SCOTTISH PLANT BREEDING STATION
PENTLANDFIELD, ROSLIN, MIDLOTHIAN

REPORT

TO THE

ANNUAL GENERAL MEETING

OF

THE SCOTTISH SOCIETY FOR RESEARCH IN PLANT BREEDING

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BY THE

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REPORT BY THE DIRECTOR

General

With the aid of generous grants from the Department of Agriculture and Fisheries for Scotland, good progress was made during the year in providing some much-needed new building and in the modification of existing buildings. The potato store, the new boiler, the C.P.C. glasshouse and the new east wing to the laboratory mentioned in the last report were all completed during the year and came into service in the early summer of 1967. New work started later in the year included: five new glasshouses, a porch for outdoor clothing, a bothy to house outside workers, a roof over the yard, a large lean-to shed to house vehicles and equipment, and sundry roadworks. At the time of writing, in early March 1968, all these works are well advanced, indeed, virtually complete. In addition, an area of land near the laboratory was surrounded by a length of high steel and concrete fencing for the protection of outdoor equipment against vandalism. As in the previous year, our warmest thanks are due to the Surveyor's Branch of the Department of Agriculture and Fisheries for Scotland for their excellent efforts on our behalf. One other building project was also started during the year but has not yet progressed very far: the construction of a new potato store at Blythbank was begun by the Animal Breeding Research Organisation on our behalf, with the aid of funds provided by the Agricultural Research Council; we hope to have it in use in the autumn of this year, 1968.

The Station's land problems now appear to be approaching solution. Our need for a proper farm has been generally accepted and there is a fair chance that we may be able to acquire one during the coming year. Meanwhile, we shall have to depend, as often in the past, on the generosity of sister organisations and of private farmers for space to run trials and selection centres. A farm of our own will by no means end the need to grow plots in many parts of the country but it will make possible many operations which are now, in effect, impossible at Pentlandfield. The programme of amelioration of the very bad Pentlandfield soil continued during the year with the application of 1,315 tons of coarse ashes to six acres. The signs, from the fields which were treated in 1965–6, are that the ashes are having the expected ameliorating effect. To date, thirteen acres of land have been treated with 3,258 tons of ashes at a total cost of £2,596.

One event of great importance to all the official Plant Breeding Stations, including our own, took place during the year. The National Seed Develop-

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ment Organisation acquired corporate status and began work. At the time of writing, the process of transfer of responsibility for commercial development of new varieties from the Stations to the N.S.D.O. is going ahead apace and should be completed during the next few months.

Potato Investigations

The official Immunity and Merit Trials, 1967, contained sixteen of the Society's seedlings: ten in the 2nd year and six in the 3rd year of trial. The Committee recommended that five of the 2nd Year group should be continued for further trial in 1968 and that two of the 3rd Year group (3992a(4) and 4283a(5)) should receive Commendation. They were named Pentland Javelin and Pentland Kappa respectively. Official descriptions follow:—

Pentland Javelin

Maturity	First Early.
Tuber	Oval: skin white, smooth; flesh white (pale); eyes shallow; sprouts pink.
Foliage	Haulm of low to medium height, vigorous, erect, fairly rigid; cover fair; stems strong, wiry, faintly coloured, wings mainly straight with faint waving at stem apices; leaf broad, close, fairly rigid; leaflets medium green, dull, rough, wrinkled, pointed, borne on long petiolules, trace of pigment on petiolules at apical rosette, fused terminals occur; strong development of secondary leaflets.
Flower	White with faint pigment on backs of petals, rare, most buds drop unopened; inflorescence stalks faintly pigmented; buds coloured, sepals often foliose.
Remarks	Cropping: very good; cooking quality: fairly good; keeping quality: fairly good; field-immune from viruses *X*, *A* and *C*, significantly less susceptible to virus *Y* than the average commercial variety; susceptible to gangrene, dry rot and skin spot; resistant to biotype *A* of potato root eelworm.

Pentland Kappa

Maturity	Second Early.
Tuber	Oval; skin white, smooth; flesh white; eyes shallow; sprouts faint pink.
Foliage	Haulm of medium height, semi-erect, bushy, rigid, rather "feathery" in appearance; cover good; stems numerous, thin, wiry, faintly pigmented in upper leaf axils; leaf small, open, fairly rigid; leaflets medium to dark green, dull, narrow, becoming hard and brittle with maturity, petiolules long, coloured in immature foliage; secondary leaflets numerous, sharply pointed, generally small.
Flower	White, tinged purple on backs of petals, infrequent; anthers orange, occasionally yellow, supernumerary petals may be attached to anther column; inflorescence stalks coloured; buds coloured; stigma protrudes from bud.
Remarks	Cropping: excellent; cooking quality: good; foliage field-immune from the common race of blight, some field resistance to other races, tuber resistant to the common race, susceptible to some other races; field-immune from viruses *X*, *A*, *B* and *C*; moderately resistant to gangrene, moderately susceptible to dry rot, susceptible to skin spot.

Pentland Javelin is immune to wart disease; Pentland Kappa is resistant but further tests, now in progress, are required to determine whether it may be classified as immune.

The crop of Pentland Javelin, which was severely damaged by crows and contained some blackleg, received a Grade A certificate. It was therefore decided to distribute only virus-tested units to specialist growers and to use the main stock for extended trial purposes. The crop of Pentland Kappa suffered no damage and received a Foundation Seed Certificate. It yielded about five tons of tubers and, with the exception of ten cwts of seed distributed for trial purposes, the bulk stock was passed to the D.A.F.S. for further multiplication and distribution after the 1968 harvest.

The customary 1st year trial of the Department of Agriculture and Fisheries for Scotland was discontinued in 1967, as a first step in the transition from Immunity and Merit Trials to Statutory Performance Trials under the Plant Varieties and Seeds Act. The latter last for two years and can be regarded as equivalent to the 2nd and 3rd years of the Department's Trials so extra trials were arranged at Pentlandfield in 1967 to compensate for the loss of the Department's 1st year trial. Eight seedlings were selected on the basis of their performance at Blythbank and Pentlandfield for inclusion in the 1968 Statutory Performance Trials. Most of them are field resistant to blight and two of them are potential canning varieties which yield a high proportion of small, firm tubers.

Trial and multiplication plots at Blythbank in 1967 covered about fifteen acres. They consisted of 13,677 single tuber selections, 2,432 three-tuber plots, 565 nine-tuber plots, 255 fifty-tuber plots, twenty-seven $\frac{1}{80}$-acre plots, twelve $\frac{1}{10}$-acre and six $\frac{1}{2}$-acre plots. Virus-tested units of the Station's named varieties and seedlings in the Merit Trials were also grown.

During the past year samples of seeds and seedling selections were sent to many different countries overseas for trial and experimental purposes. Cooperation in potato breeding with India continued and some seven thousand single tuber samples from relatively unselected progenies were again sent to the Central Potato Research Institute, Simla, for trial and selection. The same Institute submitted 228 samples for evaluation of field-resistance to blight; it was high, more than 50 per cent of the seedlings falling into groups 1 and 2.

Several potato varieties from the Station are doing well abroad, indicating interesting possibilities for the development of an export trade by Scottish seed producers. Thus Pentland Crown and Pentland Dell outyielded (and matured a week earlier than) Up to Date in Cyprus in 1967 while Roslin Castle yielded well and matured a month earlier. In Malawi, Roslin Castle and two unnamed varieties performed well over three crops and were blight resistant. It will be recalled also that Roslin varieties have been commercially grown in Kenya for several years. Contact with the Overseas Development

Ministry on the subject of potato varieties and breeding problems in Africa has been established.

As in previous years, the advanced seedlings (230) were tested for susceptibility to common scab in the plots at Archerfield. Infection was unusually severe but some forty of the seedlings showed promising resistance. In order to provide a supplementary estimate of scab resistance, the Merit Trial seedlings were also grown under the aegis of the N.A.A.S. in Cheshire, but the outbreak of Foot and Mouth disease delayed the recording of the trial.

Work on blight was continued during the year with the screening of breeding families for resistance and the assessment of resistance in individual clones of breeding stocks, Andigena materials and eelworm-resistant clones derived from *S. vernei*. In general. the complex race 1,2,3,4,5,7,8 was used in this work. A result significant from the breeder's point of view was that, in a sample of 260 advanced seedling selections, though resistance in foliage and tuber were not always highly correlated, the majority of the selections were, in fact, resistant in the tuber. As a check against the laboratory tests at Pentlandfield, 158 seedlings were grown in the Toluca Valley, Mexico, through the kind cooperation of Dr J. S. Niederhauser of the Rockefeller Foundation. The results showed that all grades of field resistance were represented and that 116 (73 per cent) of the seedlings had better field resistance to blight than the control variety Alpha.

As is now well-known, Pentland Dell showed considerable blight infection in some ware districts during the 1967 crop. The disease was earliest and most severe in the southwest of England. Pentland Dell carries several *R*-genes, the cause of its resistance to date, so field attack means that new races of the fungus have evolved. It was obviously of importance to determine what races had, in fact, appeared. Accordingly, sixty-two samples from infected crops of the variety, sent by officers of the National Agricultural Advisory Service, were examined. Nine complex races were identified, of which the most frequent were: race 1,2,3,7, race 1,2,3,5,7 and race 1,2,3,4,7. Another fifteen samples yielded race 4; such samples could not have been taken from Pentland Dell, and this was confirmed in most cases. One sample of Roslin Castle and two samples of seedlings from Cornwall also yielded complex races: race 1,2,3,7 from the former and race 1,2,3,4,5,6,7,8,9 from the latter. In 1967, only one Scottish crop of Pentland Dell was attacked (in Berwickshire). Nevertheless, a survey carried out in collaboration with the Department of Agriculture and Fisheries for Scotland and the Scottish Advisory Plant Pathologists showed that fairly complex races do occur in Scotland, though infrequently; thus most samples were the expected race 4 but races 0; 4,6; 4,7; 4,6,7; 3,4; 3,4,6,7; 3,4,6,8; 3,4,7; 3,4,7,8; and race 7 all occurred.

Studies of virus resistance in potatoes were continued during the year. Material was exposed at Cambridge to intense natural infection with virus *Y* and the leaf-roll virus. There were three control varieties, eight seedlings in the 3rd Year Merit Trials, thirty-three advanced selections of seedlings comprehensively resistant to *X* and *Y* viruses and 193 new selections. The results for the control varieties and for the two seedlings that are now named Pentland Javelin and Pentland Kappa are given below.

Variety	*Leaf roll* *per cent infection*	*Virus Y* *per cent infection*
Arran Pilot	71	100
Majestic	71	94
Pentland Crown	29	8
Pentland Javelin	50	17
Pentland Kappa	35	92

The data for the susceptible control varieties show that there was an extensive spread of both viruses. The resistance of Pentland Crown to both viruses is clear; by comparison, Pentland Javelin may be judged to have intermediate resistance to leaf roll and virus *Y* whereas Pentland Kappa has fairly good resistance to leaf roll but little resistance to virus *Y*. Among the advanced seedlings resistant to viruses *X* and *Y*, five selections contracted only small amounts (5-20 per cent) of leaf roll and gave good results in replicated performance trials at two centres, Pentlandfield and Elvingston. These, together with twenty-eight less advanced seedlings go forward for further trial. A further 10,000 seedlings were passed through the initial greenhouse tests for resistance to *X* and *Y* viruses.

