QUEENSLAND DEPARTMENT OF PRIMARY INDUSTRIES
DIVISION OF PLANT INDUSTRY BULLETIN No. 789

EFFECT OF MID-SEASON DRAINING ON PADDY RICE IN THE LOWER BURDEKIN VALLEY

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SUMMARY

Bluebonnet 50 rice, grown in the 1970 dry season and 1970-71 wet season in small paddies was drained once (early tillering), twice (early tillering and panicle initiation) and three times (early tillering, panicle initiation and pre head emergence). Continuously flooded treatments yielded 8 and 10% higher than the best drained treatment in 1970 and 1971 respectively. The draining treatments did not affect maturity, grain number per head, fertile tiller number, 1000-grain weight, plant nitrogen uptake or water usage. Differences in yellowing of the crop did not occur between any treatments. The drained treatments caused significant increases in soil redox potential readings over the time the treatments were applied. Soil redox potentials did not go below +130 millivolts so the build-up of harmful reduction products in these soils under the waterlogged conditions of paddy rice is unlikely.

I. INTRODUCTION

Rice is grown in the Lower Burdekin Valley under paddy conditions which entail growing the crop in bays which are permanently flooded with 2 to 15 cm of irrigation water. This flood is maintained from very early tillering until grain ripening, a period of about 90 to 110 days depending on whether the crop is a summer crop or winter crop.

Under these conditions crops often develop a yellowing of the leaves about mid to late tillering similar to that described by Strickland (1968) but unlike what would be considered as nitrogen deficiency before top dressing. On the other hand rice growing on contour banks, where the soil is not inundated, appears more vigorous and generally a darker green in colour. Strickland (1968) and Patrick *et al.* (1967) have prevented the onset of leaf yellowing and have increased the yield of paddy rice when the paddies were drained at various times and reflooded.

Severe reducing conditions in the soil are thought to be responsible for the yellowing symptoms because the most drastic effect submergence has on a rice soil is to greatly reduce the rate of gas exchange between the soil and the atmosphere. Ponnamperuma (1972) quotes data showing that gas diffusion rate through water filled soil pores is 10,000 times slower than that through gas filled pores so the oxygen diffusion rate suddenly decreases when a soil is submerged.

Within a few hours of soil submergence, any oxygen in the water or trapped in the soil has been consumed by aerobic micro-organisms. Anaerobes proliferate below any layer receiving oxygen by diffusion through the surface water and cause the loss of soil nitrate nitrogen by reduction, a phenomenon recognised and discussed by many authors including Patrick (1960), Jeffery (1963), Ponnamperuma (1964), Strickland (1969) and Ponnamperuma (1972). Other factors caused by soil reduction can also adversely affect rice.

The two experiments reported here were conducted to determine the effect of different drainage regimes on the yield of rice grown on a soil of the Burdekin flood plain and also to determine whether the yellowing of the crop can be prevented by soil aeration during the growing cycle.

II. METHODS AND MATERIALS

Two experiments were conducted, one in 1970 (trial 1) and one in 1971 (trial 2), on an Oakey soil (Hubble and Thompson 1953) of the Burdekin flood plain. In each season, 20 small rice bays were constructed. Prior to the bank construction, the area was fertilized with 44 kg ha^{-1} nitrogen (sulphate of ammonia) and 11 kg ha^{-1} phosphorous (superphosphate), the latter being applied with the Bluebonnet 50 rice seed. All the fertilizer was drill applied, with the nitrogen placed at 7·5 cm depth and the phosphorus and seed together at 1 to 2 cm depth. Plot size was 14 $\times$ 7·3 m in 1970 and 7·6 $\times$ 6·7 m in 1971.

After construction of the banks, the bays were flushed by pumping water onto each bay. Immediately the soil surface was covered, the excess water was pumped off. Water applied was measured with a 10 cm flow meter and water pumped off with a small 5 cm pump calibrated to deliver a certain volume of water over unit time.

The crop was sprayed with propanil at 16·2 $l\,ha^{-1}$ product when the weeds (Barnyard grass—*Echinochloa colonum*) were at the two to four leaf stage and the rice was tall enough to take permanent flood. Twenty-four hours after the herbicide application, permanent flood was applied to all bays. Water depth was maintained at 2 to 10 cm, the bays being topped up approximately weekly.

