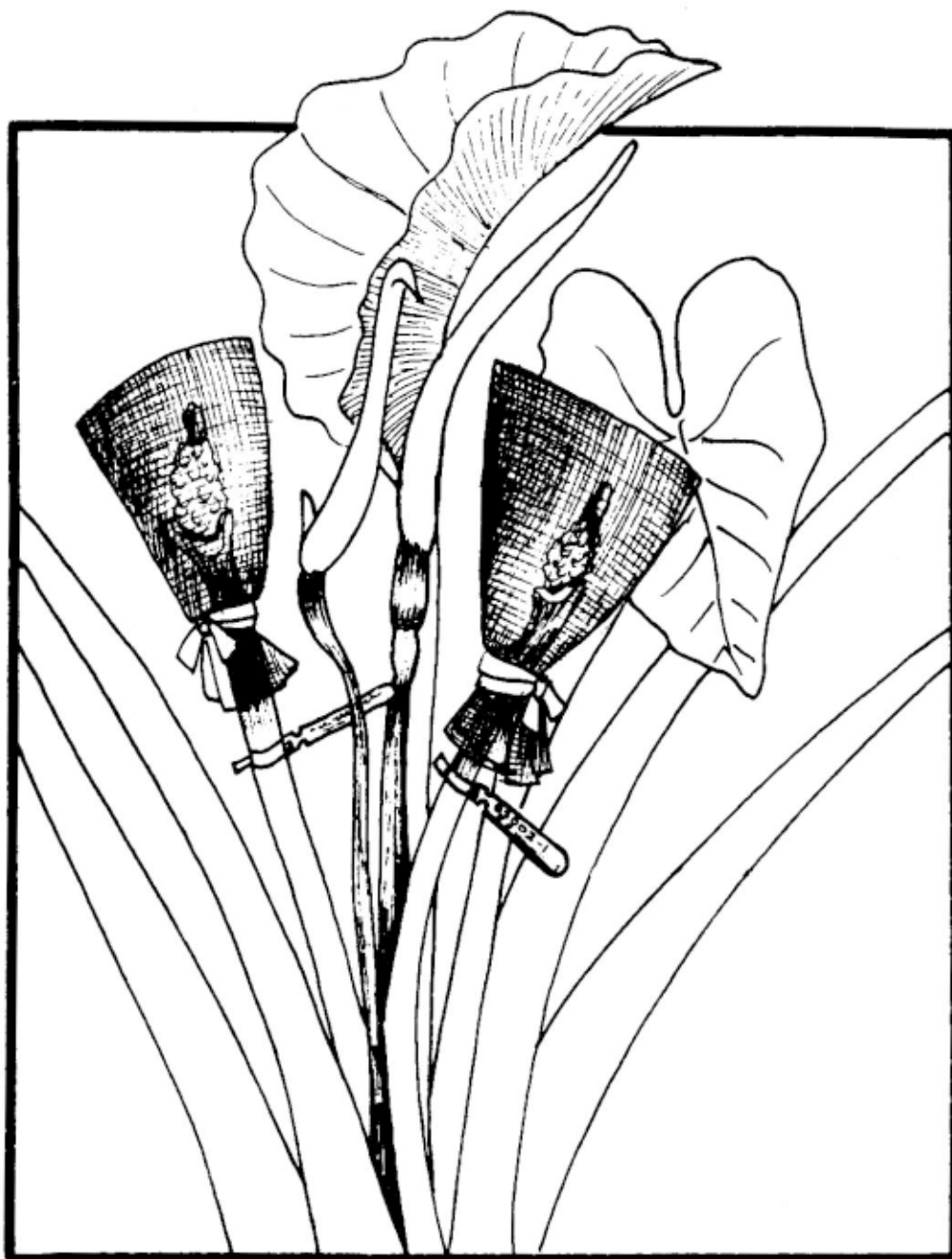




TARO BREEDING



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TARO BREEDING

This manual is for researchers in the Pacific region who are starting taro breeding programmes but lack training and experience in genetics and plant breeding. It is also for researchers and extension workers who are evaluating local and newly introduced taro germplasm. It may also be useful to teachers and students, of crop improvement courses at the diploma, degree, and post-graduate levels.

The objective of this manual is to provide you with the procedures and techniques needed to carry out a *Colocasia* taro breeding programme. Parts of the text have been, copied from the IRETA Agro-Fact, 'Sweet Potato Breeding', since breeding of these two crops is similar in many ways. Practical aspects of breeding are emphasized, rather than theory. Use of technical terminology is minimized. To keep the manual concise, detailed explanations are avoided when possible, and many concepts are simplified. After learning the material presented here, you may want to read other texts to gain more complete understanding of plant breeding.

