Applying the concept of test plane for the selection, we get the following conditions on a point to belong to 2DPT:

$$\pm (p_i + q_i) + \tau (1 + q_i) > 0,$$

$$(1 + p_i + q_i) + (1 \pm q_i) > 0.$$

The upper signs are used for the first and second test planes and the lower signs are used for the third and fourth test planes. The pattern generated by the above conditions on a given range of m, n, p and q is shown in Figure 6. It comprises the 2DPT vertices and a global fivefold rotational centre.

Starting with the novel geometrical algorithm proposed by Ramachandrarao *et al.*[9], we have derived analytical conditions for the generation of 2DPT. We establish an entirely new algorithm to generate 2DPT and make the geometrical algorithm only a mental aid. The present approach highlights effectively certain interesting aspects of quasiperiodic lattices. A relation between the indices (m, n, p, q) with the indices in higher-dimensional space (M_i) is also rewarding in considering the geometrical algorithm in 5D space. This study, for the first time, establishes a long-range definite mathematical order among the vertices selected by a window (results to be published elsewhere).

1. Penrose, R., *Bull Inst Math Appl*, 1974, **10**, 266–271
2. Makay, A L., *Sov. Phys Crystallogr.*, 1981, **26**, 517–522.
3 Schechtman, D , Blech, I , Gratias, D and Cahn, J. W , *Phys Rev Lett*, 1984, **53**, 1951–1953
4 Levine, D and Steinhardt, P J , *Phys Rev Lett*, 1984, **53**, 2477–2480
5. Conway, J. H and Knowles, K. M , *J. Phys A*, 1986, **A19**, 3645–3653.
6 Bruijn, N G de, *Proc K Ned. Akad Wet Ser*, 1981, **A43**, 39–66
7. Jaric, M V , *Phys Rev B*, 1986, **B36**, 4685–4698.
8. Sasisekharan, V , *Pramana*, 1986, **26**, L283–294
9 Ramachandrarao, P , Sastry, G V. S , Pandey, L. and Sinha, A , *Acta Crystallogr*, 1991, **A47**, 206–210
10. Sinha, A , Ph D Thesis, Banaras Hindu University, 1993

ACKNOWLEDGEMENTS. We are grateful to Prof S Lele, Prof S. Ranganathan, Prof E. S R Gopal and Dr R. K. Mandal for the fruitful discussions during this work. The financial support from DST and CSIR is also acknowledged

Received 17 June 1994, revised accepted 6 October 1994

Application of drag-reducing polymers in agriculture

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Drag-reducing polymers reduce the drag in a turbulent flow (by a mechanism not yet fully understood) while increasing the drag in a laminar flow, due to an increase in the shear viscosity. This feature of drag-reducing polymers has been utilized in reducing the energy requirements of sprinkler irrigation systems. Their use also increases the water throughput and the area of coverage of the sprinkler irrigation system. The water containing drag-reducing polymers percolates slowly in the soil, thus reducing the percolation losses of water. Utilizing this aspect, a slow-release urea has been developed by blending urea with guargum. The present paper outlines the results of a detailed investigation carried out at the Indian Institute of Technology, Kharagpur, on the application of drag-reducing polymers in agriculture.

EXTREMELY minute concentrations of large polymer molecules, fibres or particles when present in a fluid cause reduction in the friction resistance in a turbulent flow compared to that of the fluid alone. This phenomenon is called drag reduction and was first reported by Toms[1] in 1949. The historical perspectives of drag reduction phenomenon have recently been illustrated in the review of Singh[2]. In 1961, US Naval Laboratories began an investigation into drag reduction. The creditable studies of their scientists have given new dimensions to research in the field of turbulent drag reduction and drew worldwide attention. The practical implications of this phenomenon were first realized by Savins[3], who also applied the term drag reduction for the first time. A large number of papers and reports on an international scale confirming and extending the details of the drag reduction effect have appeared since these early investigations. The recent papers by Hoyt[4], Singh[2] and Shenoy[5] review the various aspects of this phenomenon and are good general references. Ever since the discovery of drag reduction with additives, many practical applications have been suggested and a few have already materialized. The list of possible areas of applications has increased enormously to include oil well fracturing, crude oil and refined petroleum product transport, fire fighting, irrigation, sewage and flood water disposal, hydrotransport of solids, water heating circuits, jet cutting, hydraulic machinery, marine applications and biomedical applications. A review by Sellin *et al.*[6] covers the progress in all these application fields except for biomedical applications. Sellin's review paper[7] discusses the applications of drag reduction with more emphasis on sewage and flood water disposals. Pollert[8] discusses its applications in the field of hydrotransport of solids, water heating circuits and agricultural irrigation in detail.

A programme of drag reduction investigations was initiated at the Indian Institute of Technology, Kharagpur, India, in 1978, which has continued until now[9-14]. The main purpose of this programme was to develop new polymeric drag reducers, to study their effectiveness, to investigate polymer degradation and to explore the feasibility of applying drag reducing phenomenon in various fields like slurry transport, sprinkler irrigation and aerofoil systems. Drag-reducing polymers reduce the drag in a turbulent flow while increasing the drag in a laminar flow, due to an increase in the shear viscosity. At the Indian Institute of Technology, Kharagpur, these aspects of drag-reducing polymers have been successfully applied in reducing the energy requirements of sprinkler irrigation systems, and in reducing the percolation losses through soil as well as in the development of slow-release urea. This paper reports the details of these aspects along with the effect of drag-reducing polymers on plant growth and evaporation suppression.

In surface irrigation systems water flows through unlined earth channels. Sprinkler irrigation can be used to prevent seepage losses and control irrigation. About 30–40% of water can be saved[15]. Burt and Keller[16] have concluded that in countries like India and Pakistan sprinkler irrigation is not possible due to high initial and operating cost. A major factor preventing the use of sprinkler irrigation is the high energy requirement. The solution to energy crisis lies both in reducing energy consumption and in developing new sources of energy. The sprinkler irrigation system is operated under turbulent flow conditions, in distribution pipes, in the riser and in the ejected water jet. Hence, application of the turbulent drag reduction phenomenon can be useful in reducing the energy requirements and thereby saving power and fuel consumption.

The application of turbulent drag reduction in sprinkler irrigation was first demonstrated by Union Carbide Company, USA, in 1966. They used polyox and observed an increase in the radius of coverage and a reduction in the energy requirement.

Significant research was also carried out in Czechoslovakia to explore the feasibility of this phenomenon in sprinkler irrigation[17]. In India, the research in this field began in 1978. Holey *et al.*[18] conducted experiments with 30 ppm concentration of polyethylene oxide (PEO) (Polyox WSR-205 BDH, UK). The results showed a positive gain in power reduction and an increase in the radius of coverage of the sprinkler irrigation system. After these early results the study was extended to other polymers such as polyacrylamide (PAM), xanthangum (XG), guargum (GG), carboxymethyl cellulose (CMC), etc., under varying experimental conditions[11]. A typical sprinkler irrigation system was used in the following experiments. In the subsequent runs, polymer-added water was used as the test fluid. The operating pressure and discharge of the system were controlled with the help of gate valves. Premixed polymer solutions were used instead of polymer injections. Operating pressures were in the range 0.104–0.224 MPa. Polymers studied were PEO, PAM, XG and GG. Three parameters, viz. the radius of coverage and hence the area of coverage, drag reduction between two adjacent nozzles and finally the reduction in power consumption, have been determined to evaluate the effectiveness of the polymers. The results are briefly discussed here.