Genetical work concluded during the year has shown that the genes *Nx* and *Nb* (controlling reactions to specific strains of virus *X* in *S. tuberosum*) are genetically independent and independent also of the genes controlling comprehensive resistance to virus *X* in *S. andigena* and *S. acaule*. By contrast, genes that control comprehensive resistance to virus *Y* in *S. microdontum* and *S. chacoense* were confirmed as identical. Families designed to test linkage between genes controlling reactions to virus *X* and *Y* virus gave disturbed segregations, probably a result of linkage to the incompatibility (*S*) locus.

Work on the potato cyst eelworm that has been going on at the Station for the past three years has reached a rather important conclusion which must affect breeding philosophy. Briefly, it has been found from study of a large sample of single cyst lines drawn from Scottish potato fields that most, perhaps all, populations are genetically heterogeneous, containing Race *A* and Race *B*, or at least the gene which, when homozygous, gives Race *B*. This gene, referred to as *vb*, is associated with a cyst colour difference as shown in the Table, and it is now clear that eelworm populations are polymorphic for the linked complex pathotype-cyst colour. This means that no single-gene resistance can be expected to remain effective for long: even a seeming patho-

Pathotype	*Transient cyst colour*	*Constitution*	*Potato resistance genes*			
			nil	H_1	H_2	H_1H_2
A	bright yellow	*Vb*	+	−	+	−
B	cream-lemon	*vbvb*	+	+	−	−
E	none	?	+	+	+	+

(+ = susceptible; − = resistant)

type *A* population must be presumed capable of generating pathotype *B* eelworms if faced with an H_1 potato variety. Pathotype *E* is less well understood but segregated with *A* in some inbred lines, so even the double major-gene resistance, H_1H_2, would sometimes prove to have a short life. In England, though not yet in Scotland, pathotype *E* has been found locally in high frequency. These results mean that resistant varieties carrying H_1 and/or H_2 are likely to be useful stop-gaps but no more; this situation (though not the underlying genetical reason for it) has of course been foreseen for several years. The implication is clear; in the longer run (as nearly always when breeding against a specialised pathogen) field resistance must be built up. The appropriate programme, based on *S. vernei*, is already well started and the difficulties, though formidable, do not seem to be unsurmountable.

The Commonwealth Potato Collection (C.P.C.) was brought to Pentlandfield early in 1967 and the new glasshouse provided for the work came into service in the summer of that year. The Collection consists both of tuber-lines and true seed, and the general policy is to discard tuber-lines when suitable selfed or crossed seed has been obtained from them. A survey of seed available permitted the discarding of a number of tuber-lines and only some 450 such lines were grown during the year. Much of the seed derived from 1961 or earlier and required germination testing or renewal. Approximately 450 progenies were grown, but sowing was delayed until the new glasshouse was ready and many failed to flower or to set seed. These are being held as tubers for re-planting in 1968. The aim is to obtain seed from at least five plants per progeny by sib-mating.

The last detailed statement of the collection published was that by Hawkes in 1944. Mimeographed lists have been distributed since, but these give little detail, especially on the South American cultivars which form the bulk of the collection. Meanwhile, inventories of the collections at Wisconsin, U.S.A., and Gross-Lüsewitz, East Germany, have been published. An inventory of the Commonwealth Potato Collection is in preparation.

Material from the Collection or from the Andigena experiment mentioned below (derived directly from the C.P.C.) was supplied in response to requests from Holland, Denmark, South Africa, Poland, India, Turkey, Thailand and Jamaica.

The Andigena selection experiment was started at the John Innes Institute in 1959 in connection with the C.P.C. and is being carried on at Pentlandfield. The aim is to recreate Tuberosum potatoes from their South American ancestors and excellent progress has been made. The selected population now crops well, has good blight resistance (see *Ann. Rep.*, 1966-7) and is good to eat. About eleven thousand plants were grown in all, about one half of them at the Rosewarne Experimental Horticulture Station, Cornwall, to which we are, as ever, much indebted. The Cornish environment permits excellent selection for field resistance to blight. The prediction is that clones drawn from this experiment should show yield heterosis in crosses with Tuberosum potatoes. Dr G. J. Paxman, working at the John Innes Institute found a very high degree of such heterosis. Another test was carried out at Pentlandfield in 1967, with similar though less striking results: hybrids outyielded Tuberosum families by an average of 13 per cent though some individual combinations did much better than this. The next step is to introduce the new Andigena stocks into potato breeding.

Cytological studies are also being developed in connection with work on the C.P.C. A start has been made on the production and study of dihaploids, potato clones having only half the chromosome number (24) of their tetraploid Tuberosum parents (48). Crosses of such stocks with improved diploids (analogous to the improved Andigenas mentioned above) sometimes show marked heterosis. Accordingly, studies of diploid populations, started at the John Innes Institute, were carried on. It is too early to attempt an assessment of the prospects of this line of work; it *might* lead to markedly improved efficiency of certain phases of potato breeding.

Apart from work on potatoes, there is need for a certain amount of routine cytology (mostly chromosome counting) as an adjunct to breeding programmes on other crops. As a matter of administrative convenience, this is now organised under the C.P.C. cytology work. During the year, extensive screening of breeding material and of colchicine-treated stocks were carried out: thus families of *Brassica*, *Raphanus* and barley were examined for induced polyploids and a collection of predominantly tetraploid *Dactylis* was screened for occasional diploids (six were found). Quick methods such as pollen grain size, chloroplast number or leaf meristem squashes are being used whenever possible.

Forage Crops Investigations

Plant Breeder's Rights have been applied for in respect of an oat, known so far only by its number, Aa 737. This is an early-maturing spring variety with a complex pedigree. It has performed well in upland districts where oats tend to be sown late and to suffer from summer drought. It has been exempted from Statutory Performance Trials but it will, of course, have to be examined for distinctness, uniformity and stability to qualify for the Index of Oat varieties and for Breeder's Rights.

There was a considerable expansion of cereal trials at centres away from Pentlandfield. This was made possible by the use of the Scottish Plot Seeder developed jointly by the Station and our neighbours, the National Institute of Agricultural Engineering (Scottish Station) (see *Ann. Rep.*, 46, 1966–7).

An interesting development of extra-mural work involves the whole island of Tiree, where grey speck " disease " (caused by manganese deficiency) is acute on oats grown on highly alkaline soils. The wild oat, *Avena ludoviciana* has been extensively used at the Station as a source of resistance to stem eelworm (*Ditylenchus dipsaci*) and has apparently also conferred " resistance " to grey speck. Seed of a suitable mixed hybrid population has been supplied to the West of Scotland College of Agriculture to be grown by crofters on the island. In collaboration with the Agricultural Adviser for North Argyll, the whole island is being treated as a trial centre in a long term selection experiment aimed at the development of oats tolerant of alkaline soil.

A mixture of oat varieties was sown in an observation plot at a trial centre in Argyll in 1967. Its performance was good enough to justify further study of oat variety mixtures. At centres in Morayshire, Fife and the Lothians, mixtures of two, three and four varieties of barley and the single varieties were compared. Averaged over nine centres, the mean yield of mixtures was 2 per cent better than the mean yield of pure varieties. All mixtures that gave yields above the general mean contained the variety Boreham Warrior.

During the four seasons, 1964–7, five unnamed barley selections, chosen from over 100 lines received since 1962 from the Cambridge Plant Breeding Institute, have been extensively tested in trials with Ymer and Maris Baldric as controls. On average, four of them yielded less than either control and none yielded as much as Ymer. Only the best one, HB 334/81, will be included in further trials.

Composite crosses of oats and of barley were again grown at selection centres and in the glasshouse. Selection for resistance to stem eelworm in oats was continued.

Minute spicules, found at the Rowett Research Institute in the intestinal lining of beef cattle fed on barley, are suspected of providing an entrance for pathogens affecting the liver. Following a suggestion by Dr Blaxter, the spicules were identified at the Station as lodicule or rachilla hairs, which look soft and silky but which were found to be highly siliceous and practically indestructible. If the suspected association is confirmed in experiments now in progress at the Rowett Research Institute, a clearly defined breeding objective for feeding barley will have been established.

Two further breeding objectives in barley for Scotland have been defined in 1967, both connected with distilling. The first of these concerns the constitution of barley starch, which occurs in two forms, called amylose and amylopectin. The glucose units which polymerise to make starch molecules do so without cross links in the case of amylose but cross linkages occur in amylopectin. The enzymes of malt can digest amylose to glucose completely but the digestion of amylopectin remains incomplete, being hindered near the cross links. It is the glucose which yeast ferments and so, the higher the proportion of amylose, the greater the yield of alcohol. By a most fortunate accident, the representative of the six-row variety, Glacier, in the Pentlandfield collection of barley turned out to be a variant with a high amylose content and recognisably different starch grains. It has been crossed with a range of other varieties; the hybrids will provide information on the genetics of amylose content and a starting point for introducing high amylose content into barley better adapted than Glacier to Scottish conditions. Such a variety would find a ready outlet for the manufacture of malt whisky.

In the manufacture of grain whisky, a barley malt with a high content of the diastatic (starch-digesting) enzyme, alpha-amylase, is required. This enzyme is only produced as the grain germinates and a high content is needed to deal with the starch of the maize, which is mixed with the malt. High diastatic barleys usually have a high content of nitrogen, unlike malting barleys for brewing, which have to be low in nitrogen content. The latter type of barley is mainly produced further south, but there seems no reason why a high diastase barley should not be produced in Scotland if a suitable variety could be bred. Here again, a ready outlet is available and it will be noted, of course, that high nitrogen content is far from being a disadvantage if the barley is used for feed. Accordingly, it has been decided to take up the breeding of a high diastase barley at the Station.

Some twenty-eight F_1 hybrids produced by crossing the Station's swede variety Pentland Harvester with high dry-matter varieties, mainly Danish, were compared with their respective parents in an unreplicated field planting. The hybrids were intermediate in dry-matter content and showed marked hybrid vigour. Their average yield of dry matter was 35 per cent above the average of the parents and 23 per cent above that of Pentland Harvester, itself a high-yielding variety. Although the experiment was not designed to allow an estimate of how much of the variation between hybrids was non-genetic, a rough calculation, using the variation between plots of Pentland Harvester to estimate this, suggested that the best 5 per cent of such hybrids would yield 43 per cent more dry matter and the best 2½ per cent would yield 51 per cent more than Pentland Harvester. Internal browning was moderate or severe in 85 per cent of the Pentland Harvester plants, in less than 5 per cent in the hybrids and negligible in the other parents. Whatever the genetic defect in Pentland Harvester causing this condition, it is evidently almost completely recessive.

On this problem of internal browning, valuable information has been obtained from the North of Scotland College of Agriculture Crop Husbandry Department. Mr Blackett has been able to show that boron deficiency is, after all, involved and that, in comparisons on plots at successively higher levels of *pH*, Pentland Harvester shows browning in conditions acid enough to prevent it in other varieties. The value of this knowledge in connection with screening for resistance to browning hardly needs stressing.

In the development of new leafy forage crops from wide crosses involving Brassica, a large effort has been put into work on Raphanobrassica. By pollinating diploid fodder radish, *Raphanus sativus* (genome formula *rr*) with thousand-head kale, *Brassica oleracea* (*cc*), several hundred diploid hybrids (*rc*) were obtained. Most of these were treated with colchicine at the seedling stage to double their chromosomes and so produce allopolyploid Raphanobrassica, which may combine the winter hardiness of kale with the vigour and resistance to club root (*Plasmodiophora*) and powdery mildew (*Erysiphe*) found in fodder radish.