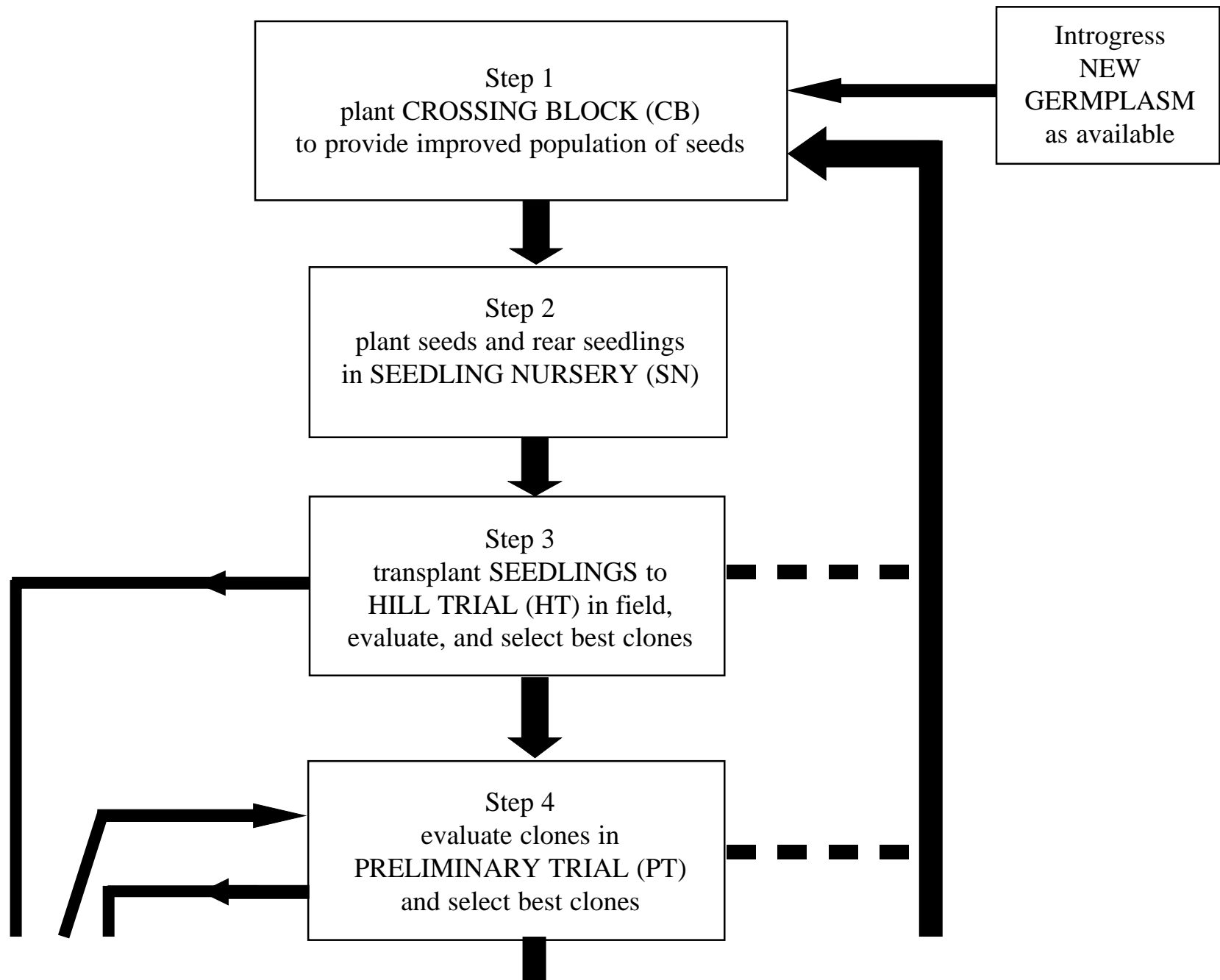
The taro breeding procedures and techniques included in this manual are being successfully used in IRETA's breeding programme. However, taro breeding is a new science, and we still have much to learn about it. World-wide there are only 6 programmes that are breeding taro or studying its floral habits and genetics. To

