QUEENSLAND DEPARTMENT OF PRIMARY INDUSTRIES
DIVISION OF PLANT INDUSTRY BULLETIN No. 290

FACTORS RESPONSIBLE FOR FAILURES IN THE ESTABLISHMENT OF SUMMER GRASSES ON THE BLACK EARTHS OF THE DARLING DOWNS, QUEENSLAND

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SUMMARY

Seventeen field sowings at 0·5-in. depth were made with seed of Rhodes grass (*Chloris gayana* Kunth) and green panic (*Panicum maximum* var. *trichoglume* (K. Schum.) Eyles). Each sowing was exposed for a maximum period of six weeks and the fate of seed divided into the following categories: seed germinating in the field, seedlings crust-impeded, non-emergent seedlings, seedling mortality, seedling survivors and seed retaining its viability.

Moisture stress was the main factor which limited field germination, the extent of which was related to the depth of saturated soil promoted by any rain. Germination levels tended to fall into two groups, viz. germination adequate for establishment with low residual seed viability, and germination inadequate with high residual seed viability.

Emergence failure was the major restriction. Occasionally crust impedance occurred, but emergence failures were normally due to mechanical impedance by the dry crumbs immediately under the crusts. This appeared to be aggravated by the development of the primary leaf of non-emergent seedlings due to the penetration of light into the surface soil. Rhodes grass was more susceptible to impedance than green panic.

Seedling mortality in Rhodes grass in the first week after emergence was often high, and caused by recrusting with light falls of rain. Mortalities due to high temperature and moisture stress affected both species similarly, but were not of primary significance.

The various factors affecting establishment are discussed, and consideration given to the most pertinent avenues of research, with a view to improving establishment reliability.

I. INTRODUCTION

The development of ley pastures for inclusion in the farming system of the black earths of the Darling Downs in south-eastern Queensland (Hart 1949; Waring, Fox, and Teakle 1958; Thompson and Beckmann 1959, 1960) is seriously restricted by the difficulty experienced in establishing climatically and edaphically suitable summer grasses of the genera *Panicum, Chloris* and *Setaria* from seed.

Wilson (1955, 1956) has described quite refined techniques for commercial sowings of *Chloris gayana* Kunth (Rhodes grass) and *Panicum maximum* var. *trichoglume* (K. Schum.) Eyles (green panic) based on fine, compacted seedbeds, but even these methods have provided insufficient reliability for their extensive

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use. Amelioration of microenvironmental stresses (Russell 1939; McCalla and Duley 1946; Jacks, Brind, and Smith 1959) and consequent improvement in establishment have been achieved by the use of stubble mulches (Leslie, unpublished data) in agreement with the results elsewhere of Moore (1943), Fults (1944), Hopkins (1954), Moldenhauer (1959) and Buckley (1959), but the practical difficulties inherent in their use, coupled with the fact that the improvements possible appear inadequate, led the author to conclude that such techniques offer little opportunity for complete success.

The difficulties of grass establishment in semi-arid and arid environments have been discussed by such authors as Evenari and Koller (1957) and Harlan (1958), and the Israeli school have demonstrated the practical value of fundamental knowledge of both seed and environment in the solution of establishment problems (Mayer 1960).

It is probable that in such problems many factors militate against establishment in interacting combinations. Thorough consideration of evidence on the local problem did not permit distinction between germination, emergence and the early seedling stage as restricted phases; nor did it permit complete elimination of factors involved in these stages, such as moisture stress, soil and air temperature, aeration, seed/soil contact, impedance, sowing depth, seed dormancy, pathogens and seed-harvesting ants (*Pheidole ampola* Forel). To direct research to pertinent aspects it was imperative that a preparatory resolution of the factors responsible for failures should be made.

II. METHODS

The selected field site was on a very dark grey-brown heavy clay, intermediate in aggregate size distribution and natural tilth between Waco and Mywybilla, the two principal soil types of the Black Earth group as described by Thompson and Beckman (1959, 1960). The site was cultivated to a fine shallow seedbed prior to commencement, maintained weed-free by hand-weeding, and sprayed with 0·2 per cent. dieldrin at 100 gal per ac for ant control.

The grasses studied were Rhodes grass and green panic. Mature seed which exhibited no dormancy reactions was employed (Crocker 1948; Crocker and Barton 1953, p. 267; Winchester 1954; Toole *et al.* 1956). The seed was dusted with 72 per cent. zineb at 0·003 g per g of seed. Rhodes grass viability was 39 per cent. and green panic viability 47 per cent.; these did not change significantly during the experimental period. The rate curves for germination and 0·5-in. emergence at an alternating temperature of 32°–20°C are shown for both seed samples in Figure 2.

It was desired to sow seed in the field in a way permitting easy relocation, scrutiny of small seedlings, and complete seed recovery, without materially affecting microenvironmental conditions. A 20-in. dia, 2-in. high galvanized iron ring coated with bitumastic paint was embedded approximately 1 in. in the soil. This ring prevented rainfall run-off from within the ring and excluded outside run-off water. In the centre of this ring, 100 seed fascicles were sown evenly over a 3-in. diameter within a 4 in. x 0·5 in. metal ring and the surface within the outer ring was levelled to just cover the inner ring. This gave a sowing depth of 0·5 in., based on the recommendations of Wilson (1955) and established in pot experiments conducted by the author (unpublished data) to be the optimal emergence depth for both species.

Sowings were made fortnightly, 17 sowings being made from September 2, 1960, to April 14, 1961. At each sowing 12 separate rings were sown for each species. At 2, 4 and 6 weeks after sowing, four replicate lots were recovered for each species, so each of the first 15 sowings was completely recovered within 6 weeks, the 16th sowing after 2 and 4 weeks, and the 17th sowing after 2 weeks. The two species and three recoveries were arranged as split plots of a 4-replicate block design randomized for sowing dates.

Recovery was achieved by embedding a cylindrical cutter around the inner ring and sliding a plane cutter beneath the cylinder. Seed, soil and seedlings were thus obtained mixed. Recovered lots were sorted to determine the number of germinating seeds and to check the total number of seeds recovered.

Non-germinating seed was left in the soil, which was spread out in aluminium trays with perspex lids to a depth no greater than 0·5 in., wetted to field capacity and incubated at 32°–20° C. Emergence was counted for 14 days and provided an estimate of seed remaining viable. This technique is similar to that developed by Champness and Morris (1948) and used by Shaw (1957).

When germinating rains had occurred prior to recovery, seedling counts were made at frequent intervals, noting factors responsible for population changes and seedling stress conditions. At recovery, the surface crust was carefully lifted to count seedlings failing to emerge due to crust impedance.

All counts were expressed as percentages of viable seed sown. The transformation rho $=$ Arcsin $\sqrt{\text{Percentage}}$ was made prior to statistical analysis.

The fate of seed was thus resolved into the following categories: (1) seed not recovered; (2) seed apparently non-viable; (3) seed retaining viability; (4) non-emergent seedlings; (5) seedlings crust-impeded; (6) seedling survivors; and (7) seedling mortality. The sum of Categories 4 and 5 represented the total number of seedlings which failed to emerge.