A few diploid hybrids were planted in August 1967 for observation in the field, with parental types alongside. The fodder radish was completely killed by frost but the hybrids all survived and retained their leaves fairly well.

At meiosis in the diploid hybrids (rc, $2n = 18$) most chromosomes were unpaired and there was on average about one bivalent per cell. This could involve chromosomes from one genus only or from both. Occasional trivalents were also seen, though they had not previously been reported in such crosses. They most likely involve pairing both within and between genera.

At the present stage of the work on Raphanobrassica, it is desirable to produce a very wide range of hybrids. One way of doing this is to produce autotetraploids of both *B. oleracea* and *R. sativus* of different strains and cultivars. Then, by crossing within each species, potential parents are produced which, when used in intergeneric crosses, should create variable Raphanobrassica populations giving scope for selection of desirable agronomic characters. So far, the intergeneric cross has proved more difficult at the tetraploid than at the diploid level, though it is too early to say whether this is a general rule. A few possible amphidiploids were produced by pollinating tetraploid radish (*rrrr*) by tetraploid kale (*cccc*). From over 2,000 of the reciprocal pollinations only one plant was produced and it was of the maternal type.

Other intergeneric crosses attempted were between fodder rape, *B. napus* (*aacc*) and fodder radish (*rr*) and between leafy forms of *B. campestris* (*aa*) and *R. sativus*. A few more hybrids were obtained from the former, a cross which has only once previously been reported in the literature as successful. The results of the second type of cross have yet to be ascertained.

In the work on composite crossing in cocksfoot, single plants of each of 484 accessions sown in the autumn of 1966, were planted in each of four randomised complete blocks in the spring of 1967. Seed was harvested separately from each plant and then bulked by accessions. Part of each has been put into cold storage and part sown for planting out in 1968 to produce a second composite cross generation. The procedure should mitigate the effects of natural selection during the early stages of the composite cross programme.

Some diploid populations have been identified among the accessions (the rest being typically tetraploid). Four of them are of the *lusitanica* type, three from West Pakistan and one from Madeira; these are being multiplied, since they might form the basis for providing out-of-season production from cocksfoot.

To make a large diallel cross in duplicate, thirty plants of each of twenty-seven of the tetraploid accessions were raised. From each plant a two-member clone was produced and all plants spent the winter under cover in a polythene-covered greenhouse developed on the Station.

In connection with an attempt to improve the yield of Scotia cocksfoot without losing its good digestibility, twelve varieties from which plants had been crossed to Scotia were space-planted in five randomised complete blocks. In the summer and autumn of 1967 observations were made on such characters as date of ear emergence, habit of growth, leaf shape and colour and also on characters which might relate more directly to digestibility, *i.e.*, smoothness and stiffness of the leaves as estimated by feel, teeth on leaf margins and midribs as seen under a dissecting microscope and internal structure of leaves as seen in sections under a microscope. Cuts were taken at the end of June and the middle of August and dry matter determinations were made. Heading in the aftermath was counted at the end of July. Samples from the second cut were ground and (with valuable help from the Edinburgh School of Agriculture) their *in vitro* digestibility (I.V.D.) was determined. The individual I.V.D. values ranged from 54 to 81 per cent, variety means from 67 to 75 per cent. showing scope for selection both within and between varieties. Stiffness of the leaves could, with practice, be estimated rapidly and with good repeatability. Inspection of the figures suggests that it is associated with I.V.D. Examination of leaf teeth confirmed estimates of smoothness by feel, which are obviously much quicker. Examination of leaf sections, under the microscope was not very informative, because of the difficulty of estimating the proportion of lignified tissue.

The behaviour of commercial cultivars of *Poa pratensis* sens. lat. obtained from various countries was observed in a field trial, with the object of selecting suitable parents for crossing with *P. ampla*, should indigenous material prove unsatisfactory. None was entirely free from infection by rust or mildew or both, though neither disease was serious until the late summer. A number of cultivars proved to be similar, at least in habit of growth, to *P. subcaerulea*, which commences growth later in the season than *P. pratensis* sens. strict., or

P. angustifolia, which was also represented among the cultivars; therefore, a first cut was not taken until June and, inevitably, flowering stems were included from some cultivars. Through the cooperation of the Edinburgh School of Agriculture, it has been possible to obtain I.V.D. estimates of the cultivars at this cut and, though direct comparisons are difficult because there is a six-week difference between the earliest (*P. angustifolia* type) and the latest (*P. subcaerulea* type), it can be said that I.V.D. percentages vary from over 70 per cent to below 60 per cent. A second cut taken in late July has not yet been analysed for I.V.D.; at this cut there were considerable differences in yield of dry matter, though in general the cultivars corresponding to *P. pratensis* sens. strict. gave the best yields. Nevertheless, two *P. subcaerulea* type cultivars from Sweden were reasonably productive in spite of their dwarf habit. The population giving the highest yield of dry matter was one collected in the wild in the Cévennes and a Hungarian land-race also yielded well. It was notable that both were among the populations least affected by rust and mildew.

The chief interest of the trial of indigenous material, some collected in Scotland, some in the south of England, was the variation within populations, some individual genotypes giving a relatively higher yield than any in the cultivar field. There was a tendency for populations from the wetter areas to give better yields of dry matter than those from the drier parts of the country but there were occasional high yielding genotypes even in populations which had relatively low mean yields.

The Cereal Breeding Situation

Introduction

Of the eight staple food crops in the world, seven are cereals: of these seven, three (wheat, rice and maize) are produced in quantities of over 200 million tons each, while the remaining four (barley, the various sorghums and millets, oats and rye) all stand at well under the 100 million ton mark. The most abundantly produced food crop of all is the potato with a world production of well on towards 300 million tons, but with a lower food content than the grains. The cereals are therefore important plants to the world at large and some of them are of great consequence in our own agricultural economy. The purpose of this survey is to review, in very general terms, the present state of breeding of the cereals important in Britain with special reference to the prospects of developments in Scotland.

The cereals as a whole show a considerable range of mating systems. Maize and rye are outbreeders; rice and most of the millets are inbreeders which indulge in a good deal of cross-pollination; wheat, barley and oats are the important cereals in Britain and behave as inbreeders, often quite rigorous inbreeders. The breeding plans appropriate to a crop are determined very largely by its mating system so that in this survey we shall be talking solely about inbreeders.

Our three leading cereals, though differing greatly in detail, share a certain amount of history in common. They all originated in the eastern Mediterranean area and migrated to north-western Europe with the spread of agriculture some thousands of years ago; and they all existed until comparatively recent times in the form of land-races. Land-races are heterogeneous populations, maintained as such over many generations and though they have now largely disappeared from Europe, can still be seen in areas having less advanced agricultural techniques. For example, the wheats and barleys of peasant cultivations in western Asia are said still to be largely of land-race type and the rice of much of south-eastern Asia has the same character. Being inbreeders, land-race populations of our European cereals tend to be composed of numerous more or less pure lines so that, although populations may be extremely variable, individual pure lines can be easily isolated. This is what happened during the outburst of agricultural improvement that occurred in the nineteenth century: pure line varieties were isolated from the European land-races and replaced them relatively quickly. Such was the success of these new varieties that the idea that, in some sense, the pure line was an ideal to be universally aimed at, became accepted doctrine. This tendency was naturally reinforced by the adoption of seed certification schemes, whereby it was necessary to be able to identify plant varieties, and by the development of conscious plant breeding which also demanded that its products should be recognisable and distinct from others. The result is that, in a hundred years or so, variable land-races have been replaced by pure lines and the very existence of the parental populations largely forgotten.

The success of this process was tremendous. Great advances in productivity and in the adaptation of cereal varieties to particular uses (*e.g.*, malting, breadmaking) were achieved. By crossing together the best pure line selections of the preceding generation, cereal breeders were able to secure, step by laborious step, ever improved varieties adapted to the changing agricultural and technological circumstances of the time. The successes that have been achieved are indeed prodigious, but what of the future? We may well enquire whether traditional methods of cereal improvement are indeed the best available or whether new techniques and new approaches may not be desirable or even necessary. Success is good but more success is even better.

The present breeding situation

The present situation is, broadly, that there is a steady flow of new varieties of wheat, barley and oats coming forward and that standard varieties are regularly being surpassed by newcomers which offer modest advances in performance over their predecessors. Scotland, however, has not had a major new barley for over twenty years so that progress is unequal. To an increasing extent, new cereal varieties are specialised to particular uses; thus, the wheats are specially bred for making biscuits or for making bread and some barleys are specially bred for brewing. But, alongside this trend towards exact technological adaptation, there is also a tendency to use excess supplies of cereals for relatively unspecialised animal feeding. Thus the tremendous rise in barley acreage in Britain since the war has been accompanied by an increasing use of the crop for feed so that, nowadays, only a relatively small proportion of the barley goes to what used to be its prime use, namely malting; some 85 per cent of British barley is now fed, so that meeting the requirement for feeding barleys is of greater importance to the economy as a whole than is the breeding of malting types.

The great advances made during this century in cereal breeding have been made on an extraordinarily narrow genetic base, only a dozen or so land-race selections having gone into the populations on which our modern cereals are founded. This combination of a narrow genetic base at the start, coupled with rapid and prolonged progress under selection, leads to the expectation that progress should slow down and eventually cease altogether, as genetic variability runs out. But of this there is yet no obvious sign; at the time of writing it looks as though new cycles of improved cereal varieties are still coming forward. One possible reason for prolonged progress on a narrow genetic base is that much of the recent advance in yielding ability of our cereals has been due to selection in a new direction, not for yielding ability *per se* but rather for tolerance of high soil fertility. Much genetic experience goes to show that selection in a new direction can be effective in populations in which response to selection for a different characteristic has ceased. Nevertheless, we must expect that, in the longer run, progress in cereal breeding will slow down unless deliberate steps are taken to broaden the genetic base. At the Scottish Plant Breeding Station we regard the evidence that barley in particular suffers from a narrow genetic base as good enough to guide our experimental programme in breeding feeding barleys; what we are doing about it will be described later.

The idea that our cereals in Britain are indeed founded upon too narrow a genetic base will not be accepted by all cereal workers. It may be pointed out, for example, that a fair number of backcross programmes involving the introduction of favourable genes from foreign breeding stocks have been carried out over the years; this is true but backcross programmes are specifically designed to introduce as little foreign genetic material as possible apart from the desired gene, and so should have had a trivial effect upon the general supply of genetic variability. Further, it is sometimes argued that, since breeding stocks are fairly widely exchanged around Europe, a fair measure of genetic variability is being maintained. This argument neglects the fact that cereals bred in different European countries are often related in earlier generations, so that what seems like a wide cross may be positively incestuous! Thus, the English Squarehead wheat runs through the ancestry of the European wheats and the Moravian Hanna runs through the modern European malting barley populations. Proctor was bred from two European land-races, Hanna and Gull, and from one English one, Archer. Proctor and Carlsberg are sisters and Proctor and Ingrid first cousins. In North America all the present varieties of hard red spring wheats trace back to a single cross, Red Fife × Hard Red Calcutta, which yielded Marquis in 1907; Marquis now appears in every pedigree.