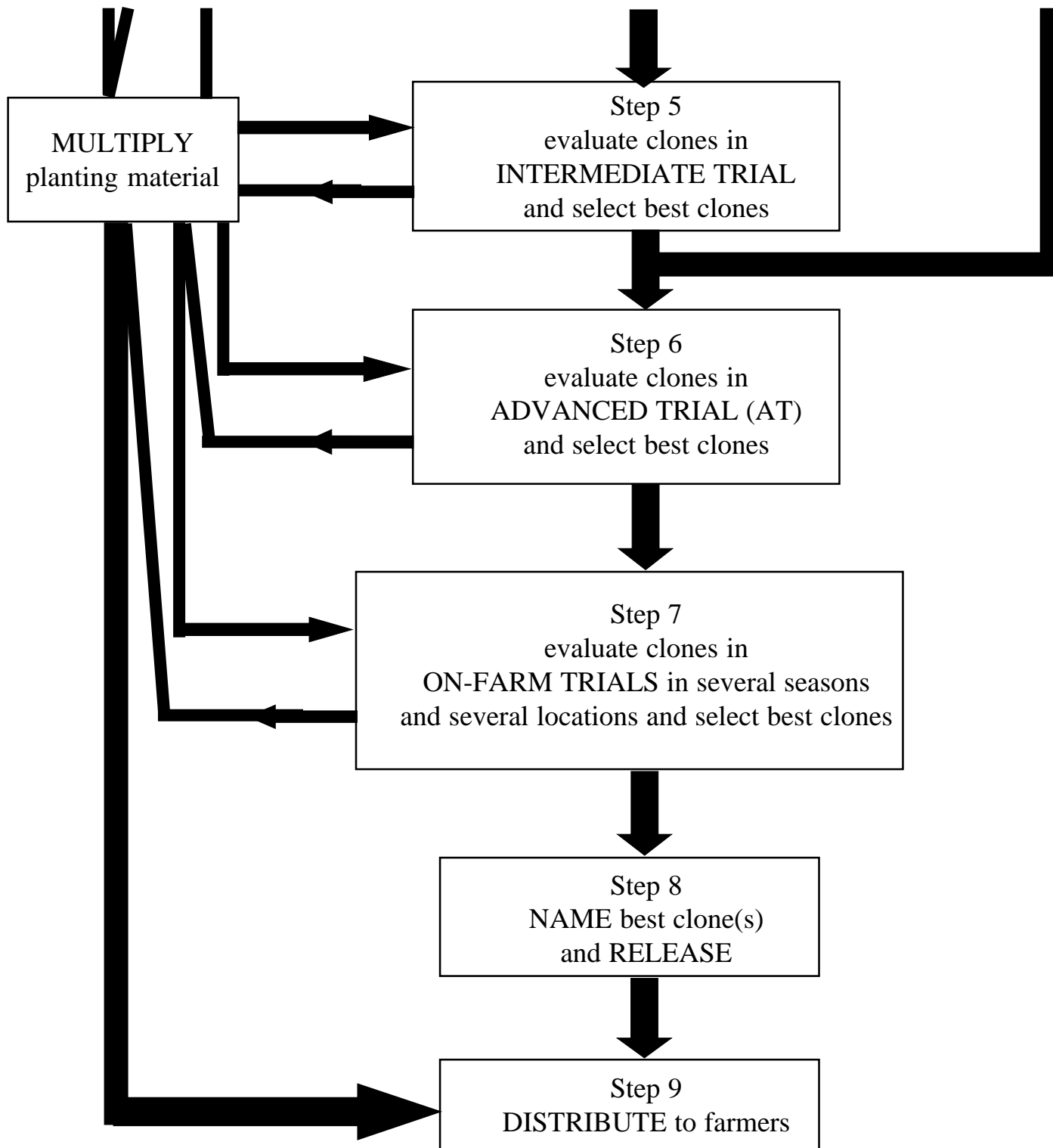
date, these programmes have developed and released only 2 improved cultivars of taro. Both of these were developed here in the Pacific: Samoa Hybrid released by the Ministry of Primary Industries, Fiji, in 1984 and Alafua Sunrise released by the University of the South Pacific (USP) Institute for Research, Extension and Training in Agriculture (IRETA), Western Samoa, in 1988.

The procedures and techniques presented here are important to the success of your breeding programme. Equally important is your knowledge of taro production in your country, particularly your knowledge of yield-reducing factors such as environmental stresses and disease, insect and nematode pests. You must also be familiar with the other problems farmers face and with the taro quality characters favoured by farmers and consumers.

Thorough knowledge of these factors is necessary to determine the goals of your breeding programme. To set your short-term goals, you must answer the question, "What type(s) of taro do the farmers need now?" And to set your long-term goals, you must answer the question, "What type(s) of taro will the farmers need in 10 years?" Remember that it often takes 10 years or more from the time you make a pollination until your new, improved cultivar finally reaches a large number of farmers.

