GERMINATION BEHAVIOUR IN BEACH SPINIFEX (*SPINIFEX HIRSUTUS* LABILL.)

By R. L. HARTY* and T. J. MCDONALD*

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Abstract

This paper deals with threshing and seed germination studies on hand-harvested beach spinifex (*Spinifex hirsutus* Labill.). This work was carried out as part of a detailed study of the autecology of beach spinifex, an important pioneer sand stabilizer on beaches and dunes along the coast of eastern Australia.

Hammer-milling was suitable for threshing out caryopses from beach spinifex inflorescences, but in the process the caryopses were excessively damaged. A barley de-awning machine produced spikelets (caryopses enclosed in lemma, palea, and glumes plus the base of the associated spine) which were free flowing and therefore suitable for mechanical planting.

Laboratory germination experiments disclosed that the caryopses were negatively photoblastic when germinated alone, or enclosed within the spikelet. Alternating thermoperiods (10–25, 15–25, 20–25; 10–35, 15–35, 20–35°C) were generally superior to constant thermoperiods (25, 30, 35°) in the induction of germination. The germination of caryopses from inflorescences harvested 2 months previously agreed with an estimate of viability made by using tetrazolium chloride. This indicated that beach spinifex seed has no pronounced after-ripening requirements.

The rate of germination of caryopses and their germinative capacity were markedly increased when the caryopses were removed from the spikelets. It is likely that germination in the spikelet is inhibited by a slow rate of gaseous exchange between the embryo and the atmosphere. A sensitivity to anaerobic conditions was demonstrated by soaking spikelets for varying periods up to 48 hr in distilled and sea water. Such treatments led to a decrease in germination. Pot trials showed that in waterlogged sand, no appreciable germination occurred below 3·75 cm. In sand held at field capacity, some germination occurred down to the maximum depth tried (8·75 cm), but the best germination was from 2·5 to 3·75 cm. Soaking spikelets in distilled water for 48 hr and testing the leachate on germinating lettuce seed failed to disclose the presence of water-soluble chemical inhibitors in the spikelets.

I. INTRODUCTION

Along most of the east coast of Australia, sandy beaches backed by vegetated sand dunes occur. In some places the existing natural plant communities have been badly damaged or destroyed. Some of the causes of this degradation are grazing by stock, mining operations, and clearing. Currently, in many of the areas where damage has occurred, rebuilding and revegetation programs are being undertaken. Beach spinifex (*Spinifex hirsutus* Labill.) is the most important pioneer sand-stabilizing

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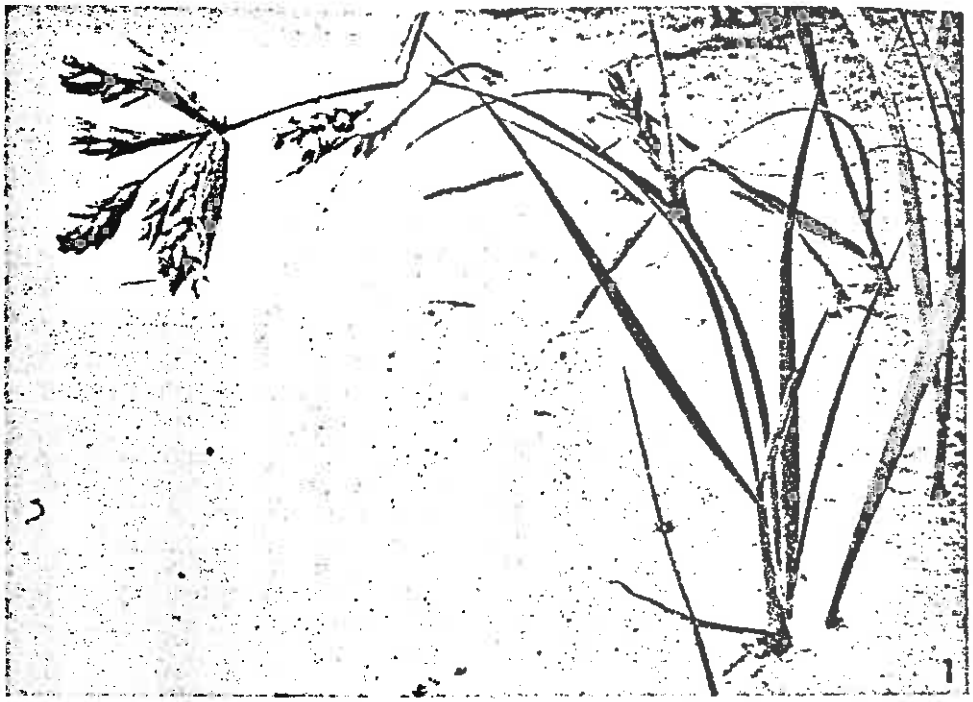