At each sowing (sowings and recoveries were, with one exception, made on the same day), soil was sampled from 0–1-in., 1–2-in., 2–4-in. and 4–6-in. depths at four sites and moisture content determined by drying at 105°C for 24 hr. Soil was also sampled from 0–1 in. at sowing and placed in 6 in. x 1¼ in. test-tubes with cotton-wool plugs. Six tubes were autoclaved at 20 lb/sq. in. for 3 hr. These and six untreated tubes were sown with 50 Rhodes grass fascicles per tube at a depth of 0·5 in., watered with sterile distilled water and incubated at 28°C. Emergence was counted daily.

As a result of observations made during the study, it was desired to obtain an estimate of the depth of light penetration into the surface soil mulch. A technique was evolved by making prints of light passing through soil columns onto Kodak G–3 bromide paper. Exposure time was 5 sec for a Weston Master III meter light reading of 28 at the printing surface. This exposure gave clear prints with a minimum of "burning".

A typical air-dry surface mulch was sieved into fractions $> 0\cdot132$ in., $0\cdot132$–$0\cdot055$ in. and $< 0\cdot055$ in. and their relative proportions determined on an oven-dry weight basis. Prints were made through the separates and the natural mulch for columns 0·25, 0·5, 0·75, 1·0 and 1·25 in. deep. Prints were also made with crusts placed on the surface of the columns.

III. RESULTS AND DISCUSSION

(a) Technique

It is not the purpose of this paper to present data obtained from the scrutiny of the technique. However, it is necessary to summarize the limitations of its use.

Under most conditions, soil temperatures and soil moisture contents within the central ring were similar to those externally. There was a tendency with high wind velocities for the 0·5-in. soil temperature within the ring to be as much as 3·0°C higher than normal. This difference narrowed to 0·5–1·0°C at 1·0-in. depth. This has been interpreted as due to reduced wind velocity and hence to a reduction in the rate of transfer of sensible and latent heat. It would be expected that this would also tend to offset the acceleration of latent heat losses by the elevated temperature, and no differences in soil moisture loss have been discernible.

The outer ring ensured the retention of rain, which was desirable, since run-off introduces factors which are difficult to assess, e.g. movement of seed in run-off water and localized siltation and pondage of water. With high-intensity run-off falls, water is ponded within the ring. This promotes soil saturation to greater depth than on unconfined surfaces and delays the onset of soil drying. In extreme cases this resulted in higher seedling emergence than occurred externally, but under most conditions no differences in emergence or seedling mortality occurred between the two environments. The presence of the internal ring just below the soil surface had no observable effect on crust formation.

The estimation of residual viability was subject to a number of errors, which occurred principally with recoveries from very dry soil. Seed not recovered is expressed in the results as a fraction of the viable seed sown, but due to sorting difficulties these losses are slightly overestimated. Errors that cannot be estimated and are often serious are caused by the use of soil as a germinating substrate, and these are discussed later.

(b) Fate of Seed

The fractions of seed in the different categories at each recovery of each sowing, and the daily rainfall, are presented chronologically in histograms in Figure 1.

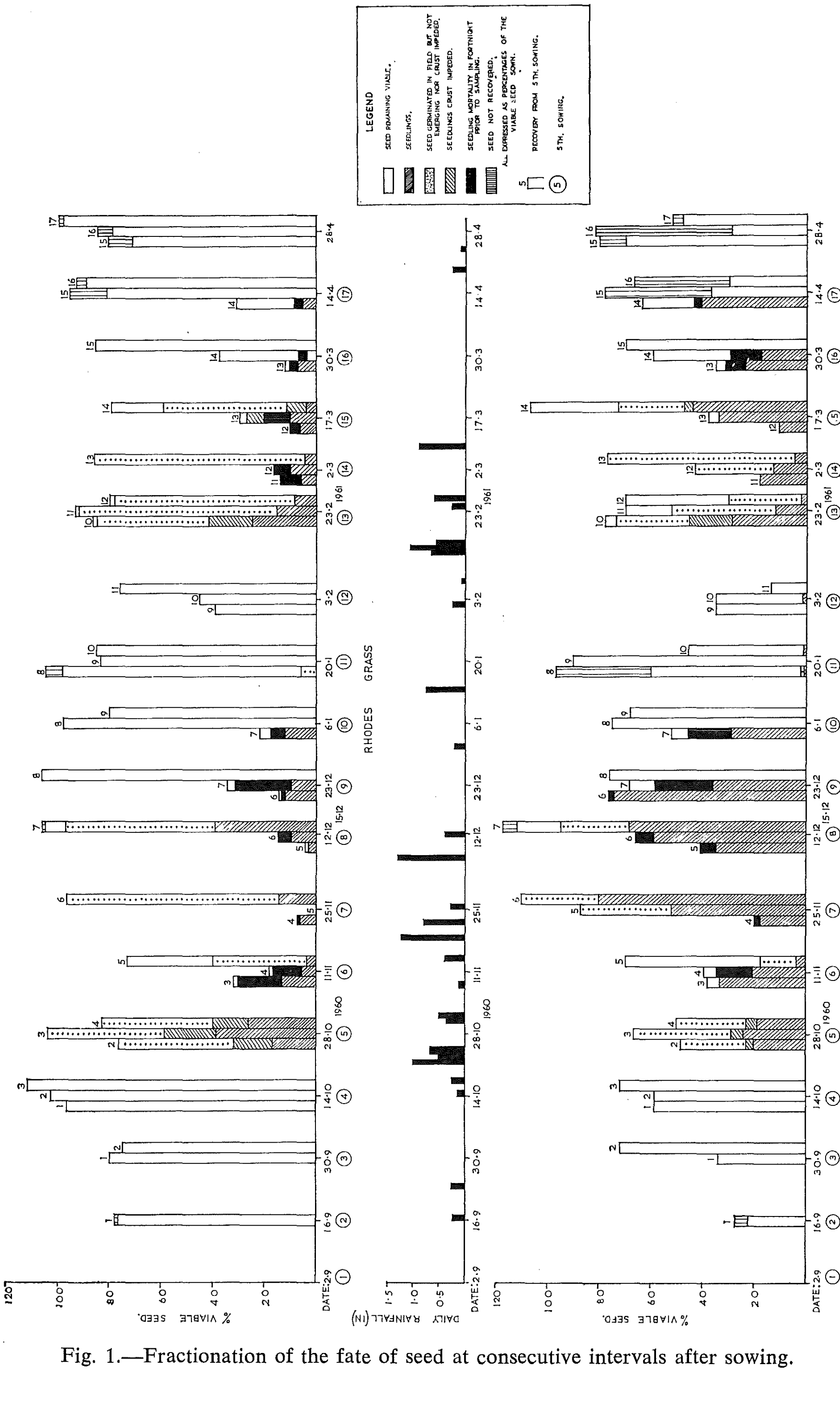

Fig. 1.—Fractionation of the fate of seed at consecutive intervals after sowing.