Figure 1. Steps in a taro breeding programme





There are 3 methods to obtain improved cultivars (agricultural varieties) of taro for distribution to farmers in your country:

- Collecting, evaluating, and selecting from the local germplasm.
- Importing cultivars that have been bred in other parts of the world and evaluating them under your conditions.
- Breeding cultivars in your own programme.

This manual will concentrate on the last of these methods, that of breeding. However, much of the discussion under Steps 4 through 9, concerning conducting trials and reducing experimental error, will be useful if you are evaluating local germplasm or imported cultivars.

STEPS IN A TARO BREEDING PROGRAMME

A proposed breeding procedure is outlined in Figure 1. In Steps 1, 2, and 3, sexual propagation is used to produce seeds and seedlings. In Step 3, each seedling is cloned by propagating it vegetatively, and in all the following steps, vegetative propagation is used.

The purpose of using sexual propagation in Steps 1, 2, and 3 is to create genetic variability. Each seedling produced during sexual propagation is genetically different from all others and is potentially a new, improved cultivar.

During Steps 4 and 5, you evaluate clones derived from the seedlings produced in Steps 1, 2, and 3 to determine which ones you will advance to additional trials for further testing in Steps 6 and 7, which ones you will use as parents in the next Crossing Block (Step 1), and which ones you will discard.

During the On-Farm Trials (Step 7), you will identify one or more clones that both you and the farmers like. You are now ready to officially name and release these clones in Step 8 and distribute them to farmers in Step 9.

Figure 1 shows clearly that multiplication is a continuous activity that begins after you harvest the seedlings in the Hill Trial (Step 3), but the largest multiplication takes place between Steps 8 and 9 to produce enough planting material for distribution to farmers.

A **clone** consists of all the descendants of a vegetatively propagated individual.

Why do you go through the process of completing Steps 1 to 5 and then return some clones to Step 1? This is done to increase your chances of finding seedlings that have all the characters you need in an improved cultivar. This process is called **population improvement**. During each breeding cycle, parent clones are selected and cross-pollinated in such a way that the resulting seedling population is improved. That is, it contains more good seedlings than previous seedling populations. The method of population improvement that we use is **RECURRENT SELECTION**. Recurrent selection, especially the step of choosing the parent clones that you plant in Step 1, determines the direction and success of your breeding programme; it is so important that a separate section is devoted to it later in this manual.

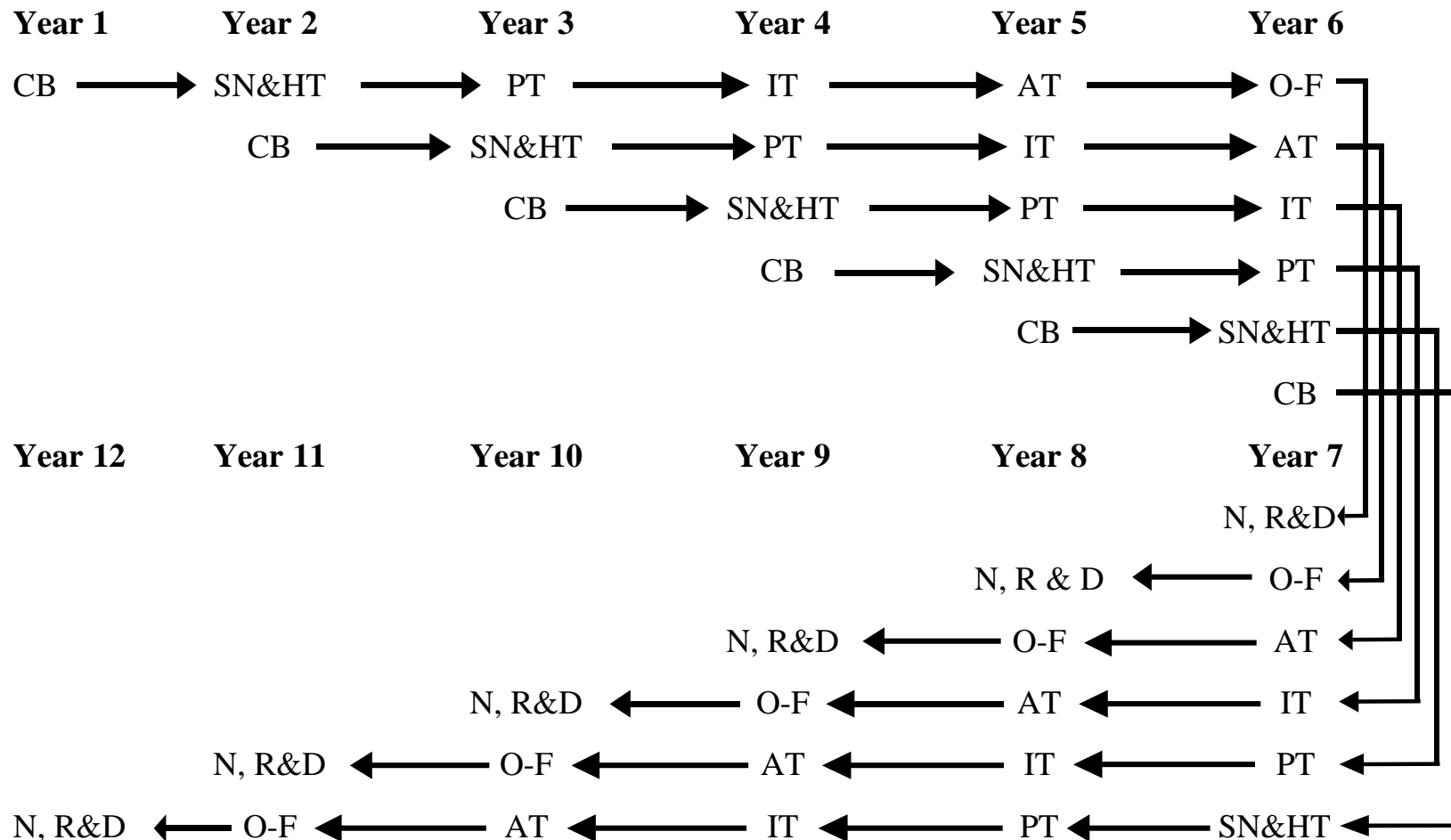
Your programme can include all 9 steps outlined above, or it can begin at Step 2 or Step 4 if you are collaborating with other breeding programmes. For example, if you receive seeds from another breeding programme, then you would start at Step 2. If you receive tissue cultures of improved clones from another breeding programme or you are evaluating your local germplasm, then you would start at Step 4.