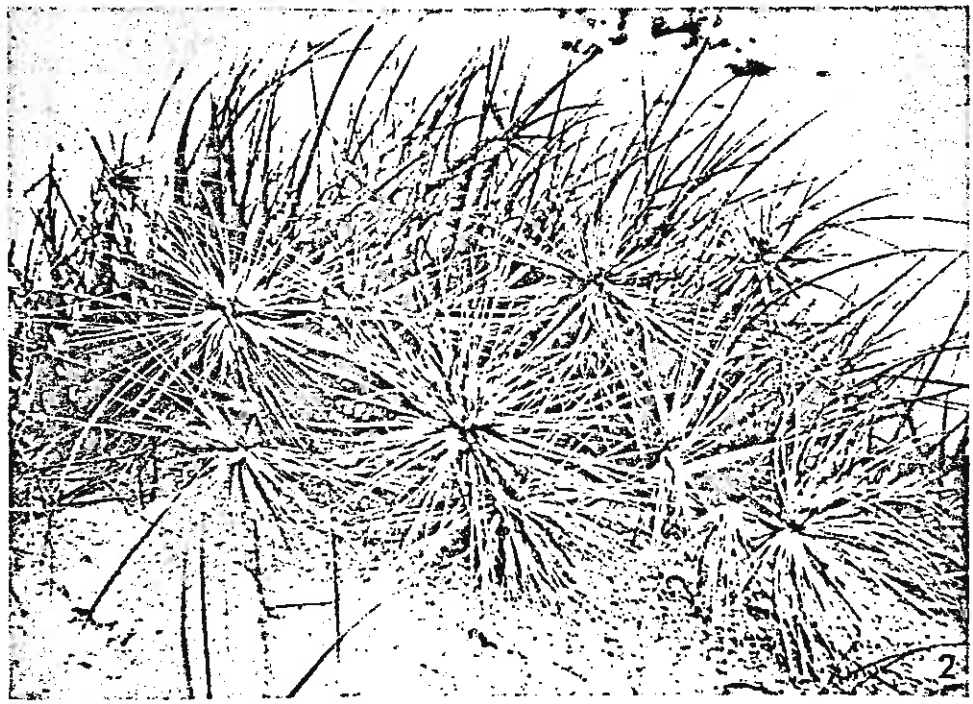

Fig. 1.—Male inflorescences of beach spinifex. (Photo, S. L. Everist.)
Fig. 2.—Female inflorescences of beach spinifex. (Photo, S. L. Everist.)

plant occurring naturally in this area, and it is the major species used in planting programs for the revegetation of frontal dunes.

This paper deals with threshing and germination studies carried out as part of an investigation into the autecology of beach spinifex undertaken jointly by the Queensland Department of Primary Industries and the Queensland Beach Protection Authority. The germination studies were undertaken to aid the understanding of the behaviour of this species in the field and to assist the development of effective field techniques for its establishment in revegetation programs.