The broad pattern with all our cereals has therefore been one of recurrent crossing and selection, the best products of one generation going to make the parents of the next. This is a frequent plant breeding pattern, sometimes referred to technically as "generationwise assortative mating." It is ideally adapted to the production of steady, unspectacular advances, cycles of new varieties each one somewhat better than the preceding and each more closely adapted to well defined agricultural and technological circumstances.

Pure line breeding

We saw above that mixed and variable land-races were replaced relatively recently by pure lines; that the best pure lines undoubtedly improved on the performance of their predecessors; and that, once established, pure lines were naturally favoured, not only for their technological excellence but also, by certifying authorities and plant breeders, because of their very purity and ease of recognition. Thus it became accepted that the pure line was, so to speak, the natural and proper mode of existence for a cereal and gave the potentiality of the highest possible levels of performance. That this proposition is true, however, has never been proved and some evidence to be reviewed later suggests that it is not, in fact, true. For the moment, though, we will simply outline the practice of pure line breeding, leaving the questions until later.

The underlying assumptions of pure line breeding are these: that by making a cross between two different pure lines and inbreeding and selecting among the later segregating generations, it will be possible to fix pure-breeding recombinants which are superior to either of the parental varieties in terms of the characters selected. In genetic terms this means that each parent must contribute favourable genes that the other one lacks, that the breeder must be able to distinguish the favourable recombinants and that the genetic variation must be of such a nature that it can be fixed in a pure line.

Most economic characters in which the plant breeder is interested are determined by relatively large numbers of genes of individually small effect; indeed, the individual effects are so small that purely phenotypic variation induced by a variable environment overwhelms them. Selection therefore becomes extremely inefficient and the elegant simplicity inherent in formal Mendelian situations is lost. The breeder is confronted instead with continuous variation in economic characters which he can deal with conceptually only by fairly elaborate statistical procedures—and even then, it has to be confessed that the analysis of such data is often unsatisfactory. An extended discussion of this "biometrical genetics," as it is called, would be quite inappropriate to this review, but readers may find it helpful to have a simple numerical picture of the kinds of gene action with which the breeder has to deal and this is attempted in the table. It will be seen that the genetic optimum in the first three categories of the table can always, in principle, be isolated in pure lines; but that in the fourth category (overdominance) it cannot be so isolated.

THE RESULTS OF CROSSING TWO PURE LINES *AAbb* × *aaBB*

Gene Action	*Parental Values*	F_1 (*AaBb*) *Values*	F_2 *mean*	F_2 *range*	*Remarks*
1. Additive: $a = b = 0$ $A = B = 10$	120	120	120	100–140	Best genotype (*AABB* value 140) can be isolated in pure line. No hybrid vigour.
2. Dominance: $aa = bb = 0$ $AA = Aa = BB$ $= Bb = 20$	120	140	130	100–140	Same result as 1, but note hybrid vigour (heterosis) in F_1.
3. Interaction: $aa = bb = 0$ $Ab = aB = 0$ $AB = 40$	100	140	123	100–140	Same as 2, but possible pure-line advance is greater.
4. Overdominance: $aa = bb = 0$ $AA = BB = 10$ $Aa = Bb = 20$	110	140	125	100–140	Best genotype (*AaBb*, value 140) can not be pure-bred. Advance by pure lines small.

Notes.—Understanding of this table will help understanding of the text but is not essential to the broad argument. The figures are purely theoretical and the situations highly simplified. The intention is merely to illustrate certain key plant breeding points: (1) that similar parents produce dissimilar offspring, some better, some worse; (2) that F_1 hybrid vigour (heterosis) may spring from several genetic causes; and (3) that the best genotypes may or may not be fixable in pure lines. In practice, genes are larger in number and smaller in effect than in the examples and the several types of gene action are often mixed. Genetically inclined readers will note that certain kinds of linkage can imitate overdominance in a very confusing way.

In our cereals, evidence as to which are the most important kinds of genetic control of important economic characteristics (such as yield) is somewhat conflicting. It is certain, however, that a good deal of it at least is in a form which is theoretically capable of fixation in pure lines. Argument mainly centres round the importance of overdominance, some workers claiming that it is significant, others that it is not, We shall see later that this is an exceedingly important question, inasmuch as it must guide decisions as to whether or not to go in for hybrid cereal programmes.

So much for a rough outline of the genetic principles involved. The practice, however complicated in actual operation, is simple enough in general form. Pairs of chosen parents are crossed; an F_1 generation is grown without selection; and then the later (segregating) generations are grown, accompanied by various kinds of selection. Selection on a single plant basis may be carried on throughout the programme, or selection may be deferred for several years of bulk-growing, or it may be practised on whole progenies rather than upon individual plants. There is a great deal of discussion (and not a little disagreement) as to the best procedures but all cereal workers would agree that, so large is the environmental component of variation, all selection for quantitative characteristics is fairly inefficient; that is, one expects to be misled very frequently. The breeder ought, therefore, to make very large numbers of selections so that the best materials may be caught in the net and the inevitable mistakes subsequently rejected as a result of further study.

Throughout the programme, the plants are allowed to self-pollinate naturally. In Britain, though not necessarily in other countries with warmer climates, natural crossing in cereals is low or even very low indeed. It is easy to show theoretically that, when more than about ten genes of individually small effect are concerned, the probability, on purely statistical grounds, of isolating the best possible pure line from a cross, is very small. In fact the frequency of the desired " best " homozygote in a F_2 family in which ten genes are segregating is one in a million; about three million plants would have to be grown in order to give oneself a good chance that it should occur at least once and it could not even be recognised at sight as being superior. The outcome of even a lot of intense selection in such a situation is much more likely to be something that is only a little better than the average rather than a line which is as good as it genetically could be. This difficulty is inherent in an inbreeding system. The complete treatment of this problem turns out to be theoretically very difficult but it ought to be amenable to what is called simulation on the computer and we are attempting thus to analyse it at Pentlandfield at the present time. In essence, one imagines a number of possible solutions and then uses the computer to simulate the resulting plant breeding situations, doing in a few minutes what would take the geneticist years of laborious field experimentation. The computer answers will emerge in time; meanwhile, we guess that the inherent inefficiency of selfing could be overcome by making recurrent crosses among selections so as progressively to concentrate desirable genes into fewer and fewer lines from any one cross. Only thus, we think, should it be possible to exploit the full potentialities of a cross. In a sense this idea is not new because it is, after all, only what is done on the grand scale in all cereal breeding, as described above. But it appears certain that we have generally been content, in the past, to accept, for purely statistical reasons, less than the best potentialities of a cross.

This is one respect in which there is reason to think that cereal breeding programmes could be made more efficient. It is a question, of course, of pure line breeding practice. There are also questions of principle. As was indicated above, it may be that the highest possible levels of performance are not to be attained by pure lines: the right kinds of hybrids or mixtures or both might be inherently more productive and to these possibilities we shall return later.

Barley composite crosses

In the early 1930s, H. V. Harlan and his colleagues in California set up a series of experiments on barley which can be seen in retrospect to have been among the most important experiments on plant breeding principles that have ever been made. Like so many good experiments, they were simple in design and execution and have perhaps posed more new questions than they have answered. Essentially, all these experiments were simply highly heterozygous and heterogeneous populations ("composite crosses"), which were sown, grown and harvested in bulk year after year. Several different populations were set up on various crossing patterns and with various starting materials, the details of which need not concern us here; the essential point is that, in every case, the population was heterogeneous and hybrid, the genetic base very wide and selection natural. No plant breeder's selection was practised, so that survival of a genotype in a population was proportional to its capacity to produce seed. In principle, therefore, there ought to have been a continual, though fairly gentle, selection on a very broad genetic base towards increasing seed fertility, that is, towards high yield.

The results bore out this prediction in the most striking fashion. Intermittent yield comparisons with the standard Californian barley variety, Atlas, showed that the yield of the one composite cross which has been most widely studied, rose steadily from about 80 per cent at the start of the experiment, to about 100 per cent after twenty generations and thereafter levelled off, fluctuating somewhat at around 105-110 per cent. This population was founded on twenty-eight parents, none of which was individually a remarkable barley in California and none of which gave remarkable progeny by conventional pedigree breeding methods: the average yield of all the hybrids was only about 80 per cent of the yield of Atlas at the start of the experiment and, even as late as F_{12}, a batch of 365 selections yielded nothing of value. At generation 24, when the population as a whole surpassed Atlas, it was still highly variable and yielded three single plant selections which, when multiplied, exceeded the standard by an average of 56 per cent. A few years later, it was estimated that some twenty-four new barley varieties, in various parts of the world, had either been selected from this population or had been bred directly from selections. Progress was therefore remarkable, though it was undeniably slow.

Genetic studies by Allard and his colleagues have shown that a surprising amount of heterozygosity remained in the population even after thirty or forty generations of (presumed) selfing. Further studies showed that, in fact, the selfing was not as rigorous as had been supposed, that about 2 per cent or so of natural crossing took place and that, also, there was evidence of selection for heterozygotes. The two effects were, of their nature, hard to disentangle (since both tend to promote hybridity) but probably both were significant in maintaining heterozygosity long after one would have expected it to have disappeared.

The implications of these experiments are profound. First, they show that even inherently fairly unpromising plant material may have a remarkable capacity for genetic response to selection if properly handled. Second, they indicate the extraordinary power of relatively gentle selection coupled with wide recombination (promoted by cross-pollination) on a wide genetic base. Third, they suggest that our conventional assumptions as to the significance of heterozygosity in inbreeders are wrong, that the right kinds of heterozygotes rather than pure lines may be inherently the most productive genotypes. Fourth, they show how large supplies of breeding material may be maintained, under a regime of steady improvement, at remarkably small cost, providing thus both a means of preserving precious genetic variability and a sort of lucky dip for the plant breeders of the future. And, fifth, the experiments suggest, though indirectly, that land-race type populations are not just mixtures of pure lines but integrated, extraordinarily complex systems of interacting pure lines and heterozygotes; the fact that there was no marked reduction of variability in the composite crosses suggests various kinds of favourable phenotypic interactions, though it must be emphasised that direct evidence on this point comes only from quite different experiments from these.

The main implications are therefore conceptual rather than immediately practical. A composite cross is a long-term complement to cereal breeding, not a substitute for it; even plant-breeders want results in less than twenty years, however willing they are to plan that far, or further, ahead.

Effects of Heterogeneity

We have become so used to the idea of homogeneous pure lines since the disappearance of our land-races that the very idea of heterogeneity in a cereal is now quite unfamiliar. But there is evidence that, in rejecting heterogeneity, we are also rejecting the possibility of utilising a factor which would contribute significantly both to performance and to stability of performance.

The notion that certain mixtures grow better and more reliably than pure lines was not uncommon in enlightened agricultural circles some seventy years ago, but it is only within the last thirty years that any serious experiments have been directed towards the problem. A very brief summary of one of the earliest of these will illustrate the point at issue; the results come from German experiments with wheat mixtures made early in the 1930s. There were four pure lines and six two-line mixtures and extensive yield trials were run over several years. The results showed that the mixtures consistently and significantly out-yielded their component lines by an average of about 3 per cent and were notably less variable in performance, as the following figures indicate:

	Yields	*Variances*				*Coeff. of*
	cwt./acre	*Vars.*	*Places × V*	*Years × V*	*P × Y × V*	*var. per cent*
Mixtures	28·8	30	9	7	7	7·3
Lines	27·8	158	25	25	16	11·6

Since that time many experiments with a number of crop plants such as wheat, oats, barley, rice and Lima beans have shown a rather wider range of behaviours but the same general trend; that is, mixtures, on balance, yield slightly more than the average of their component pure lines (though sometimes a little worse and sometimes markedly better) and they tend to perform more stably, showing less variability in response to the vagaries of site and season than do the pure lines.