After a clone has been named and released, we generally call it a **cultivar**.

Although Figure 1 may look complex, it does in fact oversimplify a recurrent selection breeding programme, since it presents only one cycle. Recurrent selection is a long-term, continuous process with a new cycle of breeding (a new Crossing Block) started every year and with the chance for new and better clones ready for release every year.

Figure 2 tries to capture the more complex picture. It is important that a breeding programme be continued for long enough to benefit from the investments made in the early years.

Figure 2. Breeding is a long-term, continuous process with a new Crossing Block started every year. In this flow chart, On-Farm Trials are grown for only one year. It is better to grow On-Farm Trials for several years in several locations.



CB = Crossing Block
 SN = Seedling Nursery
 HT = Hill Trial
 PT = Preliminary Trial

IT = Intermediate Trials
 AT = Advanced Trial
 O-F = On-Farm Trial
 N, R & D = Name, Release & Distribute

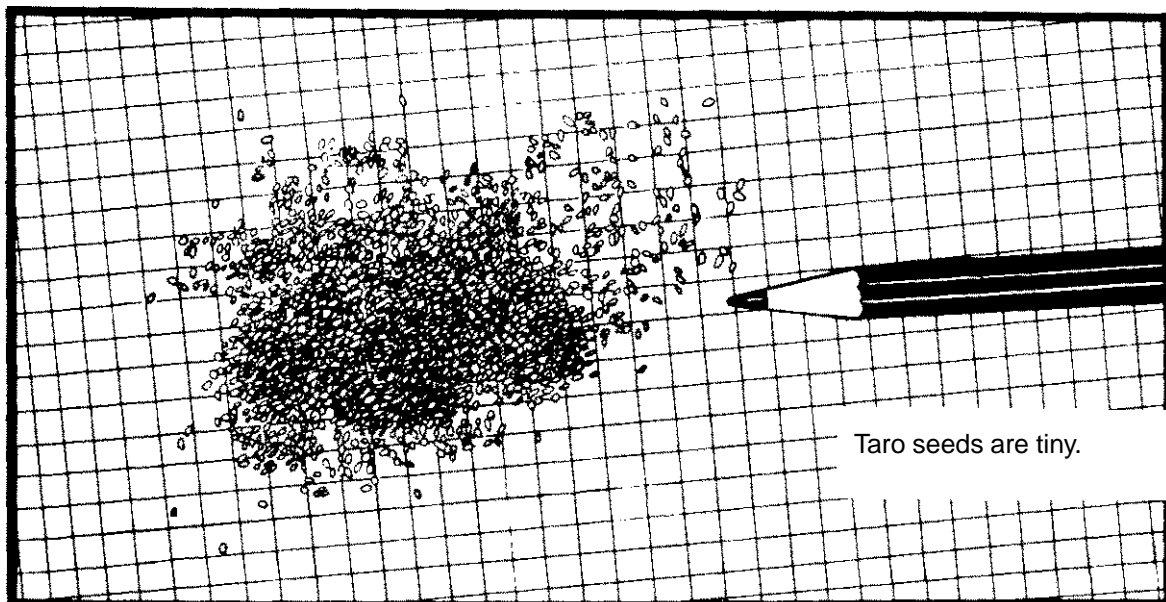
Step 1—Plant Crossing Block To Provide Improved Population Of Seeds

Locate your Crossing Block in a field where the soil is high in fertility and organic matter, and where you can water the plants whenever rainfall is not adequate for maximum growth.