II. Materials and Methods

(a) Threshing

Beach spinifex is dioecious. The male plants produce pale brown, shortly branched compact inflorescences about 5 cm long (Fig. 1); the female plants produce large, spiny, spherical inflorescences about 20–30 cm in diameter (Fig. 2). The female inflorescence is commonly a terminal head but in some specimens there is a second or third head below. The head consists of a large number of spine-like branches 10–15 cm long, each of which is associated with two bract-like structures, and bearing shortly above its base a single spikelet.

Inflorescences of beach spinifex were harvested by hand from open beach sites at Mylestom, N.S.W. (1969) and Southport, Qld. (1970) and stored in hessian bags.

Caryopses were obtained from inflorescences by hand, or by threshing the inflorescences in a hammer mill operating at 1400 r.p.m. Prior to hammer-milling, the inflorescences were dried for 6 hr at 32°C. After hammer-milling the material was cleaned in a Clipper M2B seed-cleaning machine.

Spikelets* were obtained from the inflorescences by three methods: (1) threshing the inflorescences with a dehulling machine consisting of a horizontally rotating thresher drum fitted with stout rubber beaters and capable of operating at a variety of speeds; (2) threshing the inflorescences with a peg tooth drum; and (3) threshing the inflorescences with a barley de-awning machine. This last machine consisted of a cylinder containing a centrally mounted spindle carrying long metal fingers rotating between fixed metal fingers attached to the inner surface of the cylinder.

(b) Germination

Laboratory germination tests were carried out on hand-selected well-formed caryopses and spikelets from both sources of seed, between December 1970 and September 1971. Spikelets were selected to ensure that as far as possible they contained caryopses. Preliminary tests showed that the caryopses and spikelets were very susceptible to the growth of saprophytic fungi during the period of germination, and in all subsequent tests, mould growth was controlled with a fungicidal dust made up of 12·5% thiram as the active ingredient. One part by weight of this material was applied to 200 parts by weight of caryopses or spikelets.

* A spikelet consists of the caryopsis enclosed in its lemma, palea, and glumes, and usually attached to the whole, or portion of its associated spine.

Germination was taken as extrusion of the radicle for a minimum distance of 2 mm from the caryopsis or spikelet. The germination trays and petri dishes were lined with Greens LR52 germination paper.

(i) *Tetrazolium Tests*

Tetrazolium chloride (TTC) was used for estimating viability. Imbibed caryopses were longitudinally dissected and soaked in a 1% solution of TTC for 1 hr at 30°C in darkness (Moore 1962). Embryos which were completely stained red or unstained only at the radicle tip were classed as viable.

(ii) *Light and Temperature Tests*

Exploratory tests were carried out on caryopses from the Mylestom 1969 harvest and on both caryopses and spikelets from the Southport 1970 harvest. The constant (25, 35°C) and alternating (10–25, 15–25, 20–25; 10–35, 15–35, 20–35°) thermoperiods used were those commonly recommended for the testing of warm temperate to subtropical species (Anon. 1965). The alternating thermoperiods were on a 16/8 hr low/high temperature cycle. The tests were conducted either in total darkness or in an alternating photoperiod of 16/8 hr dark/light cycles. Light periods were coincident with the high temperature phase for the alternating thermoperiods. The light (white fluorescent), was of *c.* 1000 lux intensity. For these exploratory tests, unreplicated 100 seed lots were used, and germination was recorded after 9 days.

A further germination experiment was carried out in darkness at selected constant (25, 30°C) and alternating (15–35, 20–35°) thermoperiods with spikelets from the Southport 1970 harvest. In this experiment, four replicates each of 25 spikelets on a separate tray were used, and germination was recorded after 15 days.

Small tests were carried out in association with the above experiments to evaluate the effect of hammer-milling on the germinability of caryopses from both harvests. Germination conditions were 20–35°C in darkness. Each treatment consisted of four lots of 25 caryopses on a single tray. Germination was recorded after 9 days.