At early tillering about 2 weeks after permanent flooding, some of the bays were drained and allowed to dry until the surface of the soil commenced cracking. This length of time was approximately one week but varied with the prevailing weather conditions. After the drying period, the bays were reflooded. The practice was repeated on various bays to yield the treatments set out below:

1.—Continuous flood.

2.—Drained once at mid-tillering.

3.—Drained twice, at mid-tillering and panicle initiation.

4.—Drained three times, at mid-tillering, panicle initiation and pre head emergence.

At each reflooding, 22 kg ha^{-1} of nitrogen (sulphate of ammonia) was hand broadcast across all plots after the water was applied. At the same time one quadrat (0·83 m^2) was cut from each plot for dry matter and plant nitrogen and phosphorus analyses.

At draining and again at reflooding, soil samples were taken from the top 7·5 cm of soil, using a 1·8 cm diameter sampling tube. Three subsamples per plot were bulked. Each plot sample was placed in a sealed jar with 33 ml of water and shaken immediately. On reaching the laboratory, the redox potential was determined using a bright platimum electrode and a saturated Calomel reference electrode. Maximum time from sampling to reading was 1h.

Soil pH was determined at the beginning and end of trial 1 using a glass electrode.

Prior to harvest, the bays were drained and allowed to dry out. One 0·83 m^2 quadrat was taken from each plot prior to grain harvest for final dry matter and plant nitrogen and phosphorus determinations. Plots were harvested with a rice autoheader (2·1 m width of cut) harvesting areas of 13·4 m $\times$ 2·1 m in 1970 and 7·0 m $\times$ 4·2 m in 1971. Grain moisture, 1000-grain weights and grain nitrogen and phosphorus concentrations were measured on subsamples of the harvested grain.

III. RESULTS

Table 1 sets out the yield, yield components and grain nitrogen uptake. A yield depression of 8% in 1970 and 10% in 1971 was observed in the drained treatments. The yield components which caused this are not apparent from the results obtained. There was no obvious trend in grain nitrogen uptake.

No significant difference between treatments was obtained in water usage on either trial. Mean water usage was 25·6 Ml ha^{-1} in 1970 and 16·4 Ml ha^{-1} in 1971.

Dry matter yields for trials 1 and 2 are shown in table 2. They showed a marked decrease after the first and second draining in trial 1 but all subsequent yields in trial 1 and all in trial 2 were not significantly different.

TABLE 1

GRAIN YIELD, 1 000 GRAIN WEIGHT, NUMBER OF HEADS, GRAIN NUMBER PER HEAD AND GRAIN NITROGEN CONTENT

	Grain Yield (kg ha^{-1}) at 16% Moisture		1 000 Grain Weight (g)	Number of Heads per m^2	Grain Number per Head	Grain Nitrogen Uptake (kg ha^{-1} N)
	1970	1971	1971	1971	1971	1971
Continuous Flood ..	7 937	5 416	28·15	161·0	123	76·7
Drained Once	7 207	4 847	27·82	136·1	136	68·4
Drained Twice	7 347	4 831	28·03	152·4	121	62·8
Drained Three Times ..	6 909	4 915	28·14	167·9	112	70·2
L.S.D. P = 0·05	547	496	N.S.	N.S.	N.S.	8·89

TABLE 2

DRY MATTER YIELDS (kg ha^{-1}) AT EACH OF THE REFLOODING TREATMENTS AND PRE-HARVEST

	First Reflooding		Second Reflooding		Third Reflooding		Pre-Harvest 1971*
	1970	1971	1970	1971	1970	1971	
Continuous Flood	1 616	2 270	2 798	4 549	7 828	6 353	10 237
Drained Once	1 144	2 025	2 076	4 104	7 333	5 975	8 395
Drained Twice	†	†	2 174	4 377	6 998	6 752	10 333
Drained Three Times ..	†	†	†	†	6 687	6 329	9 663
L.S.D. P = ·05	196	N.S.	339	N.S.	N.S.	N.S.	N.S.
Coefficient of Variation ..	14·1%	22·7%	10·8%	19·9%	20·0%	14·9%	31·5%

* 1970 samples accidently destroyed.