Generally you will want to plant your Crossing Block conveniently nearby and make controlled hand-pollinations to insure that specific cross-combinations are represented in the seeds you produce.

If there are naturally, occurring insects that pollinate taro in your country, you could plant parent clones in a Crossing Block isolated from other flowering taro plants and allow them to be open-pollinated by these insects. However, this will permit a significant amount of self-pollination between inflorescences of the same clone, and this self-pollination is usually undesirable. Therefore, you should use open-pollination only if you do not have enough time and labour for hand-pollination.

With open-pollination, you know the female parents of seeds, but not the male parents. With controlled hand-pollination, you know both the female and male parents of the seeds.



Taro seeds are tiny.

The Crossing Block

Taro flowers best during the rainy season. Therefore, summer is the best time for producing seeds in the Southern Hemisphere. Also, the high relative humidity typical of this season promotes abundant pollen production.

In Western Samoa, we like to plant the Crossing Block during the first week in November, but some years we must delay planting when the rainy season is late coming. About 2 months after planting, we apply gibberellic acid (GA) to promote flowering. Flowering begins about 2 months after GA application and continues for 3 months. This means that we are pollinating mostly during March, April, and May and harvesting seeds during April, May, and June.

In the Crossing Block, plant large, healthy headsets or suckers of the parent clones. Use a spacing wide enough to encourage vigorous growth and to permit you to walk around the plants while pollinating. We use 1.0 x 1.0 m or 1.5 x 1.5 m. The latter is better, if you have enough land. Usually, 5 to 10 plants of each clone are enough, although you may need more plants of sparse-flowering clones, clones that are poor pollen and/or seed producers, and clones that you plan to use in a large number of crosses.

Vigorous plant growth in the Crossing Block is essential. Why? Because rapidly growing taro plants which have not suffered water or nutrient stress produce more inflorescences, stronger inflorescences, and abundant, viable pollen. Therefore you should do everything necessary to grow large, fast growing plants in your Crossing Block. For example, mulch plants with grass, palm leaves, or old jute sacks (copra bags) and water plants whenever rainfall is not adequate. Fertilise the Crossing Block with N-P-K if soil fertility is not adequate for maximum growth.

Insects and diseases can reduce flowering and seed set. Therefore, you should regularly control them in your Crossing Block, especially armyworm (*Spodoptera*), taro hornworm (*Hippotion*), taro beetle (*Papuana*), and taro planthopper (*Tarophagus*) if it is particularly severe in your location. In Papua New Guinea, Solomon Islands, Hawaii, and some islands of Micronesia, you may need to control (*Phytophthora*), and in Papua New Guinea and Solomon Islands, you must control the devastating virus disease called alomae and bobone.

If you plant your Crossing Block before November, flowering will occur during December, January, and February, and you will find it very difficult to pollinate because of the heavy rains during these months.

Promoting Flowering

Many clones of taro do not flower naturally. In other clones, natural flowering is sporadic and not predictable enough for breeding. However, you can promote abundant, early flowering by applying a solution of gibberellic acid (GA) dissolved in water.

To make the solution, use either the technical grade GA (75% to 90%) or the commercial formulation, Pro-Gibb Plus (20% GA; trademark, Abbott Laboratories). Pro-Gibb Plus is much easier to handle and weigh because it is less hygroscopic and you are weighing larger quantities.

Since taro leaves are very waxy, a surfactant must be added to the GA solution at a fairly high rate. We use Agral at 2.5 ml/litre or Citowett at 0.36 ml/litre.

**CAUTION:
CITOWETT WILL BURN TARO
LEAVES IF IT IS NOT
MIXED VERY WELL
INTO THE SOLUTION.**

The best concentration of GA varies somewhat with the clone. Clones that never or rarely flower naturally usually require 500 ppm GA, whereas clones that occasionally or often flower naturally require only 250 ppm. We use 500 ppm, and this is a good concentration for you to try the first year. In following years, you can adjust the concentration according to how your clones behaved during the first year. If you did not get adequate flowering, then increase the GA concentration. If the plants went 'wild' and produced a large number of deformities and small weak inflorescences, then decrease the GA concentration.