(iii) *Tests for Germination Inhibitors*

In an unreplicated test 100-spikelet lots from the Southport 1970 harvest were placed in 250-ml glass flasks to each of which was added 100 ml of distilled or freshly collected sea water. The flasks were horizontally agitated on a Griffin laboratory shaker for periods of 0, 6, 12, 24, and 48 hr. Times of commencement of agitation were arranged so that all treatments were completed together.

Each 100-spikelet lot was removed from its flask, divided into four lots of 25, and germinated on a single tray in total darkness at 20–35°C. Germination was recorded at 10, 14, 18, and 21 days.

The distilled water used in the 48 hr treatment was assayed for presence of germination inhibitors, the germination of lettuce seed at 25°C being used as an index. In an unreplicated test 50-seed lots of lettuce seed were placed in 9-cm petri dishes and to each dish was added 4 ml of solution made up from the distilled water

from the 48 hr treatment. Solutions of the following strengths were used: 100, 50, 25, 12·5, and 0%, with fresh distilled water as the diluent. After 4 days germination was recorded and the length of the radicle measured.

(iv) *Sand Emergence Experiments*

Two sand emergence experiments were conducted.

Spikelets of the Southport 1970 harvest were planted at depths of 0 (experiment I only), 1·25, 2·5, 3·75, 5·0, 6·25, 7·5, and 8·75 cm in 15-cm diameter pots filled with beach sand in each of which 15 spikelets were planted. There were four replicates of each treatment. Emergence was recorded under two moisture regimes. In experiment I the sand was maintained in a wet to over-wet state by daily irrigation. In experiment II it was maintained at field capacity by weighing the pots and irrigating as necessary at 3 to 4-day intervals.

These experiments were carried out in a controlled environment cabinet, an alternating 20–35°C thermoperiod being used with a fluorescent light photoperiod of *c.* 3000 lux intensity accompanying the shorter high temperature phase. Total emergence was recorded after 30 days.

(*c*) *Statistical Analysis*

Wherever possible data were subjected to analysis of variance.

III. Results and Discussion

(*a*) *Threshing*

Hammer-milling gave a high yield of caryopses (Fig. 3*B*) but was responsible for a great deal of breakage owing to the soft nature of the caryopses.

Over the two locations and seasons, the yield of caryopses was 11–16% of the weight of the hammer-milled inflorescences, and that of the spikelets 19–22·5% of the weight of the inflorescences treated by the barley de-awner. However, hammer-milling reduced the germinability of caryopses: caryopses hammer-milled, 58±3·8%; caryopses hand-extracted, 79±2·5%. Moreover, the caryopses from spikelets obtained in the dehulling process were equal in germinability to those obtained by hand from untreated inflorescences, which indicated that the dehulling process was not detrimental to viability.

These studies led to the conclusion that grain softness would impose severe limitations on all likely methods of mechanical extraction of caryopses from inflorescences, and it was decided to aim at the production of planting material in the form of single spikelets.

The spikelets obtained with the dehuller were of varying length owing to the uneven retention of portion of the associated spine (Fig. 3*D*). The peg tooth drum produced spikelet material of shorter length but the spines tended to be unevenly clipped (Fig. 3*C*). The barley de-awning machine, on the other hand, produced spikelets in which the spines were uniformly clipped short (Fig. 3*A*). Spikelets obtained in this way were free flowing and would be suitable for mechanical sowing.

(b) *Germination*

(i) *Light and Temperature Tests*

Initial attempts to germinate caryopses led to the finding that they were negatively photoblastic when germinated alone or enclosed within the spikelet. This is shown in the results of the two exploratory experiments (Table 1) in which a range of constant and alternating thermoperiods was used in the presence and absence of light.