TABLE 1

FATE OF SEED AFTER SIX WEEKS'† FIELD EXPOSURE

(Equivalent percentage of viable seed sown)

Sowing	Field Germination		Non-emergent Seedlings		Crust-impeded Seedlings		Seedling Mortality		Seedling Survivors		Residual Viability		Seed Not Recovered	
	Rhodes Grass	Green Panic	Rhodes Grass	Green Panic	Rhodes Grass	Green Panic	Rhodes Grass	Green Panic	Rhodes Grass	Green Panic	Rhodes Grass	Green Panic	Rhodes Grass	Green Panic
1 ..	..	..	..	..	..	..	..	..	..	..	98·8***	61·3	0·0	0·0
2 ..	79·2*	49·7	44·5	25·3	15·2*	1·1	0·0	0·0	16·2	20·8	0·0	0·7	..	..
3 ..	99·8***	68·8	55·1	24·9	20·6	7·2	17·9***	0·0	12·6	33·8	2·9	3·3	..	..
4 ..	82·7*	52·0	47·5	25·1	12·3	2·9	15·8***	0·4	3·2	17·0	0·0	0·1	..	..
5 ..	37·9	87·8***	35·8	37·5	0·0	0·0	0·2	4·7	1·7	33·6**	0·2	0·0	..	..
6 ..	98·3	100·0	79·8**	30·6	0·0	0·0	6·2	0·9	10·6	76·8***	0·2	0·0	..	..
7 ..	95·9	98·6	63·2	50·7	0·0	0·0	23·4	16·1	12·1	29·3	1·6	2·6	..	..
8 ..	3·8	0·3	3·8	0·2	0·0	0·0	0·0	0·0	0·0	0·3	95·9*	62·2	6·8	35·3**
9 ..	..	..	..	..	..	..	..	..	..	..	38·7	34·6	8·2	19·1
10 ..	86·0	74·5	44·3	26·5	13·2	16·7	0·0	0·0	18·7	29·1	0·8	3·5	..	..
11 ..	94·0***	51·8	82·1*	34·8	0·0	0·0	7·1**	0·0	2·1	17·1	0·0	0·7	..	..
12 ..	77·4**	42·1	60·8	29·4	0·0	0·0	10·9***	0·0	4·4	6·8	0·0	0·0	..	..
13 ..	87·7	80·9	66·7	38·6	0·0	0·0	11·2	11·3	5·5	17·4	1·0	2·9	0·0	1·2
14 ..	59·8	77·7	30·4	19·0	5·2	1·0	8·0	7·1	5·0	40·4**	18·9	17·6	..	..
15 ..	..	..	..	..	..	..	..	..	..	..	73·5	73·9	7·4	7·8
16 ..	..	..	..	..	..	..	..	..	..	..	82·6***	18·8	6·9	50·9***
17 ..	..	..	..	..	..	..	..	..	..	..	97·1***	49·4	0·9	4·3

* $P < 0{\cdot}05$ ** $P < 0{\cdot}01$ *** $P < 0{\cdot}001$

Probabilities refer to differences between species means

† 16th sowing exposed for 4 weeks; 17th sowing exposed for 2 weeks

At the final recovery for each sowing, seed was assigned to the above categories, to represent the fate of each sowing after its full period of field exposure (Table 1). This required, in most instances, that the measurements of field germination, non-emergent seedlings and crust impedance be based on different recoveries from the measurements of seedling mortality and survival, and residual viability, which were taken from the last recovery of each sowing. Such treatment demanded uniformity of behaviour for each recovery sample. It was possible to test for uniformity of emergence and seedling mortality for the separate recoveries of a number of sowings, and no significant differences were determined.

Twelve of the 17 sowings achieved some field germination prior to recovery. The fractions of seed in each category (Table 1) have been averaged separately for these sowings, and their means are presented with the corresponding means for the non-germinated sowings in Table 2.

TABLE 2

AVERAGE FATE OF SEED AFTER SIX WEEKS' FIELD EXPOSURE

(Equivalent percentage of viable seed sown)

Category	Mean of Germinated Sowings				Mean of Non-germinated Sowings			
	Rhodes Grass		Green Panic		Rhodes Grass		Green Panic	
	rho	Equiv. %	rho	Equiv. %	rho	Equiv. %	rho	Equiv. %
Field germination	62·4**	78·3	55·4	67·8	..		..	
Non-emergent seedlings ..	45·3***	50·5	31·1	26·7	..		..	
Crust-impeded seedlings ..	8·8*	2·3	5·1	0·8	..		..	
Seedling mortality	13·7***	5·6	6·7	1·4	..		..	
Seedling survivors	15·4	7·1	29·6***	24·4	..		..	
Residual viability	11·4 N.S.	3·9	10·7	3·4	65·4***	82·6	43·4	47·3
Seed not recovered ..	3·6N.S.	0·4	10·0	3·0	12·25	4·5	27·1**	20·7
Non-viable seed	..	17·4	..	25·8	..	12·9	..	32·0
Number of sowings ..	12		12		5		5	

rho = Arcsin $\sqrt{\text{Percentage}}$

* $P < 0{\cdot}05$ ** $P < 0{\cdot}01$ *** $P < 0{\cdot}001$

N.S. = No significant difference

Probabilities refer to differences between means for species

(i) Field Germination

The overall field germination of Rhodes grass was higher than that for green panic (Table 2) and in five of the sowings this difference was significant (Table 1).

In Figure 2, it may be seen that although the two species had similar rates of germination after commencement, Rhodes grass attained a given level of germination approximately 0·8–0·9 days earlier than green panic. Assuming that the time of onset of stress was similar for both species, the differences in field germination are consistent with the germinative characteristics of the samples.

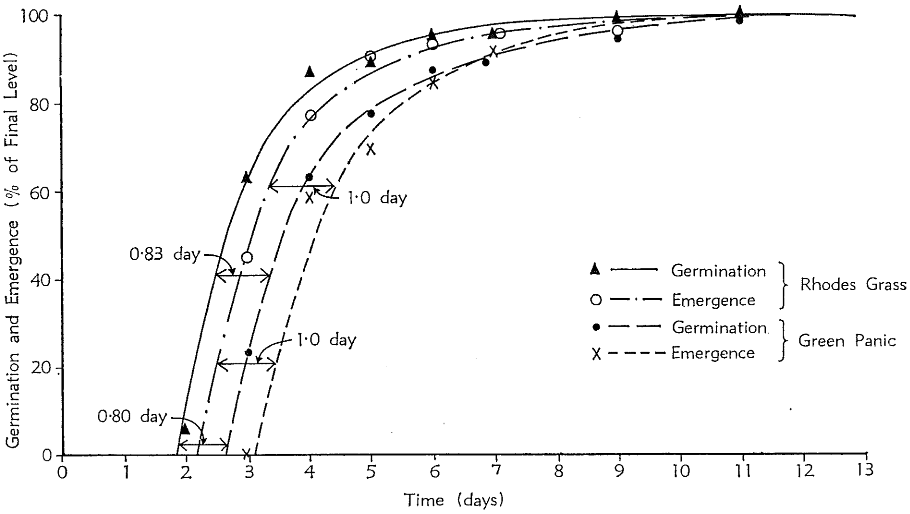

Fig. 2.—Smoothed curves for the germination and emergence of Rhodes grass and green panic as a function of time. Emergence was from 0·5-in. depth in a black earth. Temperature was 32°–20°C, alternating.

In one sowing, the fifth, final green panic germination exceeded that of Rhodes grass. The explanation of this may be drawn from Figure 1. This sowing received 0·80 in. rain in two falls on October 31 and November 1, followed by seven days of hot, dry weather. On this rain Rhodes grass germinated 39 per cent. and green panic 17 per cent. Rhodes grass, being further advanced in germination, suffered a greater loss in viability, and when 2·34 in. rain fell subsequently green panic germinated an additional 71 per cent., but Rhodes grass effected no further germination.

