley + 1 year green fallow followed by winter rye

For a more detailed explanation see Figure 2.

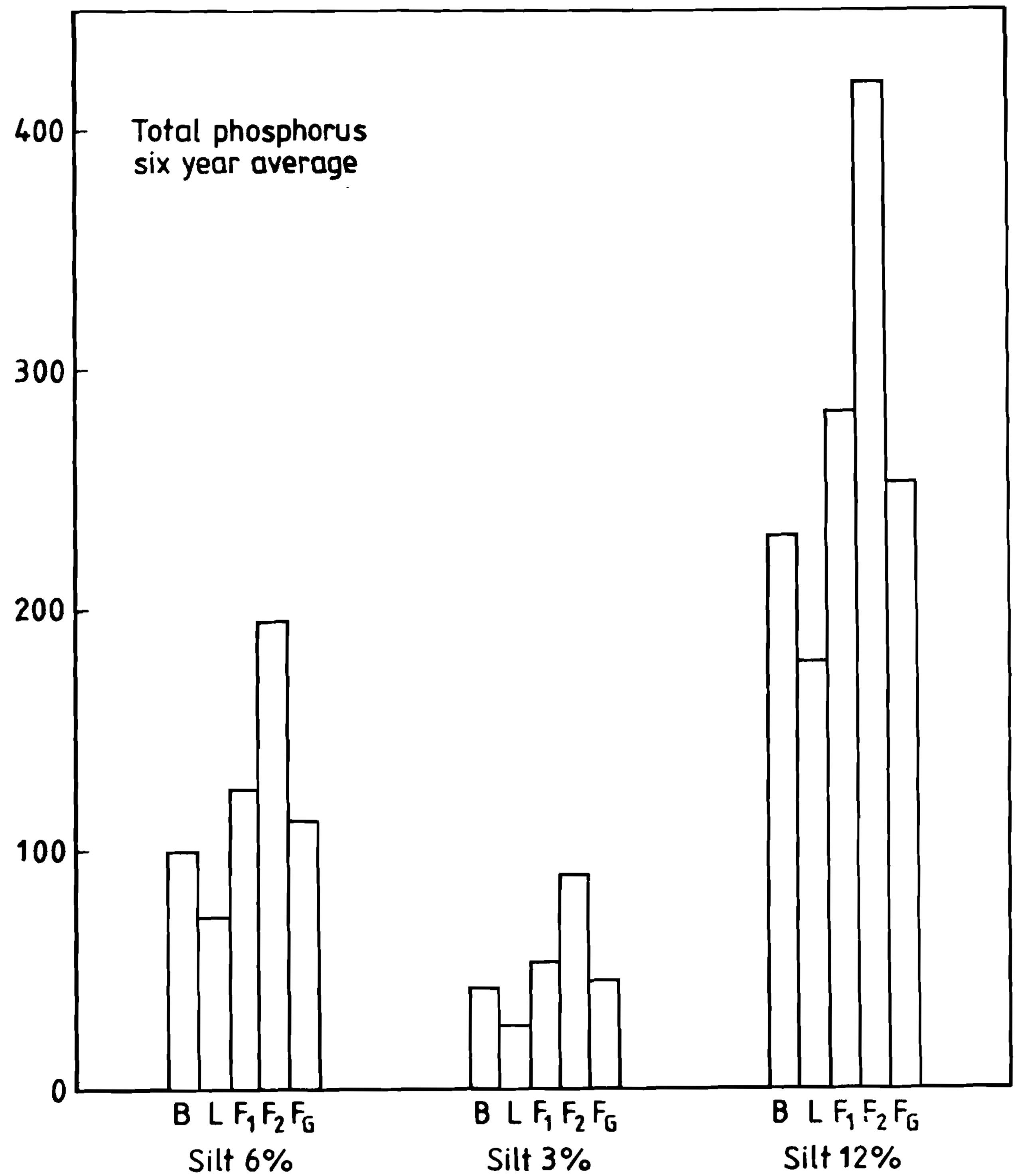

Figure 10. The relative average differences in total phosphorus losses from different management practices in silt soils with varying slope. Calculations are based on six year rotation period.

Legend:
B = continuous barley cultivation
L = 3 year ley + 3 year barley
F_1 = barley + 1 year fallow followed by winter rye
F_2 = barley + 1 year fallow followed by spring-sown barley
F_g = barley + 1 year green fallow followed by winter rye

For a more detailed explanation see Figure 2.