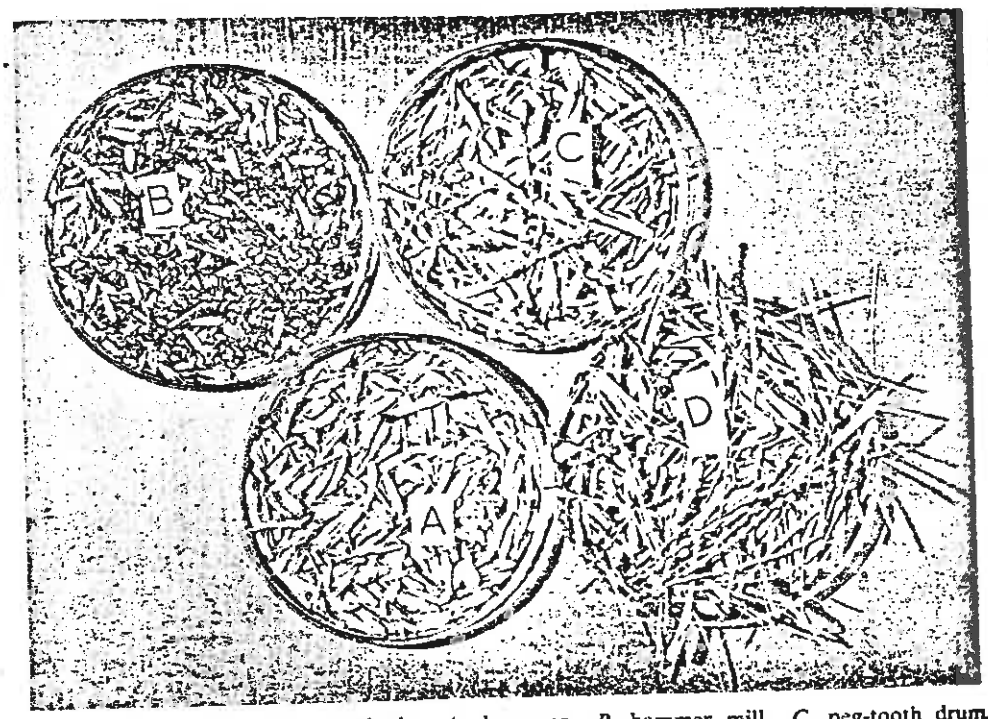

Fig. 3.—Effect of threshing methods. *A*, de-awner. *B*, hammer mill. *C*, peg-tooth drum. *D*, dehuller.

The data were analysed with use of an inverse sine transformation. Germination in both caryopses and spikelets of the Southport 1970 harvest and in caryopses of the Mylestom 1969 harvest was inhibited by light to a significant extent (1% level). This test was carried out in December 1970 and the similarity in light response for both harvests suggests that the requirement for darkness does not diminish with age. In practical terms this means that beach spinifex planting material must be buried in the sand before appreciable germination will occur. For the Southport 1970 harvest, caryopses significantly exceeded spikelets (1% level). A significant interaction of caryopses/spikelets × light/dark was due to the relative magnitude of the differences.

With the Southport 1970 harvest the 20–35°C temperature regime was associated with good germination in darkness and this is consistent with the results of the

subsequent trials. In the case of the Mylestom 1969 harvest there were no significant differences between germination results obtained at the various temperatures.

Tetrazolium tests of viability on the Southport 1970 harvest caryopses indicated a maximum potential germination of 80%. The actual germination obtained for these caryopses was 78% at 15–25°C and 79% at 20–35° in darkness (Table 1). These tests were carried out within 2 months of harvest, and the caryopses when germinated at the above temperatures did not appear to be affected by post-harvest dormancy.