The radius of coverage of the sprinkler nozzle is a function of the available pressure at the nozzle, particle size and resistance to air. Other operating conditions being more or less the same, increase in radius of coverage is an indirect measure of drag reduction. Percentage increase in the radius of coverage was calculated by using the following equations:

$$R(\%) = \frac{(R_s - R_w)}{R_w} \times 100, \tag{1}$$

where subscripts s and w denote solution and water alone, respectively. In the case of polymer-added water, the radius of coverage was found to increase at all operating pressures, ranging from 0.104 MPa to 0.224 MPa. There exists a linear relationship between radius of coverage and operating pressures. Table 1 gives the percentage increase in the radius of coverage by application of four different polymers at various concentrations of polymers and varying operating pressures. The maximum average percentage increase was found to

Table 1. Percentage increase in radius of coverage by sprinklers at different operating pressures

Operating pressure (kg/cm²)	Polyacrylamide (PAM)		Polyethylene oxide (PEO)		Xanthangum (XGM)		Guargum (GGM)	
	10 ppm	25 ppm	20 ppm	30 ppm	50 ppm	100 ppm	500 ppm	1000 ppm
1.06	13.3	20.0	26.7	33.3	40.0	46.7	33.3	40.0
1.33	–	18.8	28.1	31.3	37.5	–	27.5	31.3
1.41	5.9	23.5	26.5	29.4	35.3	50.0	29.4	35.3
1.58	–	22.9	–	31.4	42.9	42.9	28.6	37.1
1.76	12.0	14.6	14.6	25.0	30.2	35.4	22.4	27.6
1.93	–	12.5	15.0	22.5	27.5	35.0	25.0	30.0
2.11	7.3	12.2	14.6	22.0	24.4	34.2	26.8	31.7
2.29	9.9	9.3	16.3	18.6	20.9	30.4	25.6	27.9
Average	9.7	16.7	20.3	26.7	32.3	39.2	27.3	32.6

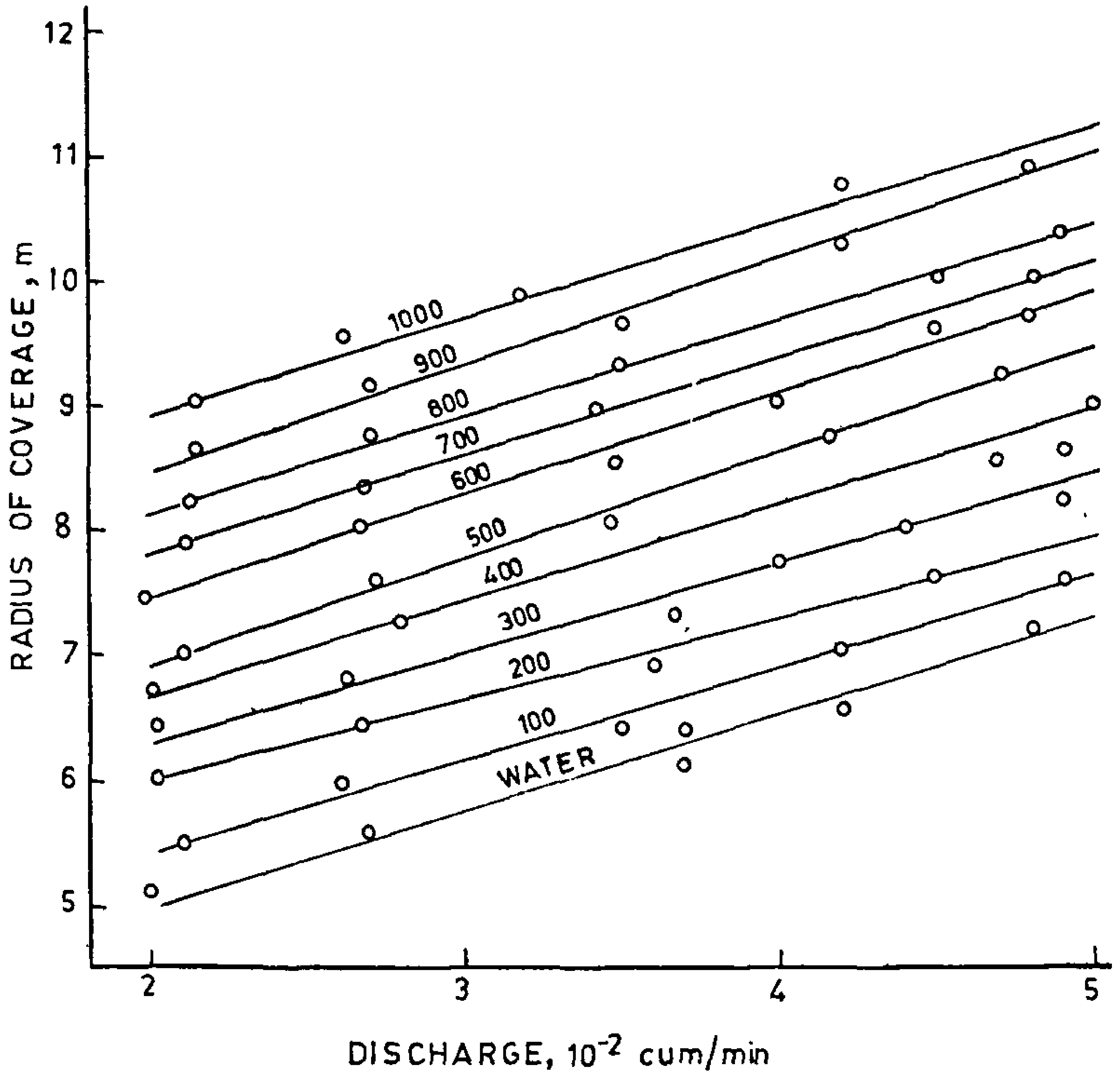

Figure 1. Effect of various concentrations of guargum on radius of coverage by sprinkler nozzles

be 39.2% in the case of 100 ppm xanthangum solution (Industrial grade, Kelco, USA). It was followed by 1000 ppm guargum (32.6%), 50 ppm xanthangum (32.3%), 500 ppm guargum (27.3%), 30 ppm PEO (26.7%) and 20 ppm PEO. Thus, all the polymers were found to be drag reducers, though the degree of effectiveness is different. The drag reduction phenomenon not only helps in the availability of greater pressures at the nozzle, but also in reducing the air drag on the liquid droplets. A jet of polymer-added water was found to be more coherent than that of water alone.

In another study[14] the effectiveness of purified guargum in increasing the radius of coverage was studied. The concentration range was 100–1000 ppm; the results are presented in Figure 1. It was observed that *R* increases with increase in guargum concentration. The purification of guargum by the method given by Whitcomb *et al.*[19] causes improvement in the effectiveness as is evident from a comparison of the data obtained by purified guargum and commercial guargum.

Drag reduction is defined as[3]

$$\text{drag reduction (\%)} = \frac{\Delta\rho_s - \Delta\rho_p}{\Delta\rho_s} \times 100, \qquad (2)$$

where $\Delta\rho_s$ = pressure drop in a given length of tube for the solvent and $\Delta\rho_p$ = pressure drop for the polymer solution, with the same flow rate of liquid for both. As it is customary in drag reduction literature, water-based Reynold's number ($\bar{u}D/\nu$, where $\bar{u}$ is the average velocity, D the diameter of pipe and ν the kinematic viscosity) has been used and percentage drag reduction vs Reynold's has been plotted in Figure 2. The percentage drag reduction was found to increase with increase in Reynold's number. Drag reduction was found to increase with concentration of the polymer. Among the gums, purified guargum gave maximum drag reduction of 58% at 1000 ppm concentrations.