† These treatments not available at this stage. Drained-once treatment at first reflooding is thus the mean of the three drained treatments, and drained-twice treatments at the second reflooding are the mean of the last two draining treatments.

Table 3 shows plant nitrogen uptake at the end of the three draining periods and at pre-harvest. No differences were observed in plant phosphorus uptake for any of the draining treatments. Pre-harvest plant phosphorus uptake levels in the tops were in the vicinity of 13 to 17 kg ha^{-1} P. Although no significant differences were observed for plant nitrogen uptake, definite trends occurred in 1970 when the mean nitrogen uptake tended to decrease with each additional draining treatment.

Table 4 shows the periods of draining with the evaporation, rainfall and temperature measured during the drained periods. At no time were the plants obviously stressed, and the actual draining periods were determined by the soil condition. Rainfall caused the length of time the bays were drained to be increased twice over the two trials. The first trial received 415 h of sunshine between panicle initiation and grain filling while the second received only 236 h over the same period.

TABLE 3

PLANT NITROGEN UPTAKE (TOPS) (kg $ha^{-1}N$) AT THE END OF EACH OF THE DRAINING PERIODS AND AT PRE-HARVEST

	First Reflooding		Second Reflooding		Third Reflooding		Pre-Harvest	
	1970	1971	1970	1971	1970	1971	1970	1971
Continuous Flood ..	34·1	33·2	45·0	47·6	84·0	52·8	*	85·1
Drained Once ..	28·8	34·2	40·2	44·1	77·0	53·4	*	81·5
Drained Twice ..	†	†	38·3	48·5	67·8	54·8	*	87·4
Drained Three Times	†	†	†	†	72·0	53·0	*	73·0
L.S.D. P = ·05 ..	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.		N.S.

* Samples accidently destroyed.

† These samples unavailable at this stage of the trial. Drained-once treatment at first reflooding period is thus the mean of the three drained treatments, and drained-twice treatments at the second reflooding are the mean of the last two draining treatments.

TABLE 4

EVAPORATION, RAINFALL AND MEAN MAXIMUM SCREEN TEMPERATURE OVER EACH DRAINED PERIOD

Drainage Period	Trial I				Trial II			
	Days Drained	Evaporation (mm)	Rainfall (mm)	Mean Max. Temp. °C	Days Drained	Evaporation (mm)	Rainfall (mm)	Mean Max. Temp. °C
First	21	68·1	26·9	26·6	7	21·8	8·0	31·4
Second ..	7	32·8	0·0	30·0	10	33·3	16·0	32·0
Third	7	36·1	0·0	32·2	6	20·1	0·0	30·0

Figure 1 and figure 2 show the Redox Potential measurements in trials 1 and 2 respectively.

The linear regression equations that best define the decline of redox potential in millivolts (Y) in the continuously flooded treatment over time in days after first sampling (X) for trials 1 and 2 are:

Trial 1 $X = -2{\cdot}88\ Y + 422{\cdot}81 \quad (r^2 = 0{\cdot}92^{**})$

Trial 2 $X = -3{\cdot}12\ Y + 309{\cdot}81 \quad (r^2 = 0{\cdot}85^{**})$

The treatments had no effect on pH measured at the beginning and the end of the trials but overall pH rose from 5·9 to 6·9 over the period the trials were conducted.