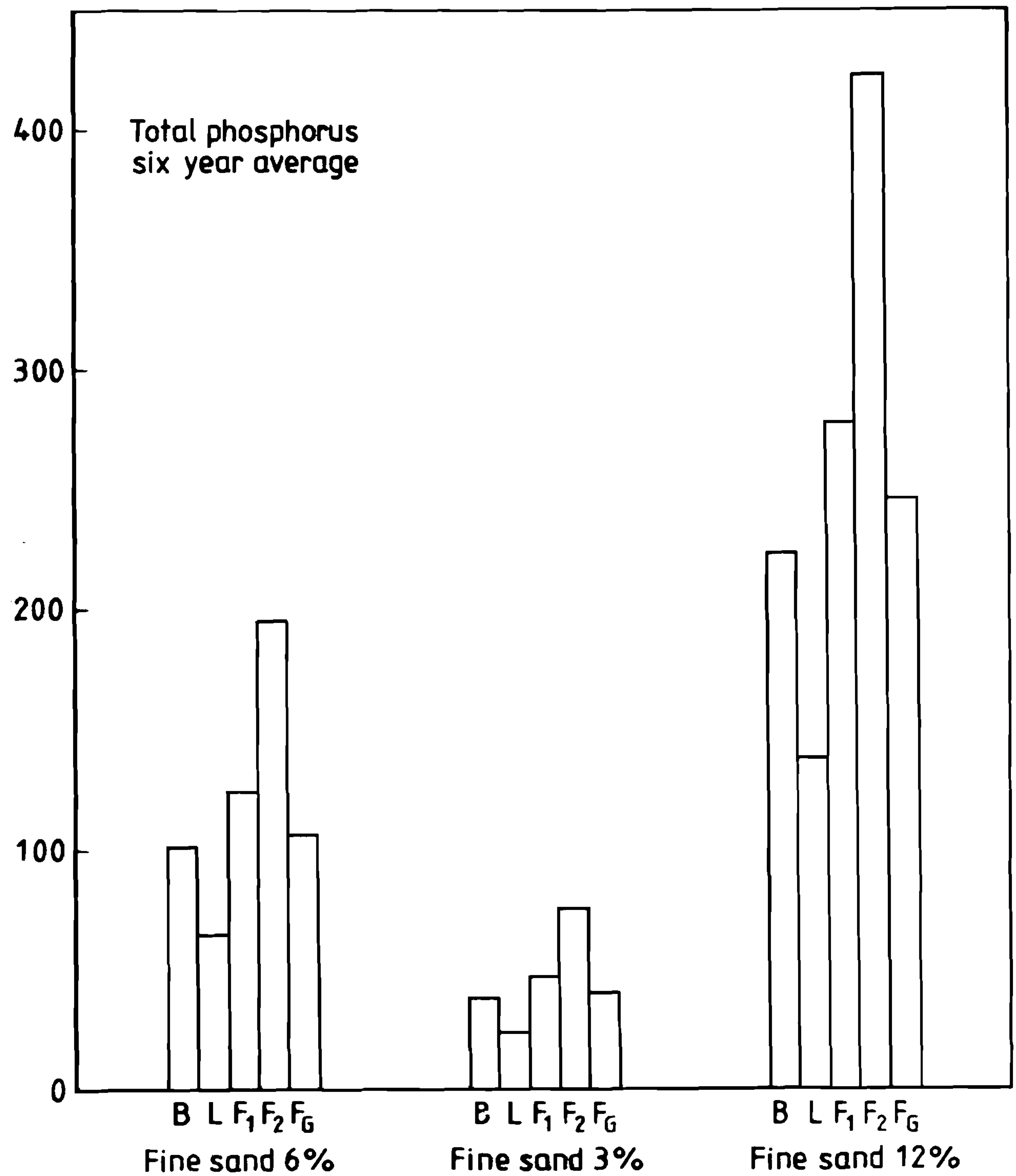

Figure 11. The relative average differences in total phosphorus losses from different management practices in fine sand soils with varying slope. Calculations are based on six year rotation period.

Legend:
B = continuous barley cultivation
L = 3 year ley + 3 year barley
F_1 = barley + 1 year fallow followed by winter rye
F_2 = barley + 1 year fallow followed by spring-sown barley
F_g = barley + 1 year green fallow followed by winter rye

For a more detailed explanation see Figure 2.