Preliminary investigation by Sankar[11] in a sprinkler set-up having two bends and three nozzles placed in a straight line indicated that energy saving of up to 46% is possible by the use of 30 ppm PEO. It was also found that the number of bends had considerable influence on the effectiveness of the polymers. However, for a normal sprinkler irrigation system, the number of bends are likely to be more than two.

Detailed study on the energy consumption aspect was, therefore, conducted in a set-up having nine bends to provide a more realistic overall picture under adverse

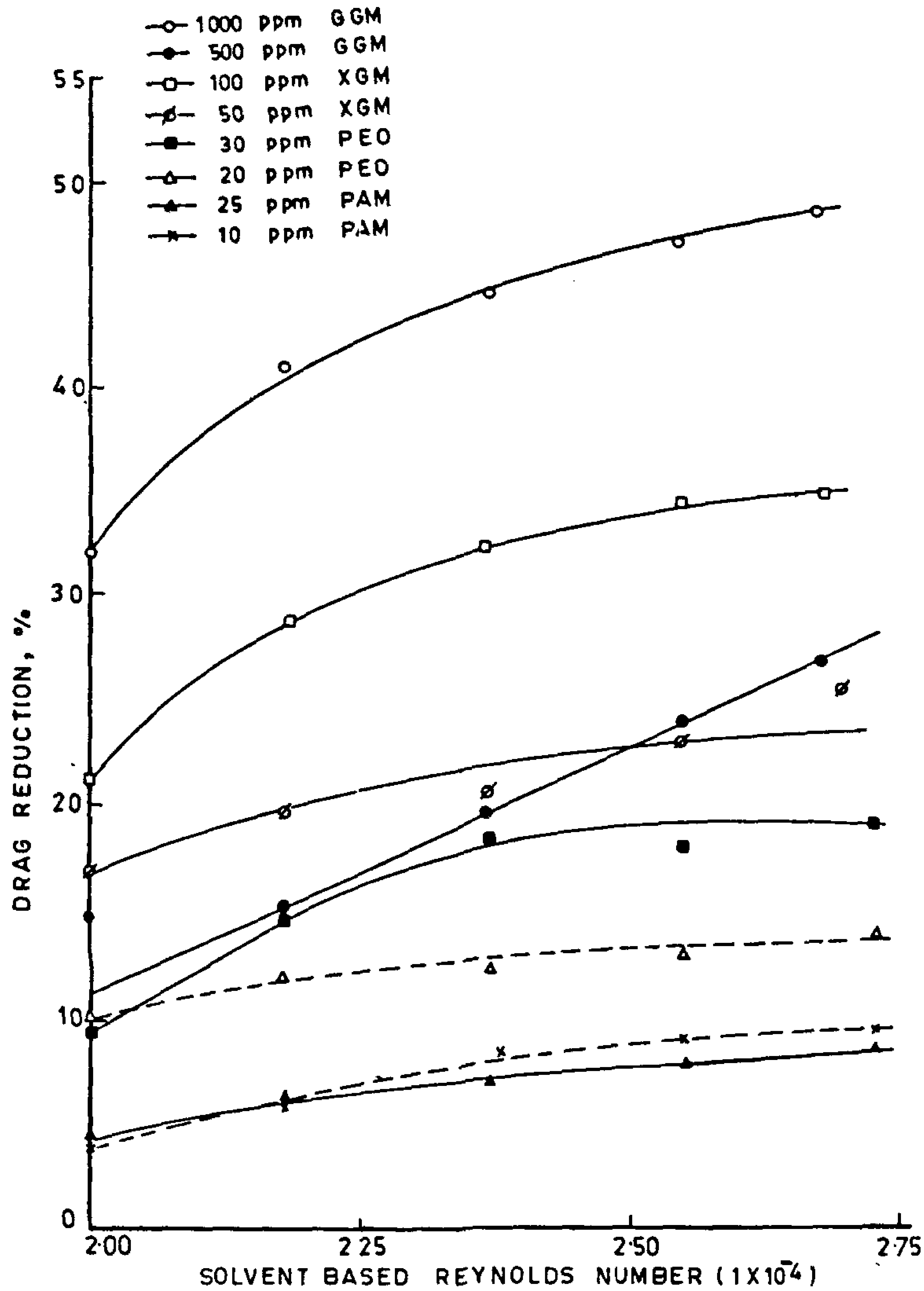

Figure 2. Change in drag reduction as influenced by different concentrations of polymers in water

conditions. The results are shown in Figure 3. Again, purified guargum at higher concentration (1000 ppm) was found to give more decrease in energy consumption. Reduction in the energy consumption due to polymer addition was more when the discharge rates were higher. In a recent study[20], while using a sprinkler irrigation set-up having only one bend, even the use of commercial and purified guargum gave a maximum reduction of about 28% in the energy requirement, at concentrations of 300 and 100 ppm, respectively. The results so far have shown that there is definite saving of energy with the addition of polymer.

To study the effect of sprinkling polymer solution on the plant, the following study[11] was conducted. The test crop chosen was wheat and the statistical design was used. Irrigation was given taking IW/CPE ratio to be 0.9. In order to simulate the spraying action of the sprinkler, two manually operated sprayers were used to apply solutions on the plant cover. The results are shown in Tables 2 and 3. It was observed that at lower concentrations, none of the polymers showed any adverse effect on plant growth. Guargum and CMC treatment showed poor performance. This can be attributed to their high concentrations. In both the cases, the concentrations were higher than 100 ppm. Due to the high concentrations of gum, the leaves were glued to the stem and soil surface, which might have hindered the photosynthesis of the plants.