The highest soil temperature measured at 0·5-in. depth in soil adjudged sufficiently moist to promote germination was 39°C. Since this is well below the maximum tolerance of both species for alternating regimens (Leslie, unpublished data) it is unlikely that high soil temperatures restricted field germination in advance of moisture stress. Soil temperature nevertheless influences the rate of both germination and emergence. On a number of occasions soil temperatures were taken during rain at 0·5-in. depth. For example, the noon temperature during the rain of February 2 to February 19 varied from 19 to 21°C. Irrespective of the daily minimum temperatures (which were not measured) such temperatures are decidedly suboptimal for both species with respect to rate of germination and emergence. Retardance of field germination due to low temperatures during rain would not normally be restrictive on final germination, since germination doubtless proceeds rapidly at the higher temperatures after the cessation of rain. It would, however, increase the likelihood of seedlings emerging through dry soil, and it will be seen later that this is a factor of some significance.

There was a wide range in both the quantity and the duration of the eight rainfalls which promoted germination but there was no apparent relationship between these factors. For example, 1·35 in. (one day), 0·86 in. (two falls in four days), 2·34 in. (three falls in 10 days), and 2·16 in. (three consecutive days) produced respectively 98, 88, 98 and 92 per cent. germination of Rhodes grass and 97, 81, 112 and 75 per cent. germination of green panic.

By comparing soil moisture levels at fortnightly intervals, it was possible to estimate the approximate depth of the wetting front for each rain. These data are presented in Table 3 with the relevant field germination figures.

TABLE 3

FIELD GERMINATION IN RELATION TO RAINFALL

Rainfall (in.)	No. of Falls/ Period (days)	Estimated Depth of Wetting Front (in.)	Sowing No.	Field Germination (% of viable seed sown)	
				Rhodes Grass	Green Panic
2·10	3/3	4	2	77	49
			3	104	68
			4	85	51
0·80	2/2	2	5	39	17
2·34	3/10	>6	5	0	72
			6	98	112
1·35	1/1	>6	7	98	97
0·75	1/1	1	8	6	1
			9	0	0
			10	0	1
2·16	3/3	>6	10	85	75
			11	92	54
			12	77	32
0·86	2/4	>6	12	0	13
			13	88	81
0·93	1/1	>6	14	59	75

With the exception of the anomalous behaviour of green panic on the 2·16-in. fall, which will be discussed later, there is some suggestion that the extent of germination was related to the depth of saturated soil. Should this occur with little influence from post-rainfall conditions, it would imply an influence of the soil moisture content well below seed depth on the moisture status at seed depth.

It seems likely that the phenomenon of supersaturation which occurs in the cultivated layer of these soils (Waring, Fox, and Teakle 1958) would lead to temporary upward saturated flow, and the depth of the wetting front could be a measure of the degree of supersaturation. Other related influences could be the promotion of heat conduction with a reduction in the rate of surface drying, and upward unsaturated moisture flow (Westelaar 1961 *a, b;* Simpson 1962; G. W. Swartz, unpublished data).

The existence of a relationship between field germination and saturation depth could not be established on so few observations, but warrants further scrutiny.

Field germination generally attained levels which were adequate to produce satisfactory establishment had the emergence and seedling phases been unrestricted. Sowings which did not reach adequate germination levels during exposure tended to retain a high level of seed viability.

The tendency towards increased field germination with increased soil wetness indicates that aeration at 0·5-in. depth was normally sufficient for the germination of both species.

It is concluded that moisture stress was the main factor limiting germination.

(ii) Crust-impeded Seedlings

Crust impedance has been shown to reduce seedling emergence (Quirk and Schofield 1958; Hanks 1960; Hudspeth and Taylor 1961).

Soil crusts developed within a few hours after the cessation of rain. Their dimensions varied greatly and tended to be large following high-intensity rains or prolonged light rains which fostered very slow drying. They varied in size from 3–4 in. wide and 0·25–0·35 in. thick to very fine fragile crusts which disintegrated completely on drying. The cracks between crusts were 0·1–0·4 in. wide.

Only the heavier crusts caused significant impedance to emergence, and this was greater for Rhodes grass than for green panic (Table 2). Seedlings of the latter were able to grow up to 1 in. horizontally to emerge through cracks, whereas Rhodes grass seedlings seemed unable to grow more than 0·25 in. This characteristic of green panic made crust impedance of little consequence on all except one occasion, the tenth sowing, when crust-impeded seedlings constituted 16·7 per cent. of the viable seed. Rhodes grass impedance varied from 5·2 to 20·6 per cent. for the five sowings affected, and three of these sowings emerged on one germinating rain.

Both species were incapable of piercing or moving crusts, irrespective of crust size. This must be due to the fragility of the seedlings and to their inability to acquire sufficient lateral support in the air layer beneath crusts to exert effective vertical penetrative forces (Taylor 1962). Unless coleoptiles had pierced the surface before crusting commenced, emergent seedlings invariably occurred in the cracks between crusts.

The position of seedling crown development was apparently governed by the level at which seedlings first received light. This frequently led to the crowns of emerged seedlings forming at depths greater than 0·25 in. below the crust surface. The primary leaf of Rhodes grass is reflexed and young Rhodes grass seedlings were often wholly below the surface. Light falls of rain at this stage were observed to "puddle" the crusts, which subsequently reformed with a different cracking pattern. This led to emerged Rhodes grass seedlings being permanently obstructed, and was in fact the greatest single cause of seedling mortality, being primarily responsible for 39·4 per cent. mortality of emergent Rhodes grass in the first week after emergence (Table 4). The lightest fall of rain to produce this effect was 0·36 in. on December 12.

TABLE 4

SEEDLING MORTALITY IN PERIODS AFTER EMERGENCE

(Equivalent percentage of seedlings present at beginning of each period)

Species	Period after Emergence (weeks)					
	0–1		1–2		2–5	
	rho	Equiv. %	rho	Equiv. %	rho	Equiv. %
Rhodes grass	40·0	39·4	19·3	10·9	26·5	19·9
Green panic	7·3	1·6	18·0	9·5	23·2	15·5
Necessary difference for significance ($P < 0{\cdot}001$)	15·6		N.S.		N.S.	

rho = Arcsin $\sqrt{\text{Percentage}}$

The primary leaf of green panic is an erect lanceolate organ which normally maintained an emergent lamina in spite of recrusting. On one occasion the crust which reformed was heavy, and the green panic seedlings were constricted just above the primordia. The new leaves were unable to pass through the constriction and bulged sideways beneath the crust (Figure 3). None of these emerged, and the constricted leaves eventually died.