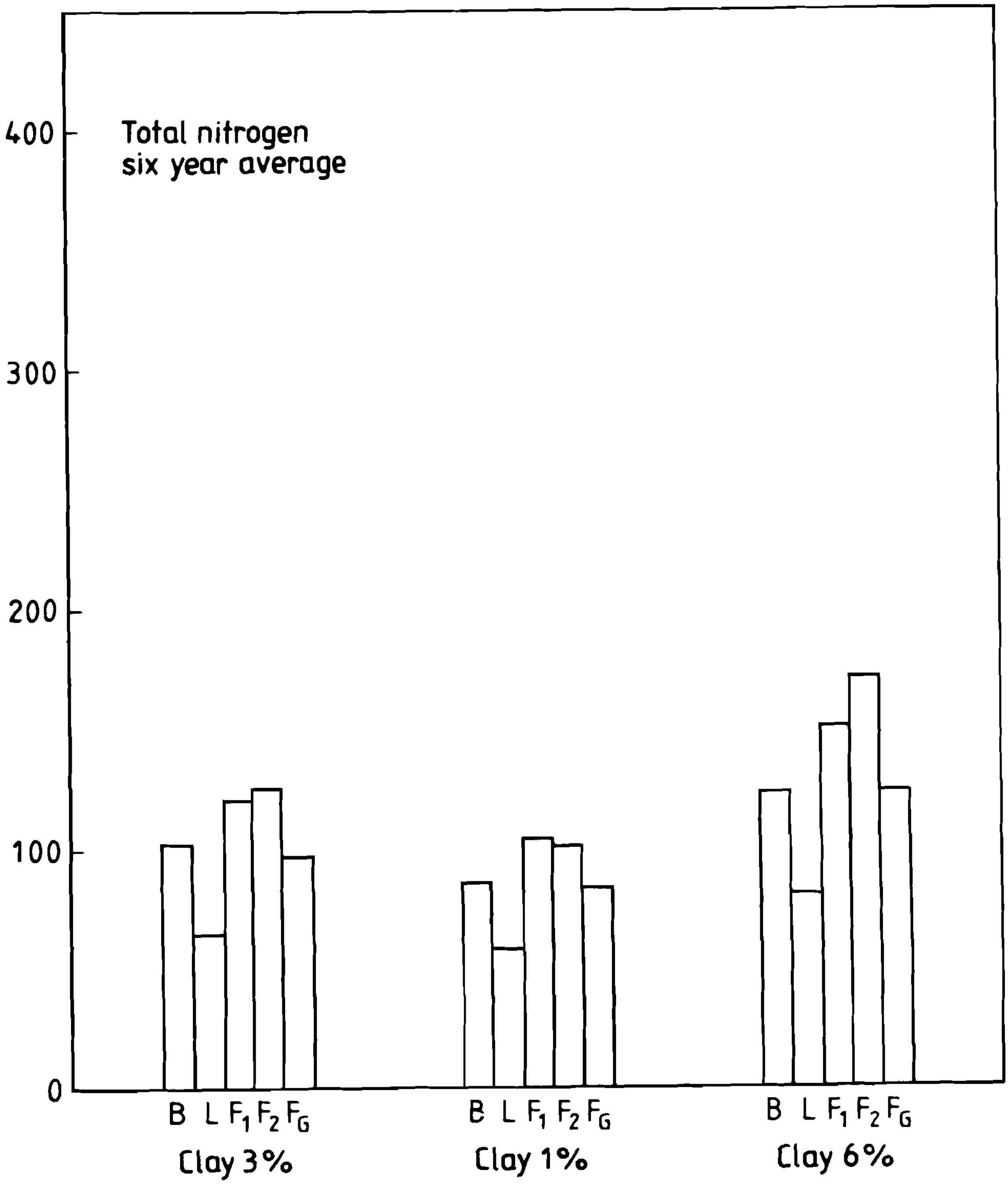

Figure 12. The relative average differences in total nitrogen losses from different management practices in clay soils with varying slope. Calculations are based on six year rotation period.

Legend: B = continuous barley cultivation
L = 3 year ley + 3 year barley
F_1 = barley + 1 year fallow followed by winter rye
F_2 = barley + 1 year fallow followed by spring-sown barley
F_g = barley + 1 year green fallow followed by winter rye

For a more detailed explanation see Figure 2.