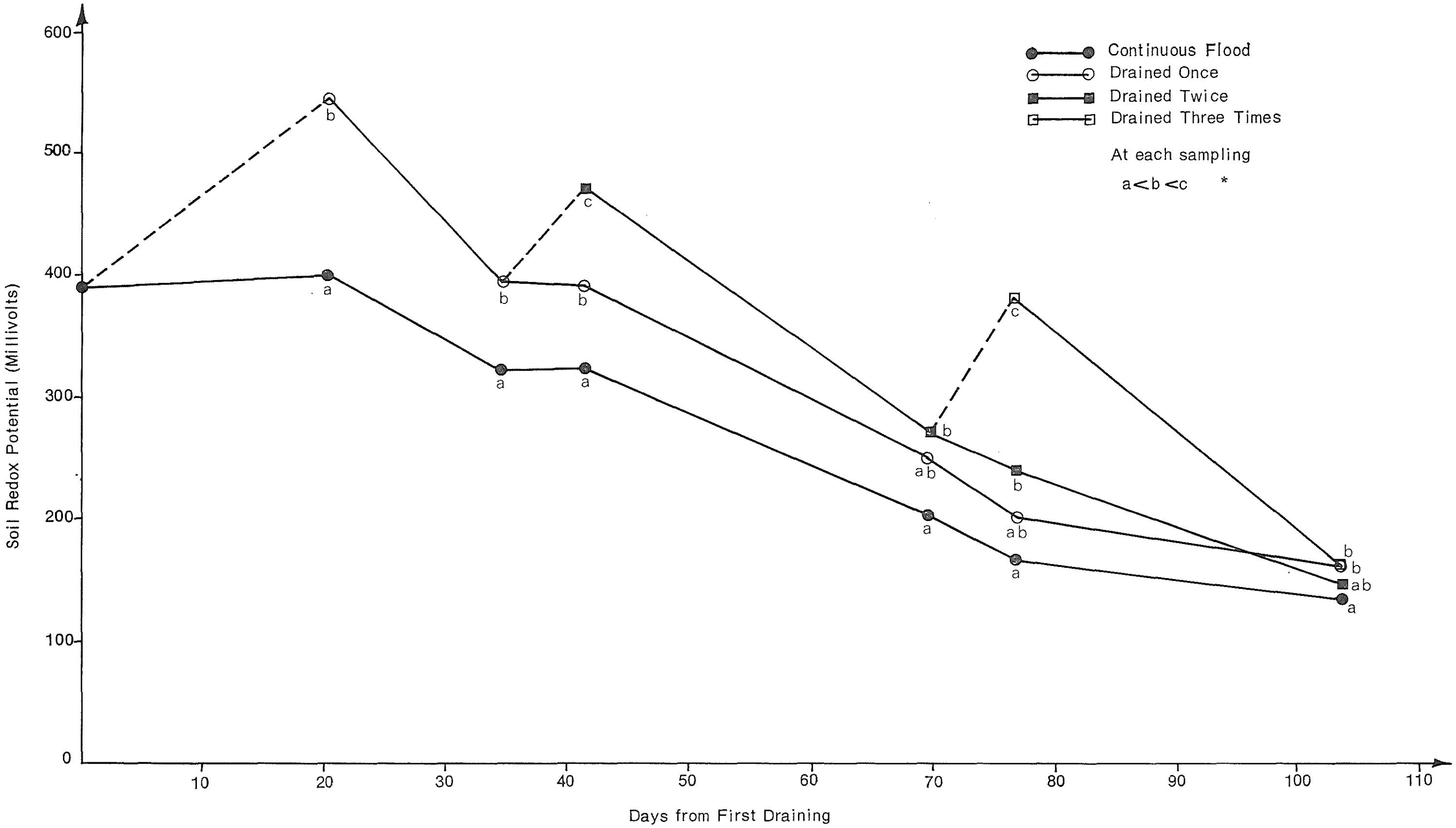

Figure 1. Soil redox potential in trial 1, 1970.