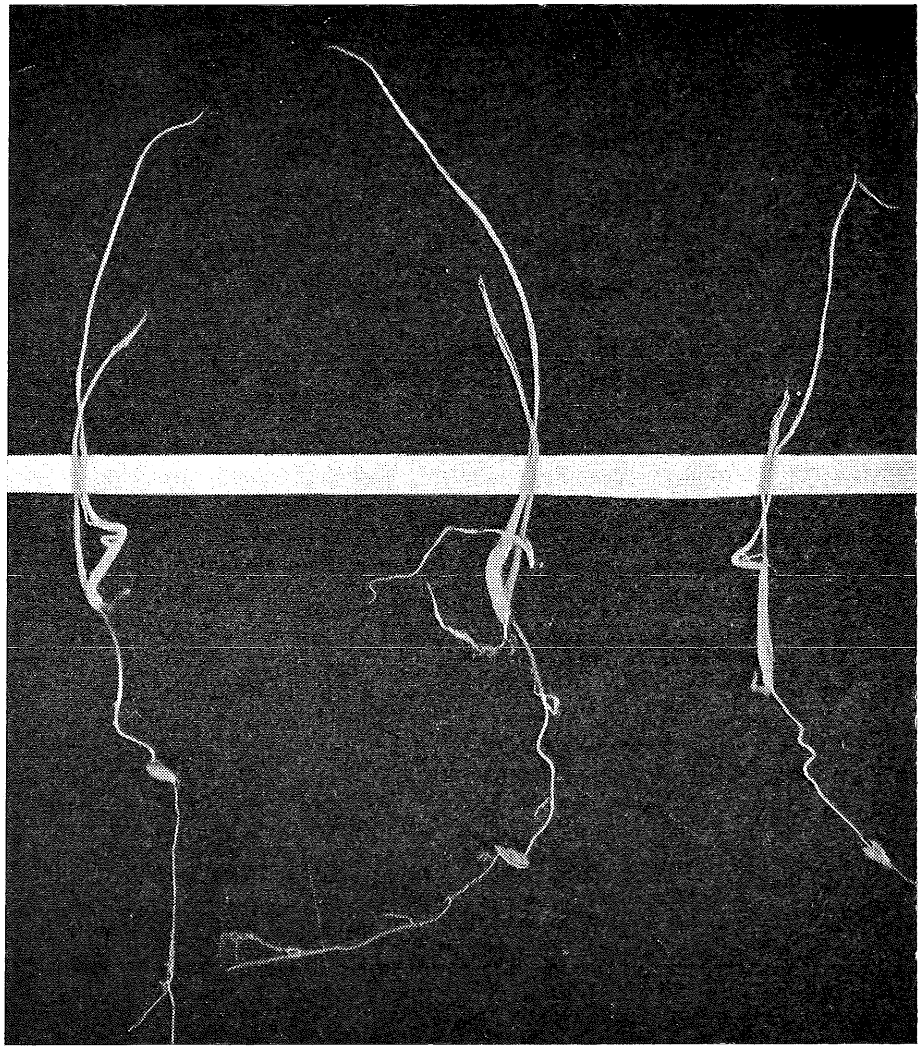

Fig. 3.—Green panic seedlings showing constriction of the leaves by crusts. The white band coincides with the former crust. The distortion of the growing point below the constriction is evident.

In instances where seedlings penetrated the surface before heavy crust development, the seedling crowns were embedded in the crusts. When the crusts curled upwards, forming an air layer beneath, many of these seedlings perished from root severance or desiccation in the air layer.

(iii) Non-emergent Seedlings

The non-emergent fraction represents seedlings which neither emerged nor were impeded by crusts. Overall it constituted 50·5 per cent. of the viable Rhodes grass seed and 26·7 per cent. of the green panic seed (Table 2). As a proportion of the germinated seeds in individual sowings, the fraction varied from 51·3 to 100 per cent. (mean 75·7 per cent.) for Rhodes grass and from 27·3 to 79·2 per cent. (mean 47·4 per cent.) for green panic. Failure to emerge was the greatest single cause of reduced establishment.

Increasing moisture stress and high soil temperatures must play an important role (Laude, Shrum, and Bieler 1952; Laude 1957), but there is reason to believe that a very significant part of this failure was not primarily due to these factors.

The data on field germination support the contention that Rhodes grass germinated more rapidly than did green panic. It may therefore be argued that Rhodes grass should have led green panic in emergence (Figure 2), and this was true of the initial emergence following each rain. The earlier lead of Rhodes grass was quickly reversed as drying of the soil surface progressed. At the time of seed recovery, the soil surrounding the seed was often well above wilting point, and the seminal roots of non-emergent seedlings extended well into the moist soil. It was noted that Rhodes grass emergence virtually ceased when the soil surface dried into crusts. Green panic continued emergence for a longer period—up to two days after crust formation. These facts indicate that moisture stress was not primarily responsible for the inferior emergence of Rhodes grass.

Examination of non-emergent seedlings showed no lesions or other abnormalities which could be associated with high-temperature damage. Parallel with the above considerations of moisture stress, it seems unlikely that lethal high temperatures would restrict emergence within the period noted. Hart (1958) has mentioned damage to the emergence of millet seedlings by high surface soil temperatures, but millet is normally sown on preplanting rains and therefore commonly emerges through dry soil under clear, hot weather conditions.

Mechanical impedance by the layer of dry soil crumbs beneath the crust is believed to have been responsible for the major part of this emergence failure, green panic being less susceptible than Rhodes grass.

A major fraction of non-emergent seedlings were observed to have pierced coleoptiles and often well-expanded primary leaves with chlorophyll. Since seedlings of these species rarely pierce their coleoptiles if germinated in complete darkness, it seems reasonable to assume that light penetration into the loose layer of dry crumbs beneath the soil crust was responsible for this phenomenon.

Non-emergent Rhodes grass with a primary leaf appeared to lose directive penetration, while the lanceolate green panic leaves retained some penetrative ability. It is considered that this ability was partly responsible for the greater emergence of green panic.

Employing the photographic technique described, the depth of light penetration in a natural mulch was determined (Figure 4). Some light penetrated to 0·75 in. in the mulch and the frequency of directly exposed points increased with decrease in depth. The natural mulch transmitted light with similar spatial frequency to that of separates greater than 0·132 in. Decrease in size of separates decreased the depth of light penetration, but even with separates in the 0·132 to 0·055-in. class, light reached 0·5-in. depth. The proportions of the size fractions in the natural mulch, on an oven-dry basis, were:— >0·132 in., 79 per cent.; 0·132 to 0·055 in., 17 per cent.; and <0·055 in., 4 per cent.