The total evidence on the matter is now quite impressive; there seems to be no doubt that mixtures hold a slight advantage in yield and stability over pure lines, even though the effect is, in some instances, very small or even negative. We have no idea of the physiological mechanisms involved though there is a suggestion from work on rice that root exudates may have a part in the story.

Nearly all the work that has been reported so far on this subject has related to mixtures compounded more or less at random from available pure lines; indeed, in the absence of any understanding of mechanisms, it is hard to see what else could be done. Since the effect of mixture is variable from combination to combination, the implication is clear that, with sufficient search, we should be able to identify combinations in which such favourable phenotypic interactions were higher than the average. Thus, Jensen has recently described oat experiments in which the average advantage of many random mixtures was 3 per cent but for one specific mixture, a highly significant 7 per cent, the mixture in this instance exceeding the highest component. Similarly, recent work with spring wheats at the Plant Breeding Institute, Cambridge, indicated an average yield advantge of 11 per cent for several mixtures but with one outstanding combination which exceeded the higher component. Favourable mixtures are thus sometimes capable of giving yield advances of roughly the same magnitude as are to be expected from the introduction of a superior new pure line variety; and, furthermore, they are capable also of stabilising performance in very marked degree. Evidently, we have here a potential technique for advancing cereal production, the practical use of which we have hardly even begun to consider. We shall discuss the practical implications later in this survey.

Hybrid Cereals

Several important out-bred crops that are reproduced by seed are propagated on the large scale as controlled hybrids. The earliest and most striking example is maize, in which the development goes back some fifty years and in which great economic successes have been scored for the past thirty; other, more recent but hardly less successful, examples are sorghum and onions. The principal of the method is this: large numbers of inbred lines are isolated and maintained by prolonged inbreeding; the lines are evaluated by a complex system of test crosses; the best combinations are then chosen for commercial multiplication. In practice it is found that really successful inbreds are exceedingly rare; many are called but few are chosen, as one might say. Inbred lines isolated from outbred species show a very marked loss of vigour which, however, is countered by selection during inbreeding and is ultimately more than restored by the heterosis (or hybrid vigour) which is shown when exceptional combinations of unrelated lines are crossed together. Sometimes, the commercial seed is an F_1 hybrid between two low-yielding inbred lines; more usually, it is a four-way hybrid between two high-yielding F_1s, the latter procedure making it possible to produce cheaper seed than the former.

The practical success of hybrid maize, onions and sorghums is not in doubt; they certainly yield a great deal more than the open-pollinated varieties which they replaced. The genetical interpretation of that success, however, is a different matter; it is still remarkably obscure, despite much work on the subject. And this is not, as it might seem, merely an academic point; it is of acute practical importance, as we shall see later. Meanwhile the question is: can hybrid maize principles be applied to our inbred cereals, and, if so, how?

There is a considerable current stir of interest in this question to which the general answer should be: hybrid wheats and barleys would be worth while only if performance were significantly determined by gene-combinations which cannot be fixed in pure lines. Unfortunately the practical application of this simple conclusion is by no means clear. Superficially, the evidence in favour of heterosis in wheat and barley is good. Many studies indicate that, on balance, F_1 hybrids (or early segregating generations) are more productive than their parents, sometimes very strikingly so. Unfortunately, F_1 seed is difficult to produce in quantity so that experimental comparisons have not always been as realistic as they might have been. And, even if we allow that the evidence in favour of heterosis is good, the inference that hybrid cereals should be worth while does not immediately follow. We saw, earlier in this survey, that some kind of heterosis (*e.g.*, those due to dominance and complementary interaction—see Table) may yet be, in principle, readily fixed in pure lines; in fact, only over-dominance and certain linked complexes would have to be bred by means of controlled hybrids. The point to emphasise here is that heterosis is not enough; one must also show that F_1 performance can *not* be fixed in pure line form—and this, as we saw above, is exceedingly difficult. At all events, the total evidence in favour of heterosis in cereals is now rather impressive and the inference must be that *either* we ought to be be able to do much better with pure lines *or* that hybrid cereals will be necessary to achieve the highest possible levels of performance. Only a great deal of hard work will give us the answer to this exceedingly important problem. We *must* know, directly or indirectly, about overdominance and on this we are still very ignorant.

Even if it could be shown that hybrid cereals offer advantages over other kinds of population, it is by no means certain that they could ever be produced economically. Hybrid seed could only be produced in bulk by an efficient male sterility: restorer system, coupled with growing conditions extraordinarily favourable for cross pollination. The details of the male sterility restorer system have been worked out beautifully in maize (they needn't concern us here) and most of the essential mechanisms are available in wheat and barley. But it is still a long step to economical production of large quantities of seed and it is probable that environments in which this could be done efficiently will prove to be rather few; it would almost certainly be impossible in Scotland, though perhaps feasible in the south of England.

From these arguments one plausible conclusion is that hybrid cereals should be regarded with a certain amount of scepticism. There might be no good genetic basis for their adoption and they might prove to be, in practice, too difficult or too expensive or both. Economically, we should then do better to devote the formidable effort required to the improvement of pure-line breeding techniques and to the development of quite different kinds of cereal population. An alternative conclusion is that, if seed could be produced cheaply enough (in relation to economic advantage to the farmer) then hybrid cereals would offer a means of by-passing relatively quickly some of the undoubted difficulties of isolating the best possible pure lines. On this basis we should seize upon heterosis and use it regardless of its genetic nature and regardless of whether equally good pure lines could or could not be made. The decision, in short, might be practical and economic rather than genetic.

The reader who thinks he detects some conflict of opinion in the preceding paragraph would be quite correct! This is indeed an area of controversy among plant breeders and one in which we, at the Scottish Plant Breeding Station, find ourselves in amiable disagreement.

Even if the conclusion were to be that controlled hybrids were unnecessary or impracticable, this would not mean that a certain amount of hybridity could not be incorporated into our cereal populations. We saw above that the evidence in favour of heterosis that could not be fixed in pure line form, is still weak—though it may yet be strengthened. The evidence in favour of hybridity making a contribution to *stability* of performance is, however, rather better; indeed, in outbreeding plants and animals it seems to be established beyond all doubt. In inbreeders it is at least very highly probable. There seems to be some sort of analogy (the nature of which we know nothing) between heterogeneity and heterozygosity: as mixed populations show stability of performance so do hybrid ones. Unfortunately, in many experiments, the two effects are unavoidably confused, as when segregating hybrid generations are compared with pure lines; here the hybrids may indeed be more stable than the lines but we don't know whether the fact is to be attributed to heterogeneity or to hybridity or to both. On balance, it seems fairly certain that stability is indeed promoted by hybridity but, once again, a great deal of hard work is wanted.

Disease resistance

The cereals have suffered as much as any group of crop plants from epidemics of airborne pathogens, usually fungi such as the rusts and mildews. In general, we have learned to live with these pathogens by a combination of commonsense, phytosanitary measures and disease resistance breeding. The economic importance of the various cereal pathogens, of course, varies widely from place to place so that, while North American cereals are periodically decimated by rust epidemics, Scotland remains comparatively free. Nevertheless, the broad pattern of cereal disease remains remarkably constant. It is this: varieties are bred to contain specific genes which confer resistance to corresponding races of the pathogen; when such a variety is cultivated on a large scale, the pathogen population evolves a new race * that can attack the new variety and the cycle starts over again. Suneson, in the United States, has referred to these alternations of immunity and epidemic as " boom and bust cycles "; we have just had the " bust " part of such a cycle of yellow rust of wheat in Britain. Comparable situations are known in other crops and it is now generally accepted that, as a defence against airborne fungal pathogens, single-gene specific resistances are, at best, short-lived. In the U.S.A. the probable life of an oat variety is reckoned to be between three and seven years.

One-gene resistance of this kind can quite easily be backcrossed into existing adapted varieties so that the plant breeder has at least a fair chance of keeping a step or two ahead of the fungus. Nevertheless, the pathogen sometimes catches up and an epidemic results. Furthermore, there may come a time when suitable one-gene resistances are not available for protection against new races of the fungus, either because they do not exist or cannot be found. A disastrous situation could then result. Is there no way of achieving a more stable control system than the adoption of boom and bust cycles?

The evidence is that there is, although it has yet to be systematically exploited in the cereals. Potato workers have, for the past fifteen years, recognised the existence of what they called " field resistance " to potato blight. As with the cereal rusts, specific resistance genes (*R*-genes) in potatoes have consistently failed to give long-term protection against blight; instead, potato breeders have been turning more and more to a polygenic resistance which offers, not *immunity* to the pathogen, but resistance to infection, together with inhibition of growth and sporulation; the result is a reduced and delayed attack which damages the plant but not severely or early enough much to affect the crop; the fungus is there but the attack is contained. In principle, the same system ought to be feasible in cereals and, indeed, several examples of field resistance to cereal diseases are known. But cereal breeders have not systematically exploited the possibilities in the way that potato breeders are now doing. The reason, probably, is that field resistance is very much harder to handle, both genetically and experimentally, than a single-gene resistance. In describing field resistance as " polygenic " we mean that it is controlled genetically by many genes of individually small effect so that inheritance follows the same sort of rather complicated biometrical rules that are followed by nearly all the other important economic characters with which the plant breeder has to deal. Nevertheless, all the (now very powerful) evidence goes to show that useful levels of field resistance could quite easily be constructed, given adequate genetic variability, extensive recombination and the right kinds of selection technique. Paradoxically, one would probably

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* This is exactly comparable with the evolution of new strains of bacteria resistant to antibiotic drugs or of rats resistant to warfarin, the new cereal variety being the selective factor in the environment, the analogue of the drug or the poison.

need to start such a programme by selecting *against* the single-gene resistances which are liable to confuse selection.

But it may be asked: why should not the pathogen adapt itself to field resistant varieties as it adapts itself to varieties having specific resistances? There is no general answer to this question except to observe that, empirically, it does not seem to happen. In potatoes, certainly, field resistant varieties remain field resistant and it is a reasonable (though unproved) expectation that the same would be true of cereals. We can only try it and see.

While the development of field resistance seems to offer the best hope of coming to terms with the airborne pathogens of the cereals, there is one other approach which might prove to be useful and is, indeed, already being tried. This is deliberately to make the host population variable in respect of its reaction to the fungus. Thus, a cereal population composed of several different lines, each resistant to some strains of the fungus but susceptible to others, might be expected to show a sort of " damping down " effect on the fungus, resulting in a delayed spread of the disease. What little experimental work there is on this point tends to confirm expectation; the response of a genetically mixed population of host to a variable population of the pathogen is indeed to slow down the attack, although not to stop it. Proposals along these lines were made for wheat in Mexico some ten years ago but have not yet, apparently, been tried in practice. The idea was to backcross a range of different single-gene resistances into the standard local wheat and put out an agronomically uniform but genetically heterogeneous composite population in the field. The same idea is currently being tried with oats in the U.S.A. and the results should be extremely interesting. If this idea were to work on the field scale—and only field test can tell—the final result would probably be a reduced and delayed onset of the disease rather similar to that which is brought about by field resistance. We might think of this effect as one aspect of the more general stabilising effect of heterogeneity which we have briefly discussed already. There is, after all, a sense in which we can reasonably say that a disease is merely one of the factors of the environment in which our crops live.