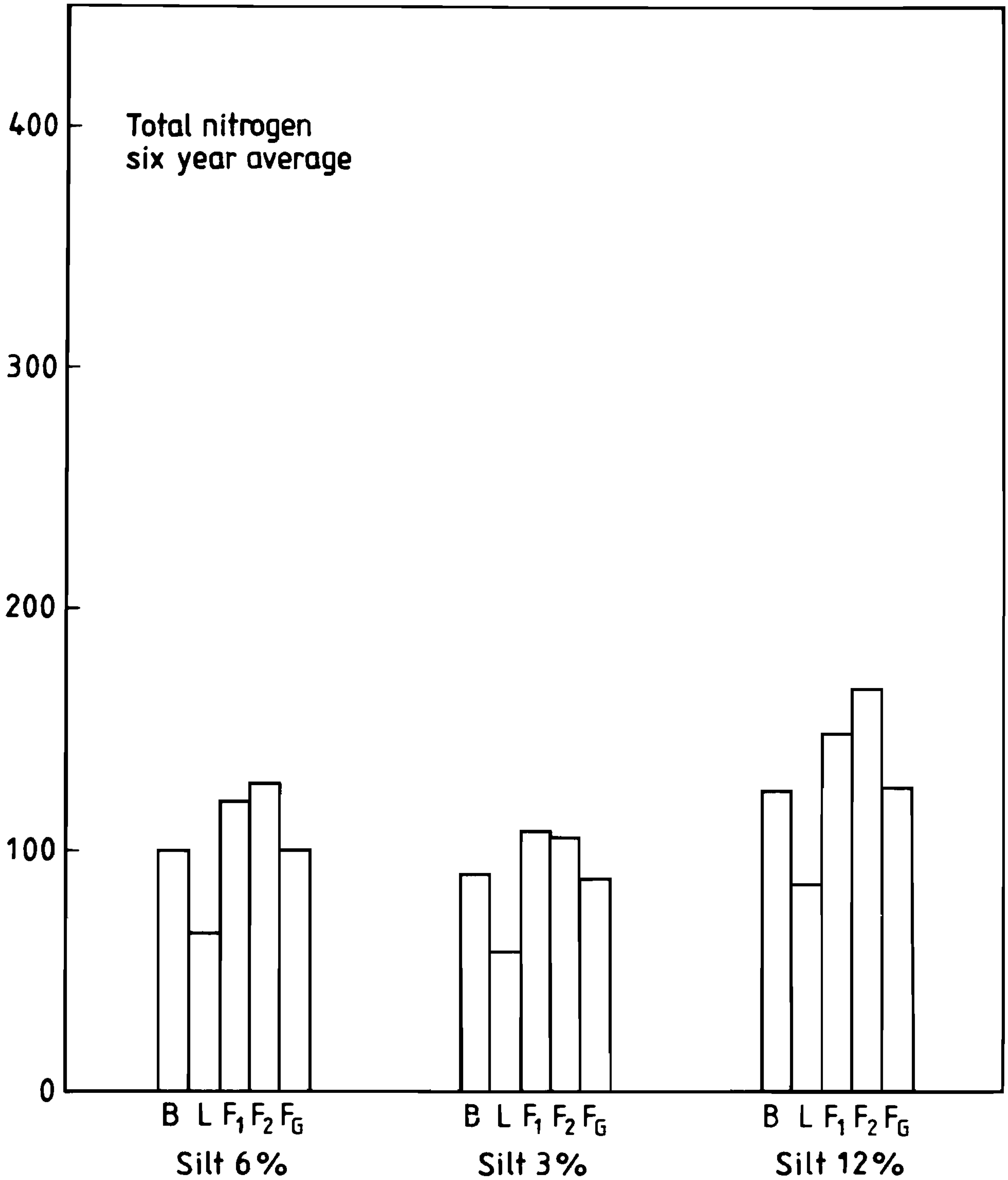

Figure 13. The relative average differences in total nitrogen losses from different management practices in silt soils with varying slope. Calculations are based on six year rotation period.

Legend:
B = continuous barley cultivation
L = 3 year ley + 3 year barley
F_1 = barley + 1 year fallow followed by winter rye
F_2 = barley + 1 year fallow followed by spring-sown barley
F_g = barley + 1 year green fallow followed by winter rye

For a more detailed explanation see Figure 2.