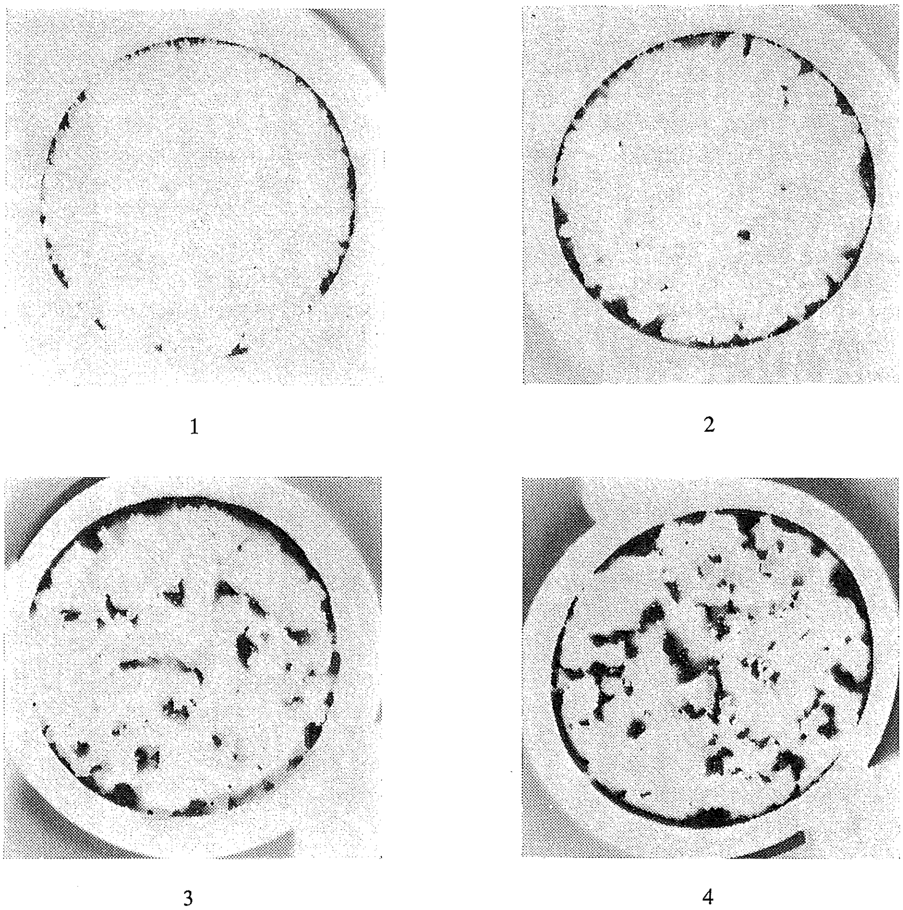

Fig 4.—Patterns of direct light penetration into an air-dry natural soil mulch. 1, 1·0-in. depth; 2, 0·75-in. depth; 3, 0·50-in. depth; 4, 0·25-in. depth.

The light intensity used in the production of these prints was very low relative to daylight, and it is probable that void spaces in natural mulches would have low light intensities at a given depth which are related to the frequency pattern of direct rays at that depth. Crusts constituted complete light barriers, and the direct light pattern followed the cracks between crusts. It would be expected that the number of non-emergent seedlings would decrease with increase in crust size, if light penetration was a significant factor. It is therefore of interest that the mean percentage of non-emergent seedlings (percentage of field germination) when no crust impedance occurred was 82·5 for Rhodes grass, whereas the mean when crust impedance existed was only 44·6. The relative figures for green panic were 51·7 and 42·3 respectively.

Further work is necessary to determine the importance of this factor as one restricting emergence. Chippendale (1949) showed a response to light by seeds, light-obligate for germination, which were covered by 0·25 in. soil.

Both forms of impedance should become increasingly restrictive as the crumb size of the natural mulch increases (Edwards 1957), and may be of vital importance on the very coarse structured Mywybilla soils. It may be worth while, as one assessment of establishment potential, to screen a range of grass species for their ability to emerge through dry soil of different aggregate sizes with impinging light.

The ultimate cause of death of these non-emergent seedlings is not known, but death was presumably effected by exhaustion of seed reserves, moisture stress and high temperatures in combination.

(iv) Seedling Mortality

It was stated earlier that serious Rhodes grass mortality occurred in the first week of emergence, due to recrusting. Mortalities of both species in this period and in the periods 1–2 and 2–5 weeks after emergence are shown in Table 4.

Apart from the effect of recrusting, both species appeared to be equally prone to mortality and there did not appear to be any particularly susceptible stage in the first five weeks of growth. This does not preclude the existence of more susceptible stages as shown for other grass species by Heyne and Laude (1940) and Mueller and Weaver (1942), since the estimates in this study are based on low populations subjected to differing stress regimens. It is considered by the author that seedling mortality is of little consequence after five weeks except in very extreme conditions.

The main causes of mortality were assumed to be high temperature and moisture stress, which have been reviewed by Levitt (1951). Moisture stress was apparently aggravated when seedlings were unable to develop secondary root systems due to dryness of the surface soil. In such cases some seedlings had their seminal roots severed by twisting in strong winds. Desiccation of the primary root in the air space beneath crusts, and root severance by crust curling, were mentioned previously.

At no time was damping-off observed to affect seedlings of either species.

Mortality due to all causes (excluding recrusting for Rhodes grass) constituted a small fraction of emerged seedlings, and while it must be recognized, it does not appear to be a major source of sowing failures.

(v) Seedling Survivors

The average number of green panic seedlings surviving at the final recovery was three times the number of Rhodes grass seedlings. The mean survival values of 24·4 and 7·1 per cent. respectively (Table 2) represent overestimates of final establishment, since these means are based on samples of various ages. Nevertheless, the relative differences should have remained, since the mortality rates were similar for both species after the first week. In all 12 germinated sowings, the seedling populations of green panic exceeded those of Rhodes grass, although only four of these significantly so (Table 1). Most of this difference has been ascribed to the superior emergence ability of green panic and to the effect of recrusting on Rhodes grass.

(vi) Residual Viability, Non-viable Seed and Seed Not Recovered

These three categories are interdependent.

The residual viability of seed which attained high levels of field germination was naturally low. In five sowings, favourable germinating conditions ceased with Rhodes grass attaining a higher level of field germination than green panic. In these instances little viable seed of either species remained, which indicates greater seed spoilage for the slower germinating green panic, and it is reasonable to suppose that green panic would have achieved greater establishment with a shorter latent period to commencement of germination. Conversely, the fifth sowing has already been cited as an example of seed which possesses a higher rate of germination being more subject to seed spoilage by marginal germinating falls.

Went (1953), Toole *et al.* (1956), and Evenari and Koller (1957) have discussed the importance of rate of germination and dormancy mechanisms in certain environments. In the majority of cases in this study, more rapid germination would have been advantageous, and attempts to stimulate germination would be well founded provided that the inherent limitations are not overlooked.

The data suggest that seed spoilage was of little consequence unless field germination was well advanced before it was interrupted. The 8th sowing barely commenced germination and the seed retained most of its original viability if the recovery loss is taken into consideration (Table 1). Five sowings achieved no field germination during their 6 weeks' exposure. The summation of residual viability and seed not recovered accounts for the greatest part of the Rhodes grass seed sown, except for the 9th sowing, which lost an apparent 52 per cent. viability. Two of the five green panic sowings retained high viability, but the 1st, 9th and 17th sowings lost an estimated 39, 46 and 46 per cent. viability respectively.

Inspection of Figure 1 shows that consecutive recoveries of certain sowings during dry periods gave anomalous estimates of residual viability, which was often greater after 6 weeks' exposure than after 2 or 4 weeks' exposure. The same type of behaviour may be observed in the field germination and emergence of the 10th, 11th and 12th sowings. This could not be the result of seed spoilage and it is probable that the technique employed did not provide a valid estimate of residual viability in dry soil recoveries.

Study is being made of a phenomenon of inhibited germination which occurs when these soils are dried at 40–50°C prior to sowing (Leslie, unpublished data). This inhibition affects green panic to a greater degree than Rhodes grass. Non-germinated seed retains some of its viability. The behaviour of field germination following hot, dry periods and the estimates of residual viability during these periods are consistent with what is known of this phenomenon from controlled experiments. The cause of the inhibition is not yet known. With this knowledge, and the observed anomalies occurring in this study, it is considered that the loss in viability by exposure to prolonged hot, dry periods at 0·5-in. depth was normally low.

In view of the apparent influence of depth of saturated soil on the efficacy of a germinating fall, and the possibility of germination inhibition developing in dry soil, sowing into very dry soil appears to be an unduly hazardous practice.