These, then, appear to be the two most promising lines of attack on the control of the airborne pathogens: field resistance and carefully constructed heterogeneity. Probably the former would be the most satisfactory but the possibilities of the latter cannot really be understood until much better experimental evidence than we have now is available. Ultimately, the ideal situation might well be one in which a crop population was homogeneously field resistant but heterogeneous for specific resistances as well. Theoretically, at least, this system would be very attractive.

Before leaving this subject, it may be worth referring briefly to two of the principal soil-borne diseases of cereals. It is generally agreed that the frequency of cultivation of (especially winter-grown) cereals in Britain, is limited by the two major soil-borne fungi: those that cause eyespot and take-all. No specific resistances are known to these diseases but field resistance to eyespot is known in several wheats and is being developed at the Plant Breeding Institute, Cambridge. If it were thought useful to increase still further the frequency of cereal (especially winter-cereal) cropping in Britain, it seems clear that it would be necessary first to construct fairly high levels of field resistance to both these two diseases. Eyespot resistance seems to be on the way; resistance to take-all could probably be developed by imposing the right sort of selection on large populations of highly heterozygous plant material. The fact that we now have no resistance to take-all is not evidence that it could not be constructed by the right techniques; in general, populations, whether of plant or animals, only show characters for which they have been selected in the past. For comparison with this statement, we may note that the Andigena potatoes of South America are all extremely susceptible to blight, not surprisingly because (until very recently) they were never exposed to blight in their native home; but mass selection under epidemic conditions in Britain has constructed excellent levels of field resistance to the disease quite easily. Whether cereals that were field resistant to the soil-borne fungi would be worth the effort, however, is another question, the agricultural implications of which would undoubtedly be extraordinarily complex.

Fancy Breeding

So far, we have been discussing what one might call more or less orthodox approaches to cereal improvement, that is, approaches which involve no fundamental changes in the morphology or genetic constitution of the plants. Fundamental changes in these respects are, however, not impossible and, indeed, in the course of time, are very likely to take place. To consider possible morphological changes first, it seems likely that our cereals will steadily become shorter as, indeed, is already happening. So long as a short plant can produce the grain yield, there is no point in growing a lot of straw which may break and which is virtually valueless at harvest. Dwarf barleys are now becoming prominent in Britain and dwarf wheats have recently gained a resounding success in the U.S.A.; dwarf oats (though some are available) have been less successful but there can be little doubt that they will follow. Dwarfness is not only a useful attribute in itself but tends to be associated with tolerance of wind and of high fertility—straw characters other than length are, of course, intimately involved as well. Another way in which the shape of our cereal plants might fundamentally change is by modification of the tillering pattern. It seems certain that all our cereals waste energy in growing tillers which not only do not help but actually hinder grain production. Under virtually perfect conditions, the highest grain production would probably be achieved by the very accurate spaced-sowing of a plant which did not tiller at all. Such a plant would not, however, compensate for poor emergence in bad patches of ground and would demand exceptionally uniform land and the use of accurate seed drills and high seed rates. A practical solution might lie in between the extremes; varieties which tillered early and very little might provide a working compromise. Whatever the practical answer turns out to be, it seems likely that we should be able to minimise tiller waste in a variety bred for the better soils and thus improve the overall economy of the plant.

At the genetical level there are a number of exciting possibilities for a fairly radical reorganisation of our cereal crops. Thus, cytogenetic techniques are now available for the introduction of a whole series of single chromosomes or bits of chromosomes from rye into wheat, as Riley's studies at Cambridge have shown. Further, studies of our allopolyploid cereals, wheat and oats, are indicating ways of recombining genetic variability on a scale hitherto quite inaccessible to plant breeders. The possibilities, which are unforeseeable in detail, are almost certainly enormous.

The effects of radiation in producing mutations in living organisms have been understood in general terms for some forty years. But it is only in the last fifteen or twenty years that the economic possibilities of induced mutations in plant breeding have been seriously investigated. This is not the place for an extended discussion of what has become a very complicated and even somewhat controversial subject. Briefly, it has been established beyond doubt that some useful mutations can indeed be produced in a wide variety of crop plants and can then be incorporated in new varieties by conventional plant breeding methods. It seems clear that " mutation breeding " as it has been called, has a definite use in producing certain specific mutations (affecting, for example, straw length or disease resistance) so long as adequate selection techniques are available. Theoretically, and in the very long run, it might be predicted that induced mutations could substitute for the natural genetic variability now largely used by the plant breeder. This, however, is arguable and at present it seems fair to say that mutation breeding is (and is likely to remain) merely a useful technical adjunct to plant breeding rather than a substitute for it. It seems a pity that the ballyhoo which is automatically attached to any subject connected with nuclear physics should have been allowed to obscure this subject. However, now that the initial dust is settling, we can begin to see induced mutations in perspective, simply as a useful additional technique for the applied geneticist and plant breeder.

New cereal populations

Let us now try to draw the preceding discussion together in the form of a survey of the sorts of cereal population which we might expect to have in the future.

First, pure lines will, no doubt, remain the standard for many cereal varieties, especially those which have been bred for specific technological purposes, for example, bread-making wheats and malting barleys. It does not seem likely that pure lines for such purposes will be supplanted by other kinds of populations in the foreseeable future. Pure lines, furthermore, have several other advantages : they are relatively easy to breed and to maintain and our systems of certification and seed production are well adapted to their use.

Second, mixtures of lines may well have a useful place when exact technological adaptation is not in question. Thus there is no obvious reason why feeding grains should not be mixed if there were advantage in doing so. One interesting possibility which has been thrown up by recent work on wheat in the United States is to grow mixtures in alternate rows in the field rather than from seed mixed before sowing. The disadvantages of mixtures are obvious: they might look unattractive, they would cause administrative difficulties and their production would certainly add to the tasks of the plant breeder. Nevertheless, gains in performance and stability might well make them worthwhile. One special situation (which would go far to avoid these disadvantages) would occur in the case of what we might call a cryptic mixture compounded of backcrossed lines of a single pure line variety, heterogeneous only, for example, for disease resistance. Such a population could be effectively equivalent to a pure line and treated as such. In the case of visibly variable mixtures, it is not clear whether intermittent reconstruction of the population from the component pure lines would be necessary or whether some populations, at least, could continue indefinitely. These are important questions for the future.

Third, new land-races, as we might call them, are another possibility somewhat akin to the preceding. In this context we are referring to heterogeneous and somewhat heterozygous populations similar to the composite crosses that were discussed earlier in this survey. Such populations would generally be unsuitable for technological utilisation but there is no obvious reason why they should not be used for, say, animal feeding. They would presumably neither be certifiable nor acceptable for Plant Breeder's Rights. Nevertheless, they might have a place, especially perhaps in more marginal agricultural environments. Over a period of years of propagation, such populations would tend to become a complex mixture of more or less pure lines, but with some residual heterozygosity. It might just be that some sort of a working compromise between this situation and the succeeding one, namely controlled hybrids, would prove to be workable. Thus, if it could be shown that hybridity really were a major advantage, early generation hybrid bulks might prove acceptable. They could have the advantages of heterogeneity and heterozygosity without the disadvantages of, on the one hand, uncertain constitution and, on the other, high seed cost.

Fourth, controlled hybrids are possible but, as we saw above, somewhat improbable. Their use would probably be justifiable only if it could be shown that they offered levels of performance unavailable in other kinds of population. Nevertheless, hybrids hold out distinct attractions to the commercial plant breeders in the sense that the seedsman has, so to speak, a built-in control of his product. The seed would, inevitably, be expensive but obviously worth while if the performance were good enough. There would be no certification problems.

These then are the four major possibilities and it will be exciting to see what happens in practice. The first essential in developing new kinds of cereal population will be research because our theoretical understanding and practical experience of such populations are still rudimentary. Only thus can we learn whether these concepts can be put to practical advantage. If it seems that they can, there will, of course, be a good deal of opposition to any suggestion that we should depart from pure lines and uniformity among our cereals. It is true that there are administrative advantages in uniformity but this is not the point. The leading criterion must be: what kind of population will give the best agricultural performance in such and such defined circumstances? Agricultural criteria are the only ones which ought to be allowed to matter.

The Pentlandfield Programme

The questions about the productivity of cereals in relation to the genetic structure of their populations which have been posed in this review are many and complex. Good answers to them will require effort and resources far beyond the capacity of any one research station. At Pentlandfield, within the limits of our own very restricted resources, we are tackling some of the problems and are designing our cereal breeding programmes in the light of what seems to be, at present, the best available information.

Our principle breeding projects are the production of feeding barleys and oats for use in Scotland. Since most European barleys have, for many years, been bred for malting, we assumed from the start that we should need to broaden the genetic base of our breeding operations and turned therefore to the composite cross approach to provide the fundamental populations. We have brought in composite crosses from other places and have made some of our own. The results are yet unforeseeable: they may be six-row or two-row types; they may be few or many in number, some more or less ecologically specialised; and they may be pure lines, mixtures or land-race type populations. Genetic studies concurrent with the breeding will, we hope, guide us towards a choice of population structure best suited to local agricultural needs. We are adopting a similar breeding philosophy in our oat programme but have chosen the barleys as the most favourable material for genetic investigations. As to disease resistance, the indications are that it is of relatively minor importance in Scottish oats and barleys and, unless forced to do so, we do not propose to become involved in the subject. If circumstances should dictate, however, we should go straight for the construction of field resistance in composite cross type populations. One exception to this statement must be noted: we already have high levels of resistance to the oat stem eelworm brought about by the combination of two specific resistance genes. The pathogen *may* adapt itself to our new oats in time but, being much less mobile than an airborne fungus, the probability that this resistance will prove to be really useful if wisely used is fairly high; but extensive field experience alone can tell. We have recently undertaken a study of certain specialised barleys adapted to the needs of the distilling trade and biochemical-genetic prospects in this connection appear to be excellent. It seems certain that the technologically specialised varieties such as are demanded by the situation will need to be pure lines.

Alongside these breeding programmes, the genetic analysis of our various composite cross populations, of various deliberate mixtures and of the behaviour of certain specific mutants will all contribute to the later decisions as to what kinds of populations we should try to produce. In addition, we are aware of, and looking into, the possibilities of making fairly radical changes in the morphology or constitution of the plants, for example: non-tillering barleys, tetraploid barleys and dwarf and compact-panicle oats. How much we can do is severely limited by our resources: there is an infinity of exciting and highly practical problems among which hard choices must be made.

Literature

Readers who may wish to enquire further into the subject will find the following review articles and books helpful.

Allard, R. W. (1960). *Principles of Plant Breeding*. New York and London.

Allard, R. W. and Bradshaw A. D. (1964). Implications of genotype-environmental interactions in applied plant breeding. *Crop Sci.*, **4**, 503-8.

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Macer, R. C. F. (1963). Developments in cereal pathology. *Rep.Pl.Breed.Inst.* 1962-3, 5-33.

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VARIETIES BRED BY THE STATION

Distribution of élite stocks of Scottish Plant Breeding Station products is in the hands of the following:—

Oats	Bell	Messrs Macfarlan, Shearer & Co., Greenock.
Grasses	Scotia Cocksfoot Scotia Timothy Scotia Perennial Ryegrass	National Seed Development Organisation.