Prepare the spray solution shortly before use. The best times for spraying are early morning or late afternoon, when no rain is expected. It is important to avoid rain because, to be effective, GA needs to stay on plants for several hours.

500 ppm GA = 0.56g/litre of
90% GA or 2.5g/liter Pro-Gibb
Plus.

**CAUTION: WHEN WEIGHING
PRO-GIBB PLUS ALWAYS SHAKE
THE CONTAINER VERY WELL
BEFORE MEASURING TO
DISTRIBUTE GA EVENLY IN
THE POWDER.**

To determine the amount of GA
Solution you need to make, multiply
the number of plants you plan to spray
X 35 ml/plant, if you are using a small
hand-pumped sprayer or X 50 ml/plant
if you are using a compressed-air
sprayer.

Apply the GA solution when plants have reached the 3 to 5 leaf stage. Apply GA only one time to each plant (unless it rains immediately after application; then it will be necessary to reapply the GA)

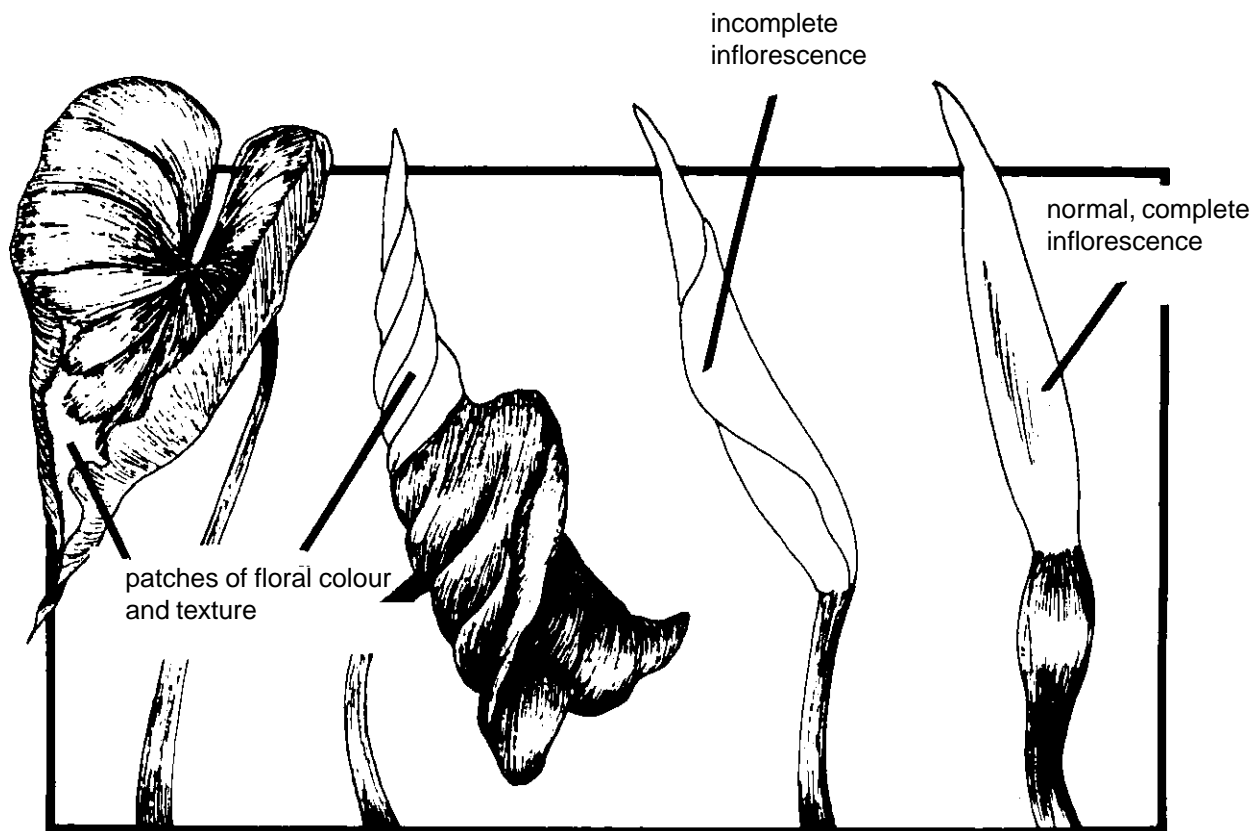
Apply the GA solution with a hand-pumped sprayer or compressed-air sprayer. Spray all the leaves lightly on both sides and spray a little of the GA solution into the cup formed by the petiole bases.