(vii) Pathogens

Soil sampled at each sowing was tubed and sown with Rhodes grass seed as described. In Table 5, the emergence from non-autoclaved soil is expressed as a percentage of that from autoclaved soil for each sampling. The difference in emergence between the two soils suggests that pathogens produced a slight decrease in emergence. This is not decisive, since the individual soil samples which produced significant reductions were taken in hot, dry periods when germination inhibition is believed to have occurred. It has been found that autoclaving dried soil reduces this inhibition slightly.

TABLE 5

EMERGENCE FROM NON-AUTOCLAVED SOIL

(Percentage emergence from autoclaved soil)

Sowing No.	Emergence (%)	Sowing No.	Emergence (%)
1	82	10	88
2	118	11	85
3	95	12	65**
4	99	13	68**
5	90	14	81
6	85	15	78*
7	104	16	103
8	86	17	86
9	91	Mean	88**

* $P < 0{\cdot}05$ ** $P < 0{\cdot}01$

Probabilities refer to difference between autoclaved and non-autoclaved soils

The seed used in the field study was treated with a fungicidal dust, and with the exception of one lot of 100 seeds in one green panic recovery, there was no suggestion that pathogens were influential. In this one seed lot, all seed was non-viable, whereas others in the same recovery were fully viable. A species of *Pythium* was isolated from this seed lot by I. K. Hughes. *Pythium aphanidermatum* (identified by D. S. Teakle) had previously been isolated by the author from seedlings grown in this soil, and shown to produce seed rots and damping-off in both species.

(c) General Applicability of the Results

It was stated earlier that the data presented give an estimate of field behaviour which would not differ greatly from the behaviour of the same seed sown at the same depth under normal field conditions.

Data were provided by Standards Branch, Queensland Department of Primary Industries, for 165 Rhodes grass samples and 180 green panic samples which met legal standards. In comparison with these samples, the Rhodes grass seed used in this study was of higher viability than average, but had a rate of germination similar to the average for all samples. The green panic sample had much higher total viability and rate of germination than normal. It is probable that the behaviour of Rhodes grass in this study was fairly "normal," and that the green panic performance was considerably better than "normal."

The depth of sowing in commercial plantings is very variable, due to variations in practice, to the tilth of the cultivated layer and to the sowing machinery. The fate of seed in this study suggests that a critical balance exists between the depth most beneficial to germination and that permitting maximum emergence. In view of the rapidity of formation of crusts and the layer of dry aggregates immediately beneath them (a total thickness of 0·2–0·4 in.), it is unlikely that shallower Rhodes grass sowing would have been more successful. At 0·5 in., field germination was generally satisfactory, and since emergence was then the prime restriction, deeper sowing would probably have been detrimental.

Green panic, with greater emergence ability but slower germination, may have attained higher field germination and possibly emergence had it been sown deeper. Although aeration did not appear to be restricted at 0·5-in. depth, it may become an important factor at greater depths (Penman 1940*a*, 1940*b*; Lemon and Erickson 1952; McIntyre 1955).

It is apparent that depth of sowing is a factor of considerable importance, and one for which accurate control of the order obviously necessary would be very difficult to achieve. The practice of rolling prior to sowing, which was recommended by Wilson (1956), may derive part of its efficacy from the more positive control of sowing depth (Hyder, Sneva, and Sawyer 1955) in addition to affecting evaporative loss by reducing porosity (Penman 1940*a*; Triplett and Tesar 1960; Stout, Buchele, and Snyder 1961). The role of seed/soil contact is considered of little importance for these species, since their germination is dependent on post-sowing rain. The porosity of these soils when saturated is very low (Fox 1963), and seed was observed to be pelleted in soil crumbs on drying. There appears to be no virtue in the practice of scattered depth of sowing.

No attempt was made to assess the importance of seed-harvesting ants, but suitable insecticidal control methods are available (Anslow 1958; Champ, Sillar, and Lavery 1961).

It seems pointless to consider the weather conditions during the study in relation to their representativeness, since a "germinating fall" defies definition by meteorological parameters and must also be dependent on the quality of the seed sown. It is generally believed that the period of rainfall required to assure establishment is longer than any of those which produced establishment in this study (e.g. Cameron 1959). This could indicate the importance of seed quality and, in particular, the rate of germination.

Most of the restrictions observed were associated with rapid soil drying and the tilth of the natural mulch. It is probable that these restrictions would be more serious on Mywybilla soils with their coarse structure and heavier crusts and less serious on the finer structured Waco soils.

IV. CONCLUSIONS

Since the purpose of this study was to direct research at the most restrictive factors, more importance is attached to the "average" restriction imposed by each factor than to restrictions which were of significance only in sporadic instances.

The abnormal establishment difficulties on black earths are related to the physical characteristics of the surface mulch, and in particular to the rapid development of crusts and a loose layer of soil crumbs beneath them following the cessation of rain. This induces serious impedance to seedling emergence, which is aggravated by the penetration of light and consequent development of primary leaves in non-emergent seedlings. For Rhodes grass, recrusting may cause serious seedlings losses in the first week after emergence.

It is concluded that this restriction and others of lesser importance are dependent on a delicate balance between the rates of germination and emergence and the rate of soil drying. Thus research would be best directed through this balance at:

(*a*) increasing the rate of seed germination (by stimulation and/or by rigid selection of seed);

(*b*) reducing the rate of soil drying;

(*c*) providing accurate control of sowing depth;

(*d*) selecting otherwise suitable species for superior emergence ability; and

(*e*) developing methods for reducing the crumb and crust sizes of the natural mulch.

It is believed that the sowing methods recommended by Wilson (1955, 1956) are sound for conventional machinery, and it is probable that failures occur more frequently than they should because these recommendations are only partly adopted. In particular, the following points should be observed:

(*a*) Sowings should not be made on very dry soils, e.g. soils requiring more than 1·0–1·5 in. rain to promote saturation beyond 6 in. depth.

(*b*) More recognition should be given to seed quality, and high viability and rate of germination should be ensured prior to purchase of seed.

(*c*) Depth of sowing should be regarded as critical. Rhodes grass appears to allow little variation from 0·5 in., while green panic may probably be best sown at 0·5 in.–1·5 in. The first requisite is a fine seedbed. On Waco soils, this is best produced by natural mulching after rain. Seedbed compaction prior to drilling is a further aid to placement of seed, but should be used with caution on erodible land.

V. ACKNOWLEDGEMENTS

The author wishes to express his gratitude to Messrs. L. R. Humphreys and F. H. Kleinschmidt for their criticism of the manuscript.

REFERENCES

ANSLOW, R. C. (1958).—Note on an improved technique for establishing *Setaria sphacelata* from seed. *Emp. J. Exp. Agric.* 26:55–7.

BUCKLEY, K. S. (1959).—Plant testing for soil conservation at Inverell. *J. Soil Conserv. N.S.W.* 15:227–45.

CAMERON, D. G. (1959).—Grasses tested for soil conservation. Results to April, 1958. *J. Soil Conserv. N.S.W.* 15:189–202.

CHAMP, B. R., SILLAR, D. I., and LAVERY, H. J. (1961).—Seed-harvesting ant control in the Cloncurry district. *Qd J. Agric. Sci.* 18:257–60.

CHAMPNESS, S. S., and MORRIS, K. (1948).—The population of buried viable seeds in relation to contrasting pasture and soil types. *J. Ecol.* 36:149–73.

CHIPPENDALE, H. G. (1949).—Environment and germination in grass seeds. *J. Brit. Grassl. Soc.* 4:57–61.