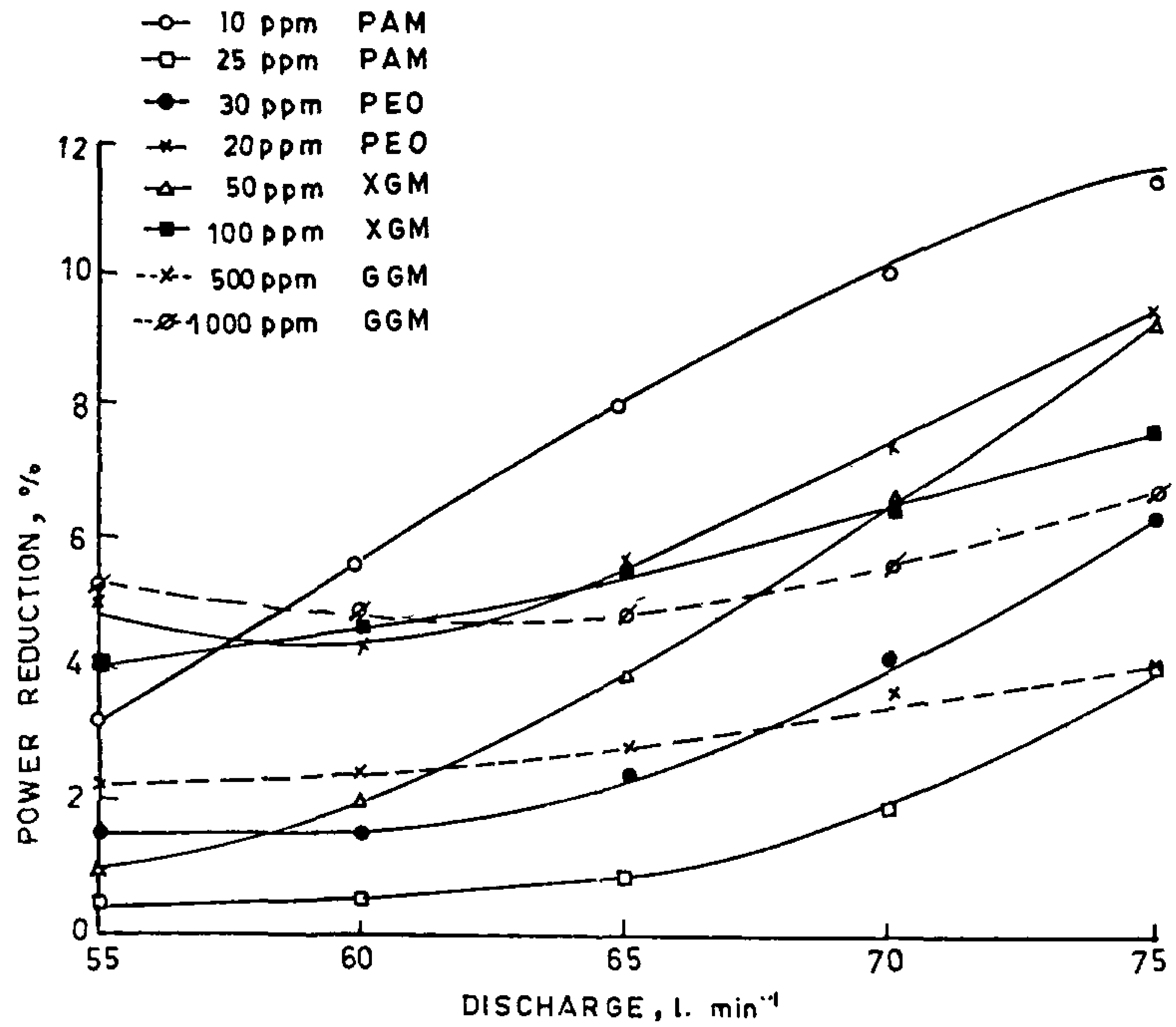

Figure 3. Relationship between power reduction and discharge as influenced by polymer concentrations

Table 2. Yield and yield attributes in wheat as influenced by irrigation with polymer solution (polymer typewise)

Treatment	Productive tlllers (no)	Length of ear (cm)	Grains per ear (no)	Test weight (g)	Grain yield (g pot^{-1})	Straw yield (g pot^{-1})
Water	3.47	7 11	21 55	29.42	5 61	15 43
Polymer	2.81	6.48	14 77	29 22	4 55	13 77
SE_m	0 21	0.38	1 20	NS	0 19	0 50
CD, $P = 0.05$	0 42	0 76	2 39	–	0.39	1 01
CD, $P = 0\ 01$	0.55	1 01	3 18	–	0 51	1 34
Polymer						
PEO	3 16	7 01	21 85	29 92	5 25	15 54
PAM	3 53	7.12	20 93	30 13	5 82	16 43
XG	2 89	6 83	19 69	29 82	4 61	14 44
GG	2 53	6 00	17 60	28 98	3 94	13 89
CMC	1 96	5 42	15 63	27.23	3.15	8 55
SE_m	0 17	0.20	0 45	NS	0 15	0.79
CD, $P = 0\ 05$	0 33	0 41	1 89	–	0 30	0.79
CD, $P = 0\ 01$	0 44	0 54	2 56	–	0 40	1 06

*Statistically not analysed.
CMC Carboxymethyl cellulose.
GG Guargum
PAM Polyacrylamide
PEO Polyethylene oxide
XG Xanthangum
CD Critical difference.
NS Nonsignificant
SE_m Standard error of mean

Table 3. Yield and yield attributes as influenced by irrigation water mixed with polymers (concentrationwise)

Treatment	Polymer conc (wt ppm)	Productive tillers	Length of ear	Grains per ear	Test weight	Grain yield (q pot^{-1})	Straw yield (q pot^{-1})
PEO	20	3 27	7 22	21.37	30.31	5 54	16 02
PAM	30	3 47	6 80	22 34	29 52	5 09	15 27
XG	50	2 73	7 01	21 84	29 93	5 13	15 33
SE_m		NS	NS	NS	NS	NS	NS
PAM	10	3 67	7 40	22 86	31 01	6 20	17 03
PAM	25	3.60	7 19	19 74	29 87	5 60	15 91
XG	50	3 33	6 77	20 18	29 53	5 66	16 36
SE_m	NS	NS	NS	NS	NS	NS	NS
XG	100	2.93	6 71	19 51	29 31	4 98	14.74
XG	150	2 87	6 84	19 80	30 42	4 59	14 63
XG	200	2 87	6.93	19.77	29 72	4 31	14 05
SE_m	NS	NS	NS	NS	NS	NS	NS
GG	100	2 60	6.59	18.32	29 05	3 98	13 98
GG	2000	2 60	5.78	17 43	29.51	3 99	14 15
GG	3000	2 40	5 64	17 13	28 37	3 86	13 54
SE_m		NS	0 352	NS	NS	NS	NS
CD, P = 0 05		–	0 704	–	–	–	–
CD, P = 0 01		–	0 936	–	–	–	–
CMC	2500	2 20	5 81	17.31	27 45	3 40	8 95
CMC	5000	2.07	5 44	14 98	27.62	3 25	8 76
SE_m		NS	NS	NS	NS	NS	NS
CD, P = 0 05		–	–	–	–	–	–
CD, P = 0 01		–	–	–	–	–	–

*Statistically not analysed.
CMC Carboxymethyl cellulose.
GG Guargum
PAM Polyacrylamide
PEO Polyethylene oxide.
XG Xanthangum.
CD Critical difference.
NS Nonsignificant
SE_m Standard error of mean

To study the percolation losses or the hydraulic conductivity, a typical constant-head permeameter was used[11, 13, 14]. Various sand compositions have been used in the permeameter. The physical properties of sand were measured by standard methods. The Mariottic bottle was filled with water or polymer solution and was made airtight by applying wax. The volume of the percolated water or the water passed through the sand block at various time intervals was recorded. After each test, sand block was washed thoroughly for more than two hours to remove any trace of polymer. Hydraulic conductivity was evaluated applying Darcey's law, which states that the quantity of water passing through a unit cross-section of soil is proportional to the gradient of hydraulic head. In mathematical symbols, Darcey's law is

$$Q = K \times i \times a, \qquad (3)$$

where

Q = volume of flow per unit time, cc/s,

i = hydraulic gradient, dimensionless,

a = cross-section of flow area, cm^2,

K = hydraulic conductivity, cm/s.