TABLE 1

EFFECT OF TEMPERATURE AND LIGHT ON GERMINATION

Temperature (°C)	Germination percentage*					
	Mylestom 1969		Southport 1970			
	Caryopses†		Caryopses‡		Spikelets§	
	Light	Dark	Light	Dark	Light	Dark
25	4	51	32	60	6	24
35	15	14	20	43	7	13
10–25	5	20	1	40	3	13
15–25	6	29	6	78	1	24
20–25	13	35	14	45	2	38
10–35	10	22	8	48	1	7
15–35	17	29	17	57	11	16
20–35	9	26	17	79	6	35
Mean	10	28	14	56	5	21

* Germination percentages after 9 days, 100-seed lots.

† Mylestom caryopses obtained by hammer-milling inflorescences. In a separate test hand-extracted caryopses with the 20–35°C alternating thermoperiod (and light) gave 84% germination.

‡ Southport caryopses obtained by hand from inflorescences.

§ Southport spikelets obtained from inflorescences passed through dehulling machine.

In a subsequent experiment spikelets from the Mylestom 1969 and the Southport 1970 harvests were tested. Results of this experiment are shown in Table 2. There was a significant interaction (1% level) between source of the planting material and temperature. Both the alternating temperature treatments were significantly better (1% level) than the constant temperature treatments for the Southport 1970 harvest. In the case of the Mylestom 1969 harvest the 20–35°C treatment significantly exceeded the 30° treatment but otherwise there were no significant differences. This suggests a decrease in specific temperature requirements with increasing age. Little is known of the mechanisms by which germination is controlled under the influence of temperature, particularly alternating temperature. Vegis (1963) described a theoretical relationship between temperature and seed dormancy in which a gradually increasing response to a wide range of constant temperatures is a feature of the germination behaviour of many species with age. The possibility cannot be ruled out, however, that the different

germination responses in beach spinifex were due to the spikelets being obtained from different sources.

TABLE 2

EFFECT OF CONSTANT AND ALTERNATING TEMPERATURE ON GERMINATION WITHIN SPIKELETS* IN DARKNESS

Temperature (°C)	Germination percentage†		
	Mylestom 1969	Southport 1970	Mean
25	46	28	38
30	33	25	29
15–35	46	68	57
20–35	52	62	57
Mean	44	46	45

Mean	SE	Least sig. difference 5%	1%
Temperature	±3·49	10	14
Seed source	±2·46	7	10
Individual	±4·93	14	20

* Spikelets obtained from inflorescences passed through barley de-awner.

† Germination percentage after 15 days, four replicates of 25 spikelets.

(ii) *Tests for Germination Inhibitors*

Germination of caryopses in spikelets was found to be consistently and usually significantly less than germination of naked caryopses at all temperatures (Table 1). It was also observed that the rate of germination of caryopses in spikelets was slower than the rate of germination of naked caryopses.

Mayer and Poljakoff-Mayber (1963) describe several seed coat effects capable of inhibiting germination, including: (1) physical restriction to expansion of the embryo and emergence of the radicle; (2) impermeability to oxygen; (3) possession of chemical inhibitory properties. In the case of beach spinifex it is not considered likely that the lemma, palea, and glumes restrict expansion of the embryo, because they are not tightly sealed and possess relatively thin textures. However, these structures could impede emergence of the radicle to some extent and this may be reflected by the slower germination in spikelets as compared with naked caryopses. In addition, the enclosing structures could partly restrict gaseous exchange and this may also be associated with the delay in germination.

The slower rate of germination of caryopses in spikelets as compared with naked caryopses and the lower total germination in spikelets could be interpreted as an indication of the presence of chemical inhibitors within the enclosing structures. McDonald (1958) reported that natural immersion of the inflorescences in sea water had a beneficial effect on subsequent germination. This would further suggest the presence of water-soluble germination inhibitors in the inflorescences.

The germination of spikelets from the Southport 1970 harvest after soaking in distilled and sea water for various periods of time is shown in Table 3. It was found that soaking led to a significant decrease (1% level) in germination compared with the unsoaked control treatment. Soaking in sea water depressed germination more than soaking in fresh water (1% level). Under the conditions of this experiment there was no evidence of any beneficial effect on germination in spikelets due to soaking. The decrease in germination was not progressive with the length of the soaking period: for both distilled and sea water the decrease after 24 hr of soaking was less than would be expected in comparison with the other treatments and no explanation can be offered for this effect.