The time from GA application to the appearance of the first inflorescences ranges from 60 to 90 days depending upon the clone and the growing conditions. You can achieve simultaneous flowering of parent clones with divergent flowering times by staggering dates of planting and/or dates of GA application.

Before a plant produces an inflorescence, it produces a floral bract or flag leaf. Bract production occurs in both natural flowering and GA- induced flowering and is a sign to you that flowering will soon begin.

Some GA-induced deformities will appear before the normal inflorescences. These deformities include incomplete inflorescences that contain spathes but no spadices and patches of floral colour and texture on the leaves.

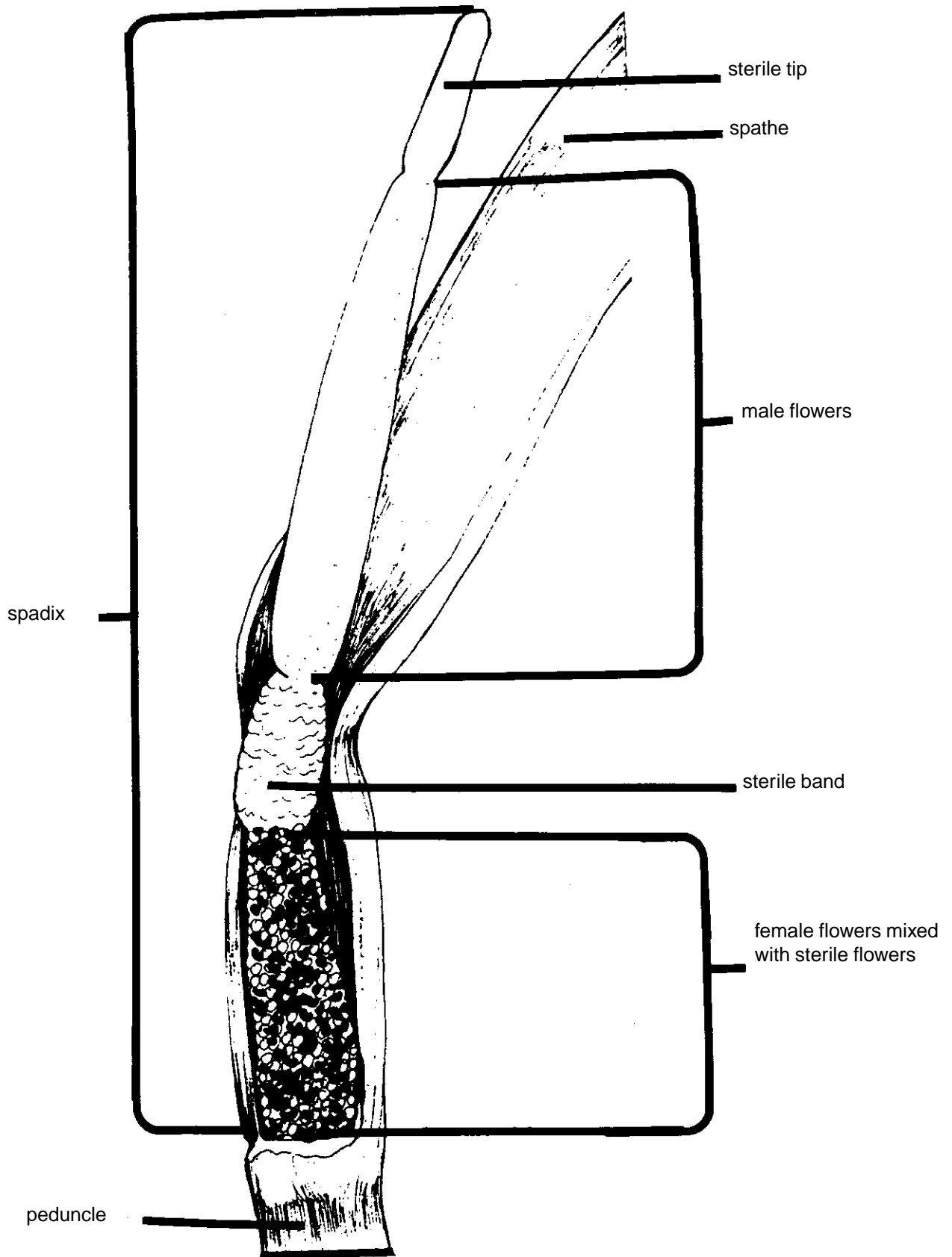
Also GA usually stimulates plants to produce more suckers than usual, as well as stolons, elongated petioles, and branching corms. Therefore, your GA-treated plants will look funny and be difficult to weed.



GA-induced deformities

Floral Biology