Other Scottish Plant Breeding Station products on the market are:—

Oats	Craigs Afterlea Albyn Donside Albyn Empress	Early Miller Albyn Bard Shearer
Barley	Craigs Triumph	
Bean	Albyn Tick	
Potatoes	Craigs Defiance Craigs Alliance Pentland Beauty Pentland Dell Pentland Falcon* Pentland Hawk* Roslin Castle* Pentland Kappa*	Craigs Royal Pentland Ace Pentland Crown Pentland Envoy Pentland Glory* Pentland Ivory* Pentland Javelin*

* Plant Breeders' Rights have been granted in these varieties and licences to reproduce and sell stocks have been issued to growers and merchants.

The National Seed Development Organisation is responsible for the commercial development of varieties bred at the official stations, including the Scottish Plant Breeding Station. Applications for licences to grow and sell protected varieties listed above should be sent to: the Executive Officer, National Seed Development Organisation Ltd., The Granaries, White House Lane, Cambridge.

COLLABORATORS

The list of collaborators in the work of the Station has grown greatly during the past year. It includes farmers, landowners, colleges and official stations, who have provided field facilities and workers in university, official and industrial laboratories, who have provided valuable scientific help. We hope the following lists are complete; to all collaborators, named or (perchance) unnamed we offer our best thanks.

(*a*) Official bodies:—

Animal Breeding Research Organisation, Edinburgh.
Department of Agriculture and Fisheries for Scotland, Scientific Services, Edinburgh.
Forestry Commission, Archerfield, East Lothian.
Grassland Research Institute, Hurley.
Ministry of Agriculture, Northern Ireland, Plant Breeding Station, Loughgall.
National Agricultural Advisory Service.
National Institute of Agricultural Botany, Cambridge.
National Institute of Agricultural Engineering (Scottish Station), Edinburgh.
Plant Breeding Institute, Cambridge.
Rowett Research Institute, Aberdeen.
Scottish Horticultural Research Institute, Dundee.
Torry Research Station, Aberdeen.
Welsh Plant Breeding Station, Aberystwyth.

(*b*) Universities and Colleges:—

Department of Botany, St Andrews University.
Department of Botany, University of Edinburgh.
Department of Brewing and Biochemistry, Heriot-Watt University, Edinburgh.
The Edinburgh School of Agriculture and Edinburgh and East of Scotland College of Agriculture.
The North of Scotland College of Agriculture, Aberdeen.
The West of Scotland College of Agriculture, Glasgow.

(*c*) Industrial Collaborators:—

Campbell's Soups Ltd.
Robert Kilgour & Co. Ltd., Kirkcaldy.
Norfolk Canneries Ltd.
North British Distillery Co. Ltd., Edinburgh.
J. & T. Rodger, Cupar.
Scottish Agricultural Industries Ltd., Edinburgh.
Scottish Cooperative Wholesale Society Ltd., Junction Mills, Edinburgh.
Scottish Grain Distillers Ltd., Menstrie.

(*d*) Individual:—

G. Clapperton, Sheriffhall Mains, Dalkeith, Midlothian.
A. G. Dewar, Hedderwick Hill, East Lothian.
G. F. Duncan, Waterton, Duffus, Moray.
G. B. R. Gray, Smeaton, East Linton, East Lothian.
M. J. Hamilton, Muirhouse, Edinburgh, Midlothian.
J. Howie, Newton, Wormit, Fife.
Sir David Lowe, Elvingston, East Lothian.
A. Macintyre, South Ledaig, Argyll.
D. MacKessack Leitch, Inchstelly, Alves, Moray.
R. Miller, Tullochgorum, Inverness-shire.
R. C. Smith Whitsome, West Newton, Berwickshire.
W. M. Stephen, Rothills, Duffus, Moray.
J. Stewart, Caberston, Walkerburn, Peeblesshire.
G. A. Storrar, Rossie, Auchtermuchty, Fife.
H. Thomson, Newark, St Monance, Fife.

STAFF LIST

(in post at 31st March 1968)

Director: N. W. Simmonds, Sc.D., A.I.C.T.A., F.I.Biol.
Deputy Director: W. Black, O.B.E., Ph.D., D.Sc., F.R.S.E.

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A. HOWIE, B.Sc.(Agric.), N.D.A., N.D.D. (North of Scotland College of Agriculture), 581 King Street, Aberdeen.
R. H. WATHERSTON, C.B.E., Crichton Mains, Ford.

Directors nominated by the Secretary of State for Scotland

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W. A. BIGGAR (*ex-officio*).
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Election of Directors

In accordance with the rules of the Society the following Directors retire from the Board at this time:—

JOHN ARBUCKLE, Logie, Newburgh.
W. ANDREW BIGGAR, O.B.E., M.C., B.Sc., Magdalene Hall, St Boswells.
GEORGE CLAPPERTON, Sheriffhall Mains, Dalkeith.
J. W. GRANT, B.Sc., North of Scotland College of Agriculture, Inverness.
F. R. HORNE, C.B.E., M.A., N.D.A., N.D.D., Hill Farm, Lolworth, Cambridge.
IAN JENNINGS, Nether Cleuch, Dalry.

To fill these vacancies the Board of Directors recommends election of the following:—

H. F. D. ELDER (Messrs William Dods & Son), Haddington, East Lothian.
W. H. M. GILL, Rosskeen, Invergordon, Ross-shire.
A. HOWIE, B.Sc.(Agric.), N.D.A., N.D.D. (North of Scotland College of Agriculture), 581 King Street, Aberdeen.
Sir DAVID LOWE, C.B.E., D.Sc., Elvingston, Gladsmuir, East Lothian.
A. GORDON PORTER, C.D.A., East Scryne, Carnoustie, Angus.
R. H. WATHERSTON, C.B.E., Crichton Mains, Ford, Midlothian.

The Board of Directors also recommends election of the following as Trustees:—

W. ANDREW BIGGAR, O.B.E., M.C., B.Sc., Magdalene Hall, St Boswells.
JAMES GRAY, M.B.E., T.D., Stirling.

Meetings

The Board of Directors met four times: on 27th July 1967; 9th November 1967; 4th April 1968; and 6th June 1968.

The Finance Committee met on 6th June 1968.

Research Committee Meetings were held as follows: Potatoes on 17th August and 9th November 1967 and on 8th February 1968; Forage Crops on 12th October 1967.

ADMINISTRATION

Finance

The abstract of the audited accounts set out on pages 46-52 reveals the Society's financial position at 31st March 1968. The Department of Agriculture and Fisheries for Scotland provided a grant of £111,000 while income from other sources amounted to £1,341, 7s. 2d. Expenditure for the year was £112,776, 0s. 4d. which had the effect of reducing the balances of grants from previous years to £6,020, 18s. 0d.

The Department also provided £40,087, 4s. 1d. to meet the cost of capital works, mainly additional glasshouses and ancillary buildings, and £1,209, 11s. 10d. for a microscope.

Membership

At 31st March 1968, the total membership was 361, comprising 182 life members and 179 annual members. Seventeen new members were elected during the year while 9 members died or resigned.

Distribution of Membership as at 31st March 1968

Aberdeen	12
Angus	25
Argyll	2
Ayr	12
Banff	2
Berwick	18
Bute	..
Caithness	4
Clackmannan	2
Dumfries	6
Dunbarton	4
East Lothian	49
Fife	22
Inverness	6
Kincardine	2
Kinross	1
Kirkudbright	2
Lanark	20
Midlothian	65
Moray	6
Nairn	1
Orkney	3
Peebles	1
Perth	20
Renfrew	2
Ross and Cromarty	10
Roxburgh	11
Selkirk	3
Stirling	6
Sutherland	..
West Lothian	7
Wigtown	4
England	27
Ireland	1
Wales	..
Abroad	5

Board of Directors

Dr Alexander Nelson, nominated member, and Mr David Bell, Trustee, retired after many years of service, with the warm thanks and best wishes of the Board. Professor Robert Brown, F.R.S., was welcomed on joining the Board as new nominated member. Mr W. L. Forrest, Mr P. P. Wade and Mr J. Watson were welcomed to the Board on first election.

Staff

The following new appointments were made during the year:—

Scientific	J. L. Fyfe, M.Sc. (Head of Forage Department). G. Mackay, M.Sc. (Forage).
Assistants	Miss K. Benn. Mrs K. I. Campbell. Mrs E. Gray. Z. P. Kozlowski. D. McCall. D. McDonald. N. Miller. A. Smith. P. Thomson. Miss E. Vallery. Miss T. Wright.
Administration	Mrs M. Smith.

The following resignations were received:—

Dr A. S. Bedi.
Miss E. Bennett.
Miss C. Brydon.
G. Duncan.
Dr D. A. Govier.
Miss A. Spencer.
Miss H. K. Young.

Dr Govier moved to a post at Rothamsted Experimental Station, Miss Bennett to a post with F.A.O., Rome; Dr Bedi completed his studentship, submitted his thesis and was awarded the Ph.D. degree in the University of Edinburgh. Our best wishes go with all.

Dr Dunnett attended the Ninth International Nematology Symposium in Warsaw in August 1967 and presented a paper entitled: " A possible genetic mechanism promoting variability in populations of potato cyst eelworm." On the way he visited the Plant Breeding Institute at Gross-Lüsewitz, East Germany, at the invitation of the Director, Dr R. Schick, and had useful meetings there with European colleagues interested in the potato cyst eelworm. Members of staff also attended sundry scientific meetings in the United Kingdom during the year and gave eight lectures or seminars to various audiences.

The Director gave a course of lectures entitled "Topics in Economic Genetics" to the fourth year Botany class in the University of Edinburgh. He also gave seven other lectures in various universities and research stations. He attended a meeting of a sugarcane breeding Technical Committee in Barbados in December 1967 and was appointed to the Coordinating Advisory Committee of the Malayan Rubber Fund Board and to the Forestry Commission Advisory Committee on Forest Research. He also served on several committees within or directly connected with the work of the Agricultural Research Service and was appointed Chairman of the A.R.C. Technical Committee on Potato Problems.

The Station made a television appearance on 18th February 1968 in the programme Farm Forum. Several members of staff were interviewed by Mr Andrew Biggar and viewers saw something of the work on eelworm-resistance breeding in oats (including an impressive screenful of wriggling nematodes) and on new *Brassica* hybrids.

The Station received many visitors during the year, including parties of students and farmers as well as many individual scientists from home and abroad. We were pleased to see them.

Awards

Sir Maurice Yonge, previously Prof. C. M. Yonge, Nominated Member of the Board of Directors, was honoured with a Knighthood. Dr W. Black received the O.B.E. for distinguished services to potato breeding. Our warmest congratulations go to both.

Acknowledgements

Acknowledgement of financial assistance from the Department of Agriculture and Fisheries for Scotland and of practical help in various forms from Universities, Colleges, Institutes, Companies and individuals has been made elsewhere in this report. To all, whether named individually or not, who have thus supported the work of the Station we offer our warmest thanks.