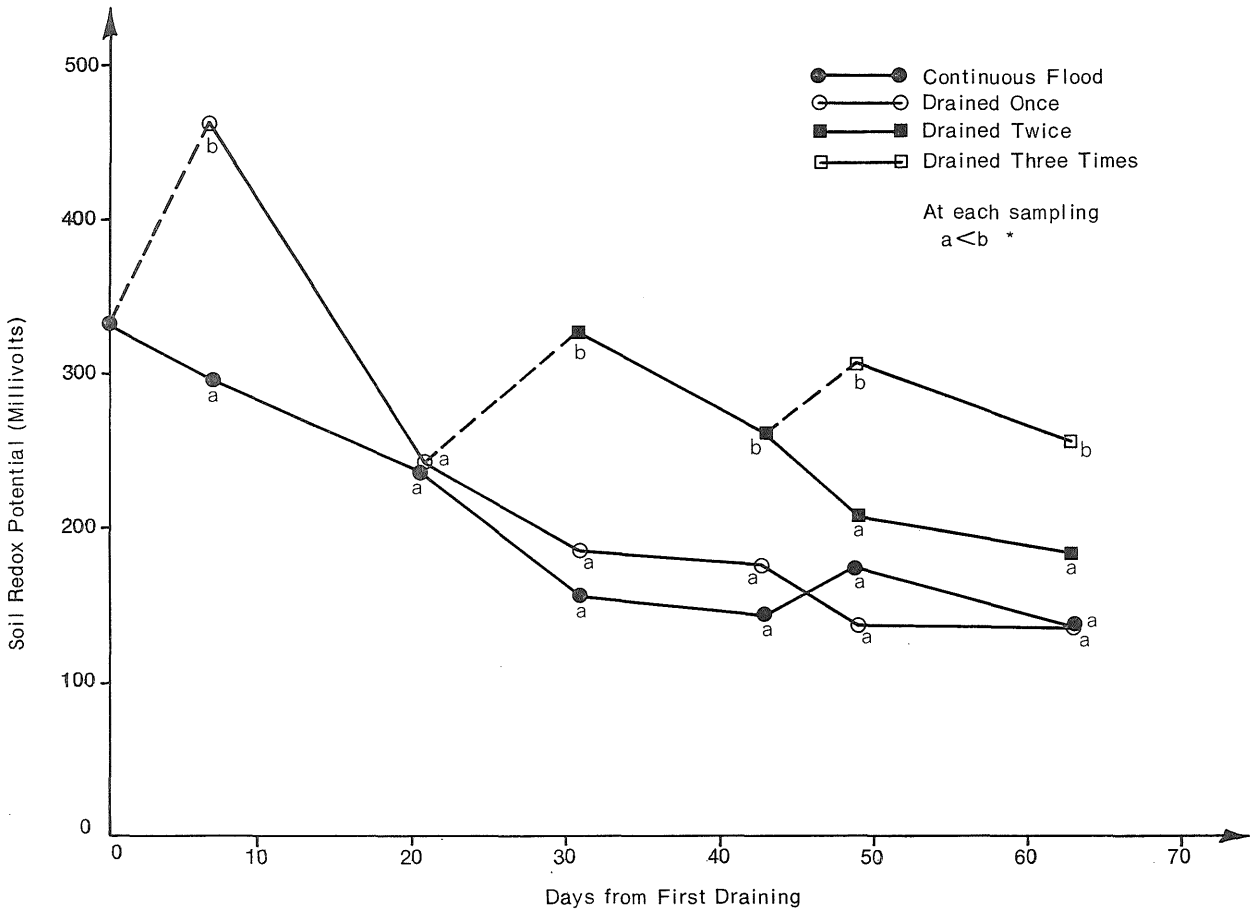

Figure 2. Soil redox potentials in trial 2, 1971.

IV. DISCUSSION

The most important result from the trials was the yield depression observed in the drained plots. This result agrees with work done by Pande and Singh (1969) but differs from that of Strickland (1968), Sheikh (1973) and Migasaka (1969). Patrick *et al.* (1967) found yield depression in low nitrogen-low organic matter situations but yield increases where apparently high nitrogen-high organic matter fields were drained.

The factor or factors causing the yield depression in the drained treatment are unknown. Although soil redox potential measurements showed a positive effect from draining, in that the soil was oxidized to a significantly greater level in the drained treatments compared to the continuously flooded treatment, no significant effect was noticed in the plant nitrogen uptake although trends were noticed in some cases. By addition of nitrogen to all the plots at the end of each draining period, it was hoped to negate any effect from losses in nitrogen that may have occurred during the draining and reflooding cycles. All plots received 110 kg ha^{-1} N and although the optimum rate is now known to be 132 kg ha^{-1} (in 2 applications of 66 kg ha^{-1} each) the more efficient distribution of the fertilizer in the trials (4 applications) would be expected to at least partly compensate for the discrepancy in the rates. Certainly the nitrogen uptake results seemed to confirm this.

The regression equations show that redox potential declined at a rate of about 3 mV per day in the continuously flooded plots in both trials. It may be seen from figures 1 and 2 that the decline, particularly initially, was more rapid in the second trial where redox potentials of all treatments were lower at the first four samplings. The higher temperatures over the early part of this trial as shown in table 4 probably stimulated organic matter decomposition by anaerobic micro-organisms increasing the rate of soil reduction.