CROCKER, W. (1948).—"Growth of Plants". (Reinhold Publishing Corp.: New York).

CROCKER, W., and BARTON, L. V. (1953).—"Physiology of Seeds". (Chronica Botanica Co.: Waltham, Mass.).

EDWARDS, R. S. (1957).—Studies of the growth of cereals on seed-beds prepared by dry-sieving of the soil. *Emp. J. Exp. Agric.* 25:167–84.

EVANARI, M., and KOLLER, D. (1957).—"The Future of Arid Lands". Publ. Amer. Ass. Advanc. Sci. No. 43.

FOX, W. E. (1963).—Ph.D. Thesis, University of Queensland.

FULTS, J. L. (1944).—Some factors affecting establishment of perennial grass for erosion control in East Colorado. *J. Amer. Soc. Agron.* 36:615–25.

HANKS, R. J. (1960).—Soil crusting and seedling emergence. *Proc. 7th Int. Congr. Soil Sci.* 1:340–6.

HARLAN, J. K. (1958).—Agronomic trends and problems in the Great Plains. III. Pasture and range crops. *Advanc. Agron.* 10:15–22.

HART, J. (1949).—Agriculture on the Darling Downs. *Qd Agric. J.* 69:1–9, 63–74.

HART, J. (1958).—Growing millets in Queensland. *Qd Agric. J.* 84:703–13.

HEYNE, E. G., and LAUDE, H. H. (1940).—Resistance of corn seedlings to high temperatures in laboratory tests. *J. Amer. Soc. Agron.* 32:116–26.

HOPKINS, N. H. (1954).—Effects of mulch on certain factors of the grassland environment. *J. Range Mgmt* 7:255–8.

HUDSPETH, E. B., and TAYLOR, H. M. (1961).—Factors affecting seedling emergence of Blackwell switchgrass. *Agron. J.* 53:331–5.

HYDER, D. N., SNEVA, F. A., and SAWYER, W. A. (1955).—Soil firming may improve range seeding. *J. Range Mgmt* 8:159–62.

JACKS, G. V., BRIND, W. D., and SMITH, R. (1959).—Mulching. Tech. Commun. Bur. Soils, Harpenden, No. 49.

LAUDE, H. H. (1957).—Comparative pre-emergence heat tolerance of some seeded grasses and of some weeds. *Bot. Gaz.* 119:44–6.

LAUDE, H. H., SHRUM, J. E., and BIELER, W. E. (1952).—Effect of high soil temperatures on the seedling emergence of perennial grasses. *Agron. J.* 44:110–2.

LEMON, E. R., and ERICKSON, A. E. (1952).—The measurement of oxygen diffusion in the soil with a platinum microelectrode. *Proc. Soil. Sci. Soc. Amer.* 16:160–3.

LEVITT, J. (1951).—Frost, drought and heat resistance. *Annu. Rev. Pl. Physiol.* 2:245–68.

MAYER, A. M. (1960).—Germination research at the Hebrew University, Jerusalem, Israel—a review. *Indian J. Pl. Physiol.* 3:13–23.

MCCALLA, T. M., and DULEY, F. L. (1946).—The effect of crop residues on soil temperature. *J. Amer. Soc. Agron.* 38:75–89.

MCINTYRE, D. S. (1955).—Effect of soil structure on wheat germination in a red-brown earth. *Aust. J. Agric. Res.* 6:797–803.

MOLDENHAUER, W. C. (1959).—Establishment of grasses on sandy soil of the southern High Plains of Texas using a mulch and simulated moisture levels. *Agron. J.* 51:39–41.

MOORE, R. P. (1943).—Seedling emergence of small-seeded legumes and grasses. *J. Amer. Soc. Agron.* 35:370–81.

MUELLER, I. M., and WEAVER, J. E. (1942).—Relative drought resistance of seedlings of dominant prairie grasses. *Ecology* 23:387–98.

PENMAN, H. L. (1940*a*).—Gas and vapour movements in the soil. I. The diffusion of vapours through porous solids. *J. Agric. Sci.* 30:437–62.

PENMAN, H. L. (1940*b*).—Gas and vapour movements in the soil. II. The diffusion of carbon dioxide through porous solids. *J. Agric. Sci.* 30:570–81.

QUIRK, J. P., and SCHOFIELD, R. K. (1955).—The effect of electrolyte concentration on soil permeability. *J. Soil Sci.* 6:163–78.

RUSSELL, E. W. (1962).—"Soil Conditions and Plant Growth". 9th Ed. (Longmans Green and Co. Ltd.: London).

RUSSELL, J. C. (1939).—Effect of surface cover on soil moisture losses by evaporation. *Proc. Soil Sci. Soc. Amer.* 4:65–70.

SHAW, N. H. (1957).—Bunch spear grass dominance in burnt pastures in south-eastern Queensland. *Aust. J. Agric. Res.* 8:325–34.

SIMPSON, J. R. (1962).—Mineral nitrogen fluctuations in soils under improved pasture in southern New South Wales. *Aust. J. Agric. Res.* 13:1059–72.

STOUT, B. A., BUCHELE, W. F., and SNYDER, F. W. (1961).—Effect of soil compaction on seedling emergence under simulated field conditions. *Agric. Engng* 42:68–71.

TAYLOR, H. M. (1962).—Switchgrass emergence through non-porous sealing compounds. *Agron. J.* 54:466–7.

THOMPSON, C. H., and BECKMANN, G. G. (1959.)—Soils and land use in the Toowoomba area, Darling Downs, Queensland. C.S.I.R.O. Aust. Soils & Land Use Ser. No. 28.

THOMPSON, C. H., and BECKMANN, G. G. (1960).—Soils and land use in the Kurrawa area, Queensland. C.S.I.R.O. Aust. Soils & Land Use Ser. No. 37.

TOOLE, E. H., HENDRICKS, S. B., BORTHWICK, H. A., and TOOLE, VIVIENNE K. (1956).—Physiology of seed germination. *Annu. Rev. Pl. Physiol.* 7:299–324.

TRIPLETT, G. B., and TESAR, M. B. (1960).—Effects of compaction, depth of planting and soil moisture tension on seedling emergence of alfalfa. *Agron. J.* 52:681–4.

WARING, S. A., FOX, W. E., and TEAKLE, L. J. H. (1958).—Fertility investigations on the black earth wheatlands of the Darling Downs, Queensland. I. Moisture accumulation under short fallow. *Aust. J. Agric. Res.* 9:205–16.

WENT, F. W. (1953).—Effect of temperature on plant growth. *Annu. Rev. Pl. Physiol.* 4:347–62.

WETSELAAR, R. (1961*a*).—Nitrate distribution in tropical soils. I. Possible causes of nitrate accumulation near the surface after a long dry period. *Plant & Soil* 15:110–20.

WETSELAAR, R. (1961*b*).—Nitrate distribution in tropical soils. II. Extent of capillary accumulation of nitrate during a long dry period. *Plant & Soil* 15:121-33.

WILSON, R. G. (1955).—Sowing summer pastures on the Darling Downs. *Qd Agric. J.* 80:79–82.

WILSON, R. G. (1956).—Machine sown pastures on the Darling Downs. *Qd Agric. J.* 82:63–70, 125–35.

WINCHESTER, W. J. (1954).—Storing seed of green panic and buffel grass for better germination. *Qd Agric. J.* 79:203–4.

(Received for publication June 2, 1964)