ABSTRACT OF ACCOUNTS

ABSTRACT OF ACCOUNTS

For year ended 31st March, 1968

INCOME

1967		
£361	Dividends and Interest	£407 7 4
437	Sales of Produce and Stock on Hand	820 12 10
85	Subscriptions—Annual	84 15 0
	Note.—Annual Subscriptions amounting to £13 10 0 are in arrear.	
29	Rent of Cottage	28 12 0
£912	*Total Ordinary Income*	£1,341 7 2
	Grant received from the Department of Agriculture and Fisheries for Scotland:—	
97,500	Maintenance for year 1967-68	111,000 0 0
£98,412	*Total Income*	£112,341 7 2
	Balance at 1st April 1967:—	
5065	Department of Agriculture and Fisheries for Scotland—Maintenance Grant	6,455 11 2
£103,477		£118,796 18 4

EXPENDITURE

1967			
	Salaries:—		
£51,738	Scientific and Technical Staff .	£56,720 5 0	
5,773	Administrative and Clerical Staff.	6,459 10 3	
1,112	Pension Supplementation . .	1,258 12 4	
£58,623			£64,438 7 7
5,391	Superannuation Contribution		5,661 18 3
10,805	Wages		12,391 3 1
2,468	National Insurance and Graduated Contributions .		3,049 10 10
3,825	Apparatus and Equipment		4,596 18 11
2,080	Chemicals and Materials		2,847 3 5
1,466	Travelling and Subsistence		1,972 7 11
1,347	Rates, Taxes and Insurance		1,534 6 2
3,781	Power, Heat and Light		4,331 17 6
337	Library Books andPeriodicals		542 13 7
609	Printing and Binding		590 9 3
940	Stationery, Postages, Telephones and Office Expenses .		1,151 14 6
—	New Vehicle	£363 16 3	
978	Maintenance of Vehicles	1,076 9 0	
			1,440 5 3
201	Audit and Legal Expenses		168 0 0
471	Property Repairs		1,159 19 9
70	Trial Centres		60 0 0
919	Edinburgh Centre of Rural Economy—Contribution towards upkeep		1,035 0 0
569	Repairs and Servicing		571 0 2
356	Seed Testing, Plant Variety Trial Fees.		644 11 0
238	Transport		25 14 10
866	Land Improvement		1,458 16 7
326	Advertising		1,117 9 9
90	Furniture		868 8 10
266	Miscellaneous		400 7 4
—	Security Patrols		717 15 10
£97,022	*Total Ordinary Expenditure* . .		£112,776 0 4
	Balance at 31st March 1968:—		
6,455	Department of Agriculture and Fisheries—Maintenance Grant		6,020 18 0
£103.477			£118,796 18 4

BALANCE SHEET

as at 31st March 1968

I Funds at 31st March 1968		
Balance as at 31st March 1967	£182,487 19 7	
Dept. of Agriculture and Fisheries for Scotland Capital Grant	40,087 4 1	
,, ,, Equipment	1,209 11 10	£223,784 15 6
II Current Liabilities:—		
Accounts outstanding due by Society	£759 7 0	
Subscriptions paid in advance	3 0 0	
Dept. of Agriculture and Fisheries for Scotland Maintenance Grant	6,020 18 0	6,783 5 0
		£230,568 0 6

	Cost	*Amounts charged to Revenue*	*Net*
I Fixed Assets:—			
Heritable Property	£215,066 1 2	}	£216,275 13 0
Capital Equipment	1,209 11 10		
Implements and Tools	12,775 13 7	£12,775 13 7	...
Vehicles	2,862 10 2	2,862 10 2	...
Laboratory Apparatus	13,545 6 10	13,545 6 10	...
Furniture and Fittings	6,138 0 3	6,138 0 3	...
Library Books	4,639 0 0	4,639 0 0	...
	£256,236 3 10	£39,960 10 10	£216,275 13 0

II Current Assets:—		
Stocks on Hand as valued by Directors	£23 0 0	
Accounts Outstanding, due to Society	1,220 2 6	
Income Tax Recoverable	151 15 10	
Investments (see Appendix), at cost	6,936 7 8	
Cash and Bank Balances	5,961 1 6	14,292 7 6
		£230,568 0 6

Edinburgh, *15th May 1968*.—The undersigned, having had access to all the Books of the Society, and having examined the foregoing Statement of Accounts and verified the same with the Accounts and Vouchers relating thereto, now sign th[illegible]d to be correct, duly vouched, and in accordance with law.

16 Alva Street.

R. L. MACDONALD, *Approved Auditor.*

J. D. ROBERTS, *Convener, Finance Committee.*

LIFE MEMBERSHIP SUBSCRIPTIONS AND DONATIONS ACCOUNT

Dividends and Interest	£395	9	0
Life Subscriptions	100	10	0
Donations	50	0	0
Gain on realisation of Investments	15	0	0
Balance at 1st April 1967	7,661	12	2
	£8,222	11	2

W. J. REID AND JAMES MUNRO BEQUESTS

Dividends and Interest	£80	3	1
Gain on realisation of Investments	22	1	0
Balance at 1st April 1967	1,767	0	9
	£1,869	4	10

DR. WILSON MEMORIAL FUND

Dividends and Interest	£14	12	3
Balance at 1st April 1967	469	14	4
	£484	6	7

Restoration of Pictures		£46 5 0
Balance at 31st March 1968, consisting of:—		
Investments (see Appendix), at cost	£5,868 4 5	
Recoverable Income Tax	120 2 10	
Sum in Bank of Scotland Savings Account	1,463 10 5	
Sum in Bank of Scotland Current Account	724 8 6	
		8,176 6 2
		£8,222 11 2

Grant for hospitality		£56 19 0
Balance at 31st March 1968, consisting of:—		
Investments (see Appendix), at cost	£1,603 4 1	
Recoverable Income Tax	19 12 0	
Sum in Bank of Scotland Savings Account	78 4 6	
Sum in Bank of Scotland Current Account	111 5 3	
		1,812 5 10
		£1,869 4 10

Balance at 31st March 1968, consisting of:—		
Investments (see Appendix), at cost	£368 17 6	
Recoverable Income Tax	5 4 9	
Sum in Bank of Scotland Savings Account	52 16 4	
Sum in Bank of Scotland Current Account	57 8 0	
		£484 6 7
		£484 6 7

APPENDIX

LIST OF INVESTMENTS

General Account

Nominal Value				*Market Value at 31/3/68*
£375	0	0	Courage, Barclay & Simonds 750 Ordinary 10s. Shares .	£1,003
225	0	0	National Commercial Bank of Scotland 450 Ordinary 10s. Shares	866
160	0	0	Royal Exchange Assurance Co. Capital £1 Stock . .	968
525	0	0	Imperial Chemical Industries Ordinary £1 Stock Units .	1,470
325	0	0	Electric & Musical Industries 650 Ordinary 10s. Stock Units.	1,528
2,846	5	7	6¾ per cent Exchequer Stock 1971	£2,789
£4,456	5	7		£8,624

Life Membership Subscriptions and Donations Fund

£416	8	1	Funding 6½ per cent Stock 1985-1987	£381
360	0	0	City of Birmingham 6¼ per cent Redeemable Stock 1972-1973	336
247	10	0	National Commercial Bank of Scotland 495 Ordinary 10s. Shares	953
120	0	0	Royal Exchange Assurance Co. Capital £1 Stock . .	726
240	0	0	Courage, Barclay & Simonds 480 Ordinary 10s. Shares .	642
345	0	0	Imperial Chemical Industries Ordinary £1 Stock Units .	966
220	0	0	Electric & Musical Industries 440 Ordinary 10s. Stock Units	1,034
1,983	10	6	6¾ per cent Exchequer Stock 1971	1,944
£3,932	8	7		£6,982

W. J. Reid and James Munro Bequests

£67	0	0	Imperial Chemical Industries Ordinary £1 Stock Units .	£187
150	0	0	Defence 5 per cent Bonds, 2nd Issue	150
1,359	5	9	Funding 6½ per cent Stock 1985-1987	1,244
£1,576	5	9		£1,581

Dr Wilson Memorial Fund

£30	0	0	Royal Exchange Assurance Co. Capital £1 Stock . .	£182
217	12	0	Funding 6½ per cent Stock 1985-1987	199
£247	12	0		£381

SCOTTISH SOCIETY FOR RESEARCH IN PLANT BREEDING

APPLICATION FOR MEMBERSHIP

The subscription is ten shillings for the year 1st April to 31st March or part of the year. Advance subscriptions will be accepted. Donors of £10 or over become life members without further payment. Applications should be addressed to:

The Secretary,
Scottish Plant Breeding Station,
Pentlandfield,
Roslin, Midlothian.

I desire to be enrolled a member of the Society and enclose the sum of

....

Name: ....

Address: ....

....

....

Signature: .... *Date:* ....

A note on the Scottish Plant Breeding Station

The Scottish Society for Research in Plant Breeding was founded in 1921 with the aims of conducting scientific investigations into plant breeding and of breeding plants for Scottish agriculture. Membership of the Society is open to any interested person whether farmer, merchant, scientist or other, in or out of Scotland. Management of the Society is vested in a Board of Directors which is elected partly by the members and partly nominated by the Secretary of State for Scotland. The principal activity of the Society is to run the Scottish Plant Breeding Station. The Station was for thirty-three years at Craigs House, Corstorphine, and moved to new premises on the Bush Estate of the Edinburgh Centre of Rural Economy in 1954. The Society met a third of the cost of the new laboratories but the recurrent expenses of running the Station were, from an early stage, greater than the Society could bear and nowadays nearly the whole cost is met from public funds granted by the Department of Agriculture and Fisheries for Scotland under scientific advice from the Agricultural Research Council.

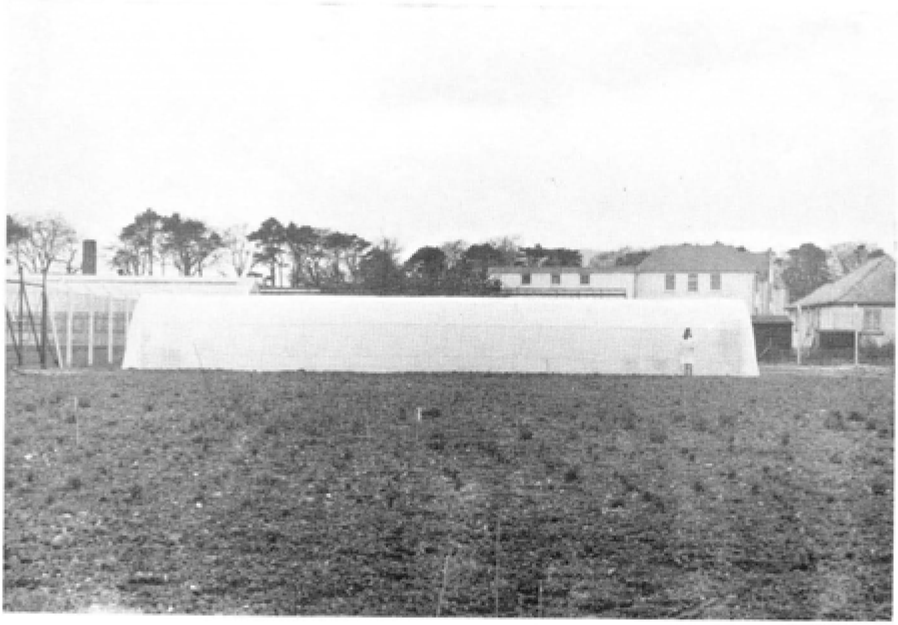
Interested persons are invited to submit the adjacent membership form. Members receive the Annual Report and any other publications and are eligible to participate in the affairs of the Society.

Address: Scottish Plant Breeding Station, Pentlandfield, Roslin, Midlothian, Scotland.

Telephone: 031-445 2171.

Location: See map at back cover.

Printed by William Blackwood & Sons Ltd., Edinburgh



POLYTHENE GREENHOUSE DESIGNED AND BUILT AT PENTLANDFIELD, 1968