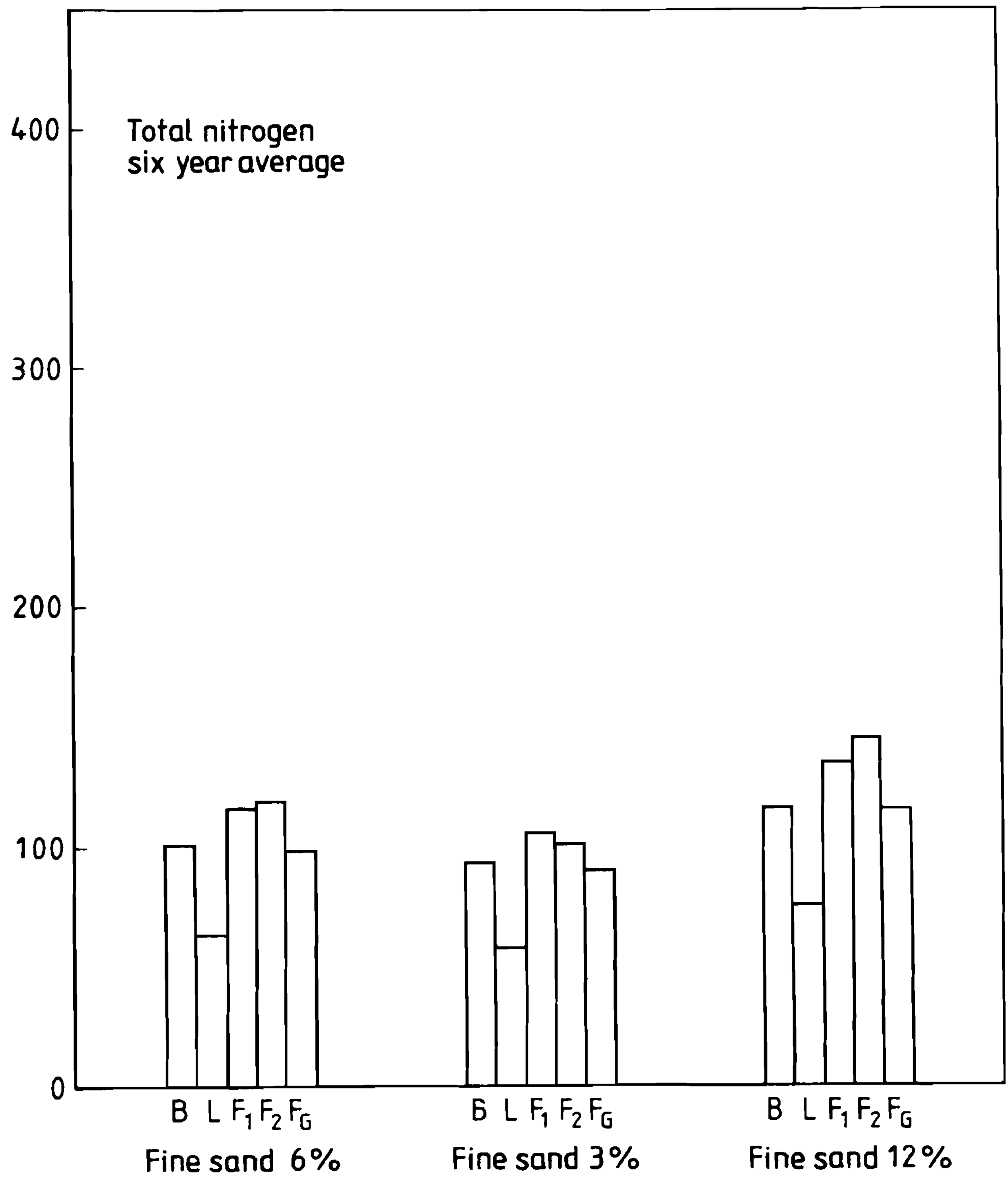

Figure 14. The relative average differences in total nitrogen losses from different management practices in fine sand soils with varying slope. Calculations are based on six year rotation period.

Legend:
B = continuous barley cultivation
L = 3 year ley + 3 year barley
F_1 = barley + 1 year fallow followed by winter rye
F_2 = barley + 1 year fallow followed by spring-sown barley
F_g = barley + 1 year green fallow followed by winter rye

For a more detailed explanation see Figure 2.