The polymers used to study percolation losses were guargum and CMC. The results are shown in Figures 4 and 5 as flux versus time and hydraulic conductivity versus concentration. It was observed in the first set of experiments[11] that the hydraulic conductivity was reduced to 86% and 99% in cases of 1000 ppm guargum and CMC, respectively. Attention was then paid to studying the effect of concentration on hydraulic conductivity[14]. It has been observed that with increase in concentration, the reduction in hydraulic conductivity is more. Up to 800 ppm concentration, there is significant increase in reduction of hydraulic conductivity. However, with further increase in concentration the increase in reduction of hydraulic conductivity is very small. The extent of reduction of hydraulic conductivity is exponential. The relation between percentage reduction in

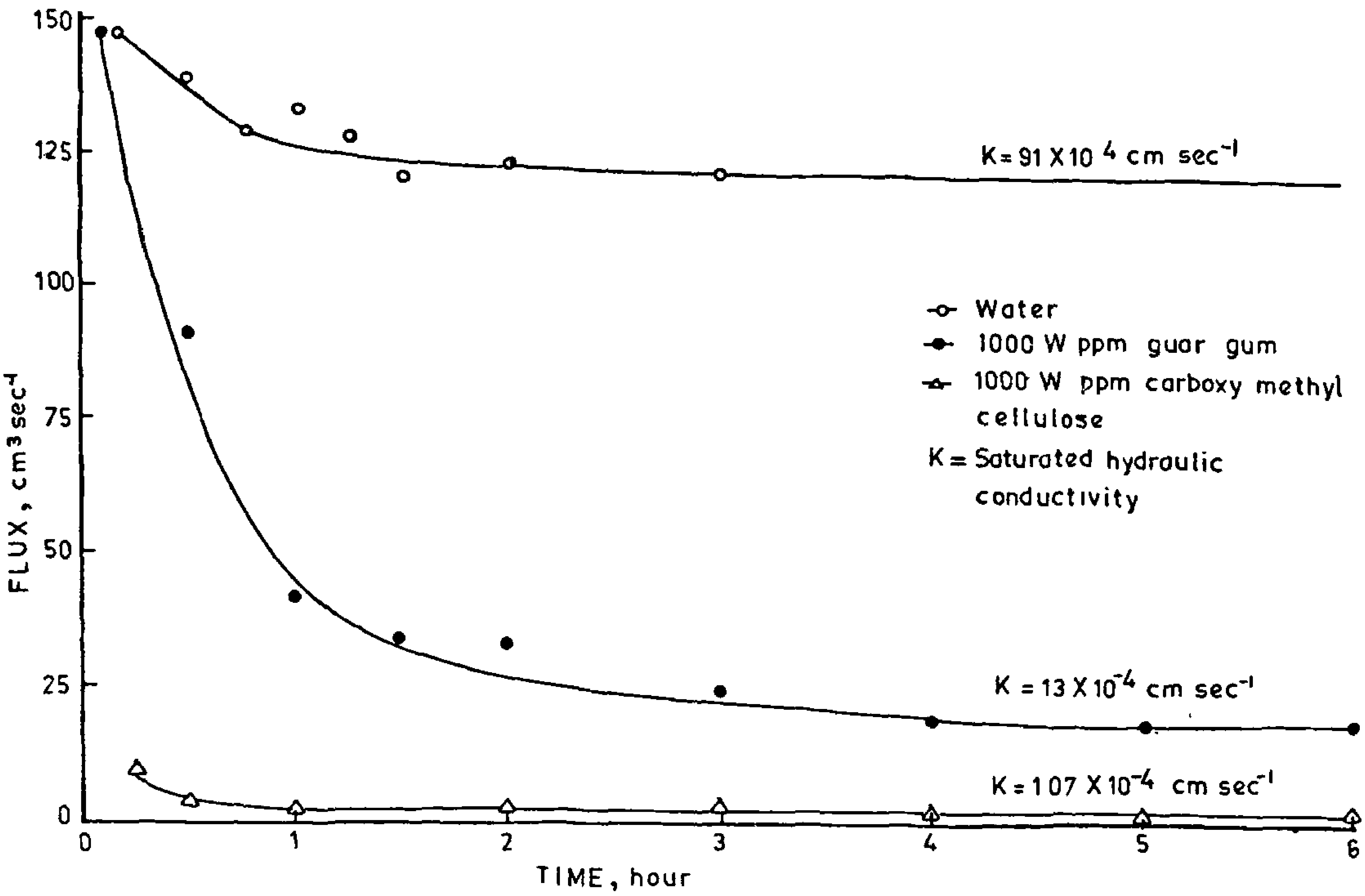

Figure 4. Effect of polymer solution on hydraulic conductivity

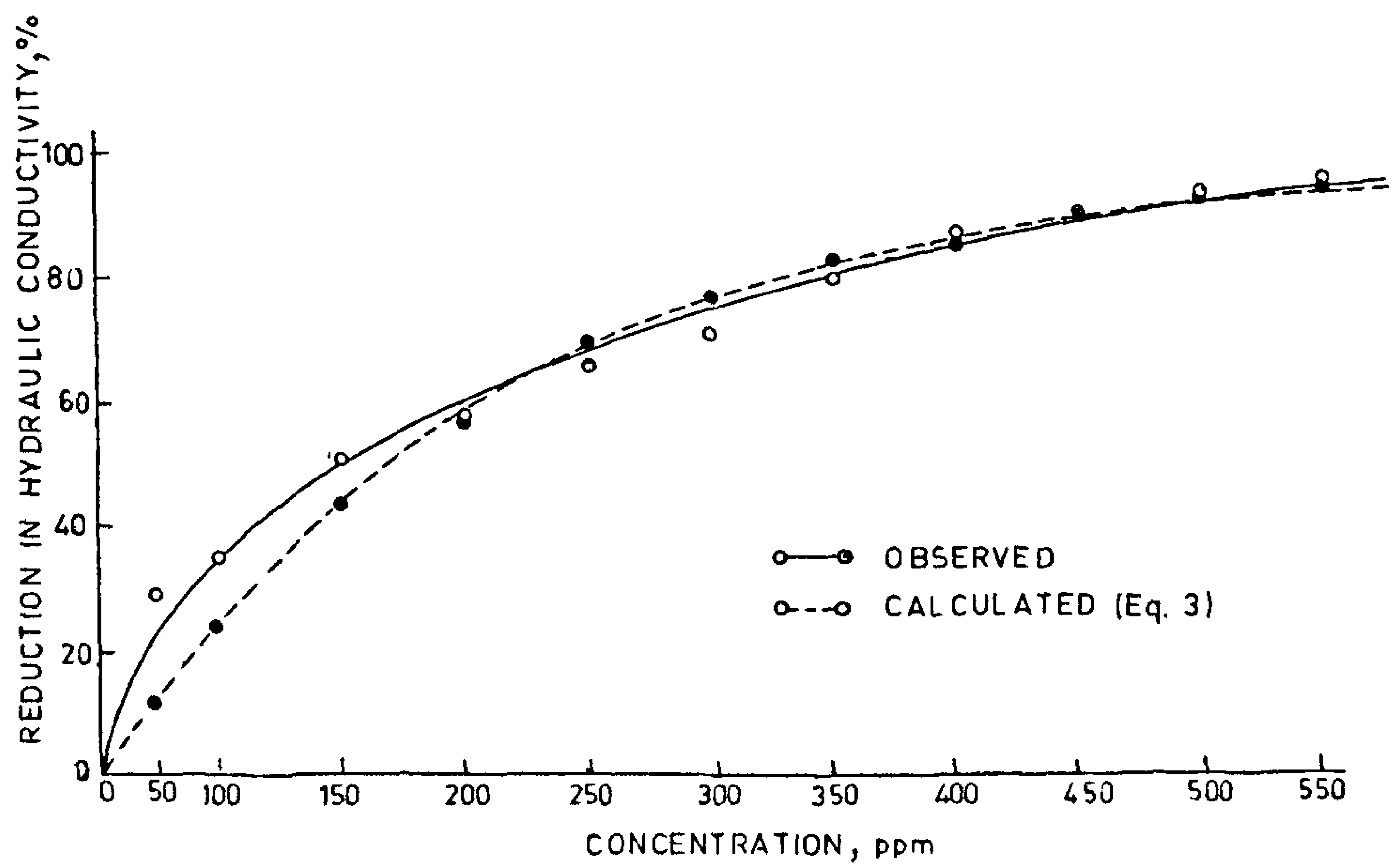

Figure 5. Relation between percentage reduction in hydraulic conductivity and guargum concentration in water

hydraulic conductivity (K') and concentration (C) of purified guargum is given by the following equation (*Figure 5*).

$$K' = 100 - (103.4\, e^{-0.00303C}), \tag{4}$$

where K' is the percentage reduction in hydraulic conductivity and is given by

$$K' = \frac{K_w - K_s}{K_w} \times 100. \tag{5}$$

The effect of polymer on flux (volume of fluid passed per unit area through sand block) is shown in Figure 4. The flux reduces with time and then attains a constant value for water. This constant value was attained after 2.5 h, whereas in 100 ppm purified guargum the constant value was attained in 30 min[14]. It was observed that with increase in concentration, the flux decreases (Figure 5). The relation between flux and time period is given by the following equation:

$$q = b\, t^c, \tag{6}$$

where b and c are constants. The form of equation suggests that b and c are dependent on sand characteristics. b is also dependent on polymer concentration. Although the above experiments were conducted with sand samples, as is evident from the following, drag-reducing polymers reduce the hydraulic conductivity of soil too, which contains more than 50% sand.