Because of the small redox potential fall over the last 28 and 32 days in the continuously flooded plots shown in figures 1 and 2, there is some evidence that redox potential may stabilise just above 125 mV. As Ponnamperuma (1972) states that after 6 to 12 weeks of flooding, redox potential asymptotically approaches a value characteristic of the soil, it appears that 125 mV may be the value characteristic of the Oakey soils used.

The draining treatments caused significant re-oxidation in all cases but the soil became fully oxidized only when the initial redox potential was above 300 mV. When the initial redox potential was below 300 mV, complete re-oxidation did not occur in the 6 or 7 days allowed indicating that the reduced systems were fairly stable. Only in the case of the second draining, second trial, had the redox potential fallen to be not significantly different from the control by the sampling before the next draining. High temperatures over the period (late February-early March) probably caused this rapid reduction.

The rise in pH over the first trial was 0·9 units while redox potential fall was about 250 mV. This conflicts with the theoretical value for the redox potential/pH slope of —60 mV per unit of pH rise given by Rodrigo (1963) and used by Strickland (1969) to bring results to Eh_7. Patrick (1960) reports a slope of —232 mV per unit of pH rise and states that this may occur where the Fe^{+++}—Fe^{++} system is the main one controlling redox potential. Patrick and Mahapatra (1968) give +100 to +150 mV and Parr (1969) gives +100 to +300 mV as the redox potential ranges in which ferric iron is reduced so the large fall in redox potential per unit of pH rise and the apparent stabilization of redox potential above 125 mV may indicate that the Fe^{+++}—Fe^{++} system is dominant in controlling redox potential in the soils used. As Englar and Patrick (1973) found that redox potential was reduced to about —100 mV before sulphide was detected in soil samples with and without oxidants added before flooding, it is unlikely that significant sulphate reduction occurred in these trials.

The lowest redox potential recorded in the continuously flooded treatments was +130 mV. Available information on rice soils suggests that this represents moderately reduced to reduced conditions (Patrick and Mahapatra 1968), reduced conditions (Strickland 1968) or healthy reducing conditions (Jeffery 1961). According to Patrick and Mahapatra (1968), low soil redox potentials are unlikely to harm rice until sulphide accumulation occurs and Ponnamperuma (1964) states that draining of rice soils will be beneficial only where soluble reduction products accumulate under continuous flood. It appears that these conditions will not occur until redox potential is zero or lower (Jeffery 1961; Ponnamperuma 1964; Patrick and Mahapatra 1968; Parr 1969). Soils high in organic matter are more likely to reach these levels of reduction on permanent flooding. As the soil used had only about 1% organic carbon (Reeve, Hubble and Thompson 1960) and as Patrick *et al.* (1967) found a yield increase from draining only where soil organic matter had apparently been increased, our findings of only moderate soil reduction in the continuously flooded plots and yield reductions due to draining appear reasonable.

It is not known which components of yield caused the yield reduction in the drained treatments. This could be due in part to the small sample size for fertile tiller number and grain number per head. Gomez and Alicbusan (1969) showed that at least 8 to 12 m^2 plots are required to give a reasonable estimate of tiller number. This was not known at the time of conducting the trials and was beyond resources available to the authors at the time.

The 1970 trial gave higher grain yields and had higher soil redox potentials at panicle initiation and pre-heading than did the 1971 trial. The possibility of a positive correlation between soil redox potential at these stages and grain yield was considered but as the individual trials gave negative correlations, this was not proceeded with. Because Murata (1975) showed that solar radiation or sunshine hours from booting to grain filling was the most important climatic factor limiting plant growth where low temperature was not limiting, the difference in hours of sunshine from panicle initiation to grain filling is an alternative explanation for the yield difference between our trials.

No differential yellowing was caused by the treatments in the trials, probably because the darker green areas noticed on rice banks in the district may be caused by the soil on the banks being in an oxidized state for most of the crop cycle whereas in the trials even the drained treatments were moderately reduced for most of the period.

V. ACKNOWLEDGEMENT

The authors wish to thank the officers of Biometry Branch for the statistical analysis of the data and the Staff at Millaroo Research Station for assistance in conducting the trials.

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(Received for publication 12 August 1977.)

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