TABLE 3

EFFECT OF SOAKING WITH DISTILLED AND SEA WATER ON GERMINATION PERCENTAGE (21 DAYS) IN SPIKELETS,* SOUTHPORT 1970 HARVEST

Control (spikelets, not soaked): 63 (0·919)†

Time of soaking	Germination percentage‡		
	Soaking treatments: Dist. water	Sea water	Mean
6 hr	47 (0·755)†	28 (0·553)	37 (0·654)
12 hr	34 (0·621)	18 (0·432)	25 (0·526)
24 hr	44 (0·724)	30 (0·579)	36 (0·652)
48 hr	21 (0·478)	10 (0·330)	15 (0·404)
Mean	36 (0·644)	21 (0·474)	28 (0·559)

Mean	SE	Least sig. difference 5%	1%
Distilled, sea	(0·0327)	(0·094)	(0·127)
Times	(0·0463)	(0·134)	(0·180)
Individual	(0·0655)	(0·189)	(0·255)
Control *v.* rest		(0·142)	(0·191)

* Spikelets from inflorescences passed through barley de-awner.

† Transformed means (inverse sine transformation, in radians) shown in parenthesis. Percentages are equivalent means to nearest whole number.

‡ Four lots of 25 spikelets for each treatment.

The distilled water from the 48 hr soaking treatment was tested for inhibitory properties by using the germination of lettuce seed as an index. Germination was not impaired by the extract over four dilutions and there was no decrease in mean radicle length in germinated seed. There was thus no evidence for the presence of water-soluble chemical inhibitors in the spikelets of beach spinifex.

(iii) *Sand Emergence Tests*

The inhibitory effect of light on germination indicated that for any planting program to be successful spikelets would need to be buried to such a depth as to exclude light. To obtain information on germination with respect to depth of planting,

two sand emergence experiments were carried out on spikelets from the Southport 1970 harvest. Results are shown in Table 4.

In experiment I (waterlogged sand) emergence was negligible from depths below 3·75 cm and no germination in surface-sown spikelets occurred. Emergence was highest from 1·25 cm but there were no significant differences between 1·25, 2·5, and 3·75 cm. It was found that spikelets below 3·75 cm rotted in the waterlogged conditions.

TABLE 4

SAND EMERGENCE TESTS, SOUTHPORT 1970 HARVEST

Spikelets obtained from inflorescences passed through barley de-awner. Four replicates of 15 spikelets per pot

Depth (cm)	Emergence percentage	
	Experiment I*	Experiment II†
1·25	40 (0·681)‡	24 (0·517)
2·5	30 (0·577)	50 (0·785)
3·75	25 (0·519)	53 (0·820)
5·0	2 (0·131)	17 (0·429)
6·25	0 (0·065)	27 (0·541)
7·5	2 (0·131)	28 (0·557)
8·75	1 (0·093)	5 (0·224)
SE of treatment means	(0·094)	(0·061)
Least sig. diff.:		
5%	(0·277)	(0·179)
1%	(0·378)	(0·244)

* Experiment I, waterlogged sand. Emergence percentage after 30 days.

† Experiment II, sand held at field capacity. Emergence percentage after 31 days.

‡ Transformed means (inverse sine transformation in radians) shown in parenthesis. Percentages are equivalent means to nearest whole number.

In experiment II (sand held at field capacity) appreciable germination occurred at all depths above 8·75 cm. Maximum germination occurred at 2·5 and 3·75 cm. Emergence from 1·25 cm was markedly reduced in comparison with the first experiment, and this was probably due to the drier conditions at 1·25 cm in experiment II.