In another study, the soils were puddled with polymers and the effect on hydraulic conductivity was observed. The puddling itself is found to be much more effective and addition of polymer further reduces the conductivity. However, this treatment was found to be less effective than the earlier treatment, i.e. passing polymer solutions through a soil column. For a crop like paddy, ponding of water in fields is essential. It was observed that puddling also helps in reducing percolation losses. To simulate the ponded condition, the following experiment was designed and the effect of polymers guargum, CMC and their mixtures and crosslinked guargum was studied[13]. In this study, the hydraulic conductivity of unpuddled soil, of soil with puddling in the presence of water alone and of soil treated by puddling in the presence of polymer solution was determined. The puddling was carried out by Remi stirrer. The results are depicted in Figure 6. The results show that puddling itself has considerable influence in controlling percolation losses. It was observed that reduction in hydraulic conductivity increases significantly with puddling and the addition of polymer has very little effect on hydraulic conductivity. The relation between cumulative volume collected at the bottom (loss due to percolation) and time can be expressed as

$$V = a + bt + ce^{dt}, \tag{7}$$

where a, b, c and d are constant. The values of coefficients a and b were found to be positive while the values c and d were found to be negative. The equation fits well to the data as correlation indices vary from 0.9990 to 0.9999. The exact values for each case are given in Figure 6. In the above study, it was observed that guargum crosslinked by sodium tetraborate at 0.05% concentration gives the best results. In general, guargum was found to be best among guargum, CMC and their mixtures. The polymer molecules being large in size, the flow gets obstructed while passing through porous soil. This is due to high elongational viscosity encountered in the porous media. The crosslinked guargum was found to be more effective than guargum alone. This is naturally due to the bigger size of giant aggregated molecular entity formed due to crosslinking[21].

For water management in agriculture, another factor which is equally important as percolation losses is loss of water due to evaporation. Evaporation suppression plays an important role in conserving the water for efficient and judicious water management. Considerable amount of research work has been carried out throughout the world in this aspect. Various methods have been suggested. The important one is spreading the monomolecular films of chemical suppressants which act as a barrier between water surface and atmosphere. An exhaustive review of literature relating to evaporation retardation by monolayers was done by Roberts[22] and Singh and Das[23].

It was suggested that polymer, if dissolved, might help in reducing evaporation losses. Preliminary studies[11] were conducted to investigate the evaporation suppression characteristics of drag-reducing polymers. From the results obtained, it was quite clear that the polymer cannot be used for this purpose. PEO and PAM showed increased evaporation whereas very high concentrations of guargum (500 ppm), CMC (1000 ppm) and xanthangum (100 ppm) caused evaporation reduction of 6.19%, 5.84% and 0.54%, respectively, which are insignificant.

Nitrogen is an important fertilizer for plant growth. The performance of urea as nitrogeneous fertilizer is due to its relatively low cost and high content of nitrogen. Urea being quickly soluble, large percentage of losses occur due to leaching and run-off. This has motivated the development of slow-release urea fertilizer. The various processes which contribute to nitrogen losses in agriculture fields – particularly, paddy fields – are leaching, ammonia volatilization, nitrification, denitrification and run-off. The other transformations are biological immobilization and ammonia fixation. Any process which interferes with these transformations will increase nitrogen use efficiency. Slow-release fertilizers are those which have low rates of dissolution.

In USA sulphur-coated urea has been developed. It did not become popular in India due to its high cost and limited availability. Lac-coated urea is still in experimental stage and its cost also will be high. It has re-

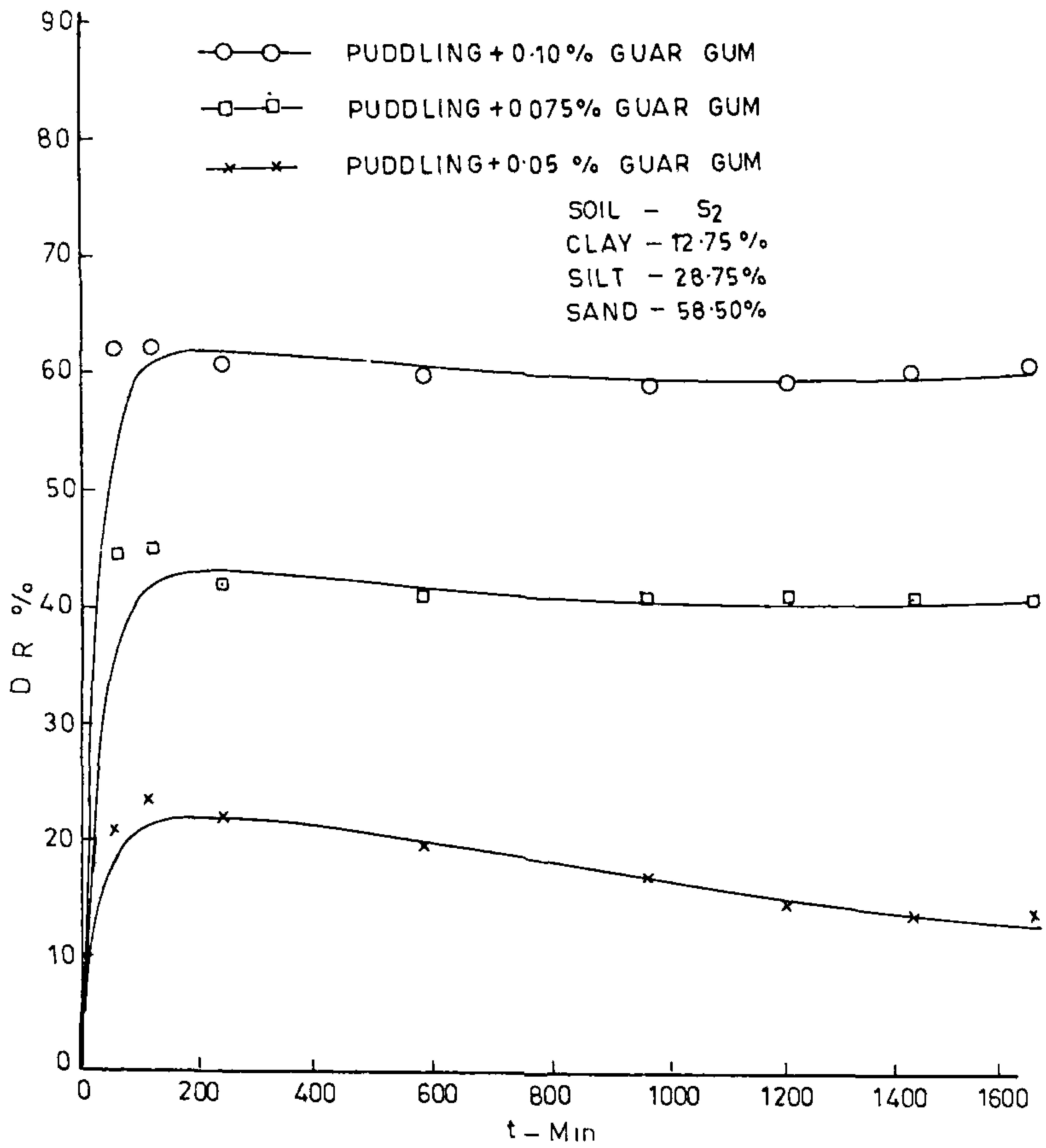

Figure 6. Effect of guargum on percentage reduction of percolation loss for soil S_2

cently been pointed out that if urea is coated with brittle coatings such as glass or sulphur, as soon as the coating fractures the fertilizer is immediately released and percolates quickly through soil. Blending is a better process for slow release of fertilizers[24]. It was thought that a logical process would be to blend urea with some material which would act as a diffusion retardant. It was then decided to blend urea with water-soluble polymers and study its properties. A project[12] was undertaken with the following objectives:

(i) Development of polymer-blended urea of various compositions.
(ii) Evaluation of infiltration, hydraulic conductivity and release characteristics, urea under laboratory conditions in soil columns having sandwiched.

Blending was carried out by two methods: (a) melt blending (MB) and (b) ordinary physical blending (OB). The polymer used was again guargum. The guargum was blended with urea in various proportions. The results of these experiments show that melt blending is usually more effective than ordinary physical blending. However, loss of nitrogen occurs during the melt process. Further, urea forms a hard cake after melting and further grinding is, therefore, essential before end use. An experiment[12] in which different kinds of ureas were sandwiched in a column of soil at a depth of 10 cm from top and 40 cm from bottom was conducted. The soil column was initially prepared in a 75 cm long lucite cylinder having an inside diameter of 5 cm. The bulk density of the soil was 1.50 g/cm^3. A water head of 10 cm is maintained over the top of the soil in all experiments. The relationship between water front advance and time can be given by the following equation:

$$L = a + bt - ce^{-dt}. \quad (8)$$

The constant b in the above equation provides a good measure of the effectiveness of the treatment. Decrease in the value of b gives reduction in the rate of water front advance. The results have been plotted as b vs. blend composition and are given in Figure 7. The best results were obtained at 0.8% MB urea (0.8% guargum was melt-blended with 99.2% urea). In the case of

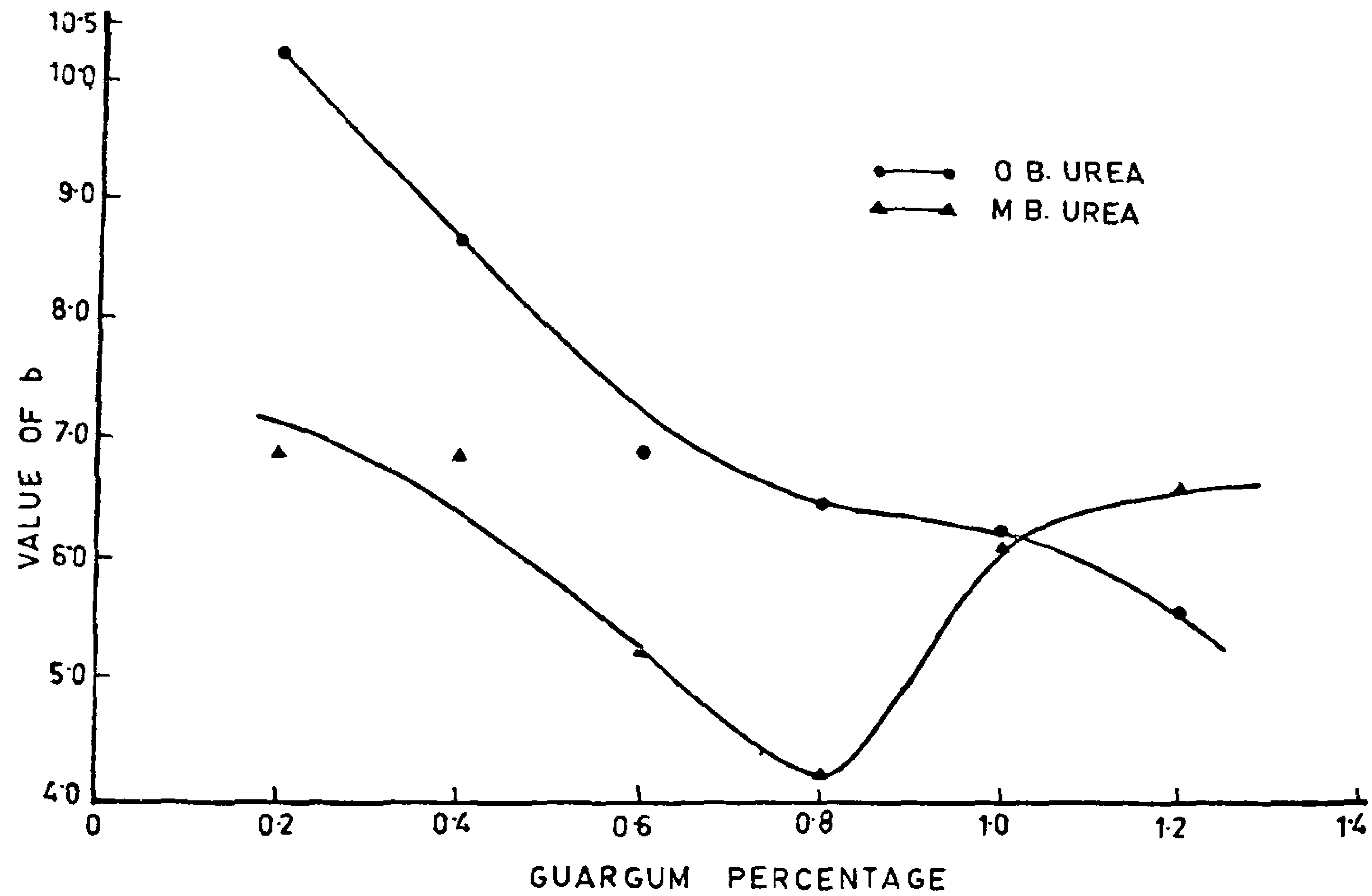

Figure 7. Variation of constant *b* of equation (8) with guargum concentration in water

Table 4. Time taken by different urea/urea–guargum blends to get dissolved completely[12]

Weight (g)	Urea/urea blend	Average time taken (min)
12 6	Urea	2 67
12 6	0 2% OB	3 67
12 6	0 4% OB	5 5
12 6	0 6% OB	10 17
12 6	0 8% OB	12 83
12 6	1 0% OB	16.50
12 6	1 2% OB	19 67
12 6	0 2% OB	7 0
12.6	0.4% MB	8 67
12 6	0 6% MB	16 33
12 6	0 8% MB	18 67
12.6	1 0% MB	28 00
12 6	1 2% MB	38.33

MB Melt blending.
OB Ordinary physical blending.

Table 5. Effect of nitrogen source and nitrogen level on grain yield of rice (g/ha)

	Levels of nitrogen, kg/ha				
N_2 source	0	40	80	120	Mean
Control	22 89				
Urea (split treatment) (50 25·25)	–	35 98	43 37	48 89	42 79
Gypsum-coated-urea	–	34 07	41 25	44 61	39 98
Rock-phosphate-coated urea	–	33 85	41.46	45.48	40 10
Nitrohumic-acid coated-urea	–	32 97	40 06	42 88	38 64
Guargum-coated urea	–	35 81	42 07	46 46	41 45
Urea super granules (1 0 g size)	22 89	34 81	42 21	46 42	

CD 5%, two levels, including control	0 81
Two sources	1 11
Interaction, two-sources means for the same level	1 925
Two-levels means at the same source	1.932

physical blending the value of *b* was found to be continuously decreasing with increase in guargum concentration. Thus, it was observed that infiltration can be retarded by polymer due to the superabsorbent nature of coated guargum. To study the dissolution rate, a separate experiment was carried out in which pellets of urea and blended urea were suspended in water and dissolution was studied (Table 4). It was again observed that blending imparts resistance to dissolution of urea.

The preliminary laboratory studies were then extended to field trials[25, 26]. In field trials, 0.8% blended urea was chosen for the treatment. The efficiency of this blend was compared with other commercially available slow-release urea preparations. The guargum–urea blend showed results comparable to other commercially available preparations. The results are shown in Table 5. In an independent study by Kotur[21] the performance of our guargum-coated urea has been tested in cultivars of cauliflower in comparison with urea super granule, lac-coated urea and neem-extract-coated urea. The highest yield is obtained with our urea and neem-extract-coated urea. In cauliflower and brinjal cultivars, net return is obtained using our urea. In comparison with other slow-release areas, the preparation technique (simple mixing in a tumbling mill) adopted in our case is simpler and cheaper.

The above-described results indicate that drag-reducing polymers not only reduce the energy required by sprinkler irrigation systems by reducing the turbulent drag but also reduce the percolation losses of soils and thus may be used as blending agents for the development of slow-release urea. Though the application of drag-reducing polymers in agriculture to serve any individual purpose may be expensive, the cumulative benefits of polymer additives in sprinkler irrigation, decrease in hydraulic conductivity, slow-release preparation, etc., may prove this technology economically feasible[26]. A large number of efficient shear- and biodegradation-resistant grafted polysaccharide-based drag-reducing agents have been developed in the first author's laboratory[10, 27] at Materials Science Centre. Efforts are in progress to choose among them a drag-reducing polymer which will give optimum reduction in the energy requirement of sprinkler irrigation as well as in percolation losses.

1 Toms, B. A, in Proceedings of the International Congress on Rheology, Scheveningen, 1949, vol. 2, pp. 135–142
2 Singh, R P., in *Encyclopedia of Fluid Mechanics*, Gulf Publisher, Houston, USA, 1990, vol. 9, pp 425–480
3. Savins, J. G, *SPE J*, 1964, **4**, 203–213
4 Hoyt, J W, *Encyclopedia of Polymer Science and Engineering*, (eds. Mark, H F, *et al*), John Wiley, New York, 1985, vol. 5, 2nd edn, pp 129–151
5 Shenoy, A V., *Colloid Polym. Sci*, 1984, **262**, 319–337.
6 Sellin, R. H J., Hoyt, J. W., Pollert, J. and Scrivener, O, *J. Hydraul. Res*, 1982, **20**, 235–292
7. Sellin, R H. J, in Proceedings of the Third International Conference on Drag Reduction, University of Bristol, U K..1984, p. I 3-1-17.
8 Pollert, J, in *The Influence of Polymer Additives on Velocity and Temperature Fields* (ed Gampert, B), Springer, Berlin, 1985, pp 371–395
9 Reddy, G. V and Singh, R P., *Rheol. Acta*, 1985, **24**, 296–311
10 Deshmukh, S R, Singh, R. P, *J Appl. Polym Sci*, 1985, **30**, 4013–4020, 1986, **32**, 6163–6177; 1987, **33**, 1963–1975; 1991, **48**, 1091–1101
11 Sankar, G, M Tech Thesis, Indian Institute of Technology, Kharagpur, 1980; Sankar, G, Singh, R P. and Singh, J., *J. Agric Eng (India)*, 1982, **19**, 9–14
12. Kumar, D., M Tech Thesis, Indian Institute of Technology, Kharagpur, 1982
13. Kumar, A, M Tech Thesis, Indian Institute of Technology, Kharagpur, 1982, Kumar, A, Singh, R. P. and Singh, J, *Indian Water Resour Soc*, 1988, **8**, 53–58
14 Nagdeve, M B, Tiwari, K N, Singh, R P., *J. Agric Eng*, 1986, **23**, 217–222, 310
15 Srivanappan, R. K, *The Hindu*, Survey of Indian Agriculture, 1994, 155–157.
16. Burt, C. M. and Keller, J, Very low pressure sprinkler irrigation, Utah State University, Logan, Utah, 1977
17 Elias, V. and Vocel, J., Long-term field experiments with polymer additives for sprinkler irrigation, *Commun. Inst Hydrodyn* (Prague), October 1980, No 10.
18. Holey, S H., Singh, R. P. and Singh, J, *J. Agric. Eng*, 1979, **16**, 53–59.
19 Whitcomb, P. J, Gutowski, J. and Howland, W W., *J. Appl Polym Sci.*, 1980, **25**, 2815–2827.
20. Phukan, S, M Tech Thesis, Indian Institute of Technology, Kharagpur, 1993.
21. Kotur, S. C., *Indian J. Agric Sci.*, 1993, **63**, 436–439.
22. Roberts, W. J, *Adv Hydrosci*, 1966, **3**, 343–366.
23. Singh, R. V. and Das, G., *Soil Conserv Digest*, 1975, **3**, 22
24. Hepburn, C. and Arizal, R., *Plastics and Rubber, Proc. Appl*, 1989, **12**, 129–134.
25. Annual Report, All India Coordinated Agronomic Research Project 1985–86, IIT, Kharagpur.
26. Singh, R P, Singh, J., Kumar, D, Kumar, A., in *Drag Reduction in Fluid Flows. Techniques for Friction Control* (eds. Sellin, R. H J. and Moses, R. T), Ellis Horwood, Chichester, 1990, pp. 240–246.
27. Singh, R P., Deshmukh, S. R. and Majumdar, S K., Proceedings of the 10th International Congress on Rheology, Plenum Press, New York, 1988, vol II, pp. 278–281.

Received 8 July 1991, revised accepted 18 January 1995

Neodymium monazite from the Gajularega cordierite gneisses, Eastern Ghats, India

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Neodymium monazite, occurring as an accessory phase in cordierite gneisses at Gajularega in the Eastern Ghats, is reported for the first time from India. *Optically, it is* characterized by bright honey yellow to rose colour, low optic axis angle, biaxial positive interference figure and pleochroic haloes with weak pleochroism. X-ray diffraction data with *d* values at 3.280, 3.081, 2.846, 2.425 Å reflect monazite–Nd mineral structure. Monazite–Nd invariably shows LREE (light rare earth elements) selectivity. The PO_4^{3-} impoverishment in analysis suggests higher fCO_2 conditions. It is considered as uniphase multicomponent solid solutions containing U, Th, Zr and Y, with Nd-rich LREE dominance with coupled substitutions. Metamorphic origin is assigned to Nd-rich monazite from the Eastern Ghats. Nd-rich REE derived from the pegmatitic intrusions in khondalites and entered into cordierite gneisses during metamorphism.

NEODYMIUM monazite (monazite–Nd)[1] has been found as an accessory mineral from a lensoidal outcrop of cordierite gneisses from the Eastern Ghats at Gajularega village (lat. 18°8'10"N and long. 83°23'20"E) in Viz-