Experiments I and II ran for 30 and 31 days respectively but maximum emergence occurred in both experiments by 20 days. It is considered that experiment II would approximate field conditions more closely than experiment I. This would indicate that a depth of *c.* 3·75 cm (settled) should be tried for field planting, but this would need to be tested by field experiments under a range of seasonal conditions.

IV. CONCLUSIONS

Future investigations of mechanical harvesting should be aimed at the production of spikelets by the partial threshing of influorescences, and by winnowing. The

caryopses of beach spinifex are apparently too soft to withstand complete threshing from the inflorescences.

Mechanical planting procedures, with spikelets as units of dissemination, would warrant investigation for the establishment of this species over large areas. Ground broadcasting and aerial sowing are not likely to be successful planting techniques. The dark requirement for maximum germination emphasizes the need for seed to be adequately covered at planting. Some of the failure of establishment noted in the past, when whole inflorescences have been broadcast and covered with brush matting, may have been due to insufficient accretion of sand to cover the brush-matted areas and bury the seed.

The depth at which beach spinifex should be planted to ensure maximum emergence is likely to be dependent on the balance between moisture content and oxygen availability at various depths in sand. Pot plantings disclosed that the seed is prone to rotting under waterlogged conditions except where lying close to the surface: under drier conditions emergence from greater depth is possible. Field plantings undertaken since this work was completed have given good germination with seed planted at *c.* 3 cm (settled depth) but the authors consider that detailed field planting studies should be carried out to examine the relationship between temperature, depth of planting requirements, seasonal patterns of field temperature, and rainfall distribution. The basic germination behaviour described in this paper will complement the life cycle studies currently being undertaken by one of us (T.J.M.).

V. Acknowledgments

The advice of Mr. D. A. Barr, Senior Beach Erosion Officer, Department of Harbours and Marine, and the technical assistance of Miss Margaret McKay are gratefully acknowledged. Mr. Barr also carried out the hammer-milling and associated seed-cleaning work. Particular thanks are due to Miss E. A. Goward, Biometrician, Department of Primary Industries, who provided the statistical analysis.

The Soil Conservation Service of New South Wales assisted by providing the inflorescences from the Mylestom (1969) harvest.

VI. References

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25 July 1983

Dr Colin Ogle
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WELLINGTON

Dear Colin,

I am able to answer your specific query about Spinifex but I have also arranged to have copies of your letter sent to Peter Johnson, Dunedin who is co-ordinating our recent survey of dune areas throughout New Zealand and Alan Esler, in case they have any opinions regarding the botanical values of the area. I expect I don't have to draw your attention to Mrs F. Duguid of Levin who had considerable knowledge of the flora of the Levin coast and may have information about the area you mention. Some years ago she showed me where Sebaea ovata grew on the Levin coast. I also showed your letter to David Given.

With regard to your specific enquiry, I enclose a xerox copy of a paper "Germination behaviour in beach Spinifex (Spinifex hirsutus Labill.) by R.L. Harty and T.J. McDonald from the Australian Journal of Botany, 1972, 20. pp 241-51. Also Ivor Brown, curator of our gardens has made available (enclosed) his experience with growing Spinifex from seed. As you well know Spinifex at one time grew at New Brighton at its southern limit of distribution on the east coast, but Ivor's plants were not able to withstand the rigours of a Lincoln winter. It would seem that there are no real problems in producing plants for revegetating the dune areas.

Yours sincerely,

Margaret Bulfin

M.J.A. Bulfin (Mrs)

Notes on Spinifex hirsutus growing

Seed sown in pans 30.4.81 half soil, half sand with seed just covered, set in bottom heat 25°C. Germination began 11.5.81 and continued till October. Planted outside in plots from pots 2.12.81. Plants grew and developed well with runners over one metre long by autumn. All plants frosted badly and died out completely over the winter 1982.

I.C. Brown

Note: From 20 to 60% germination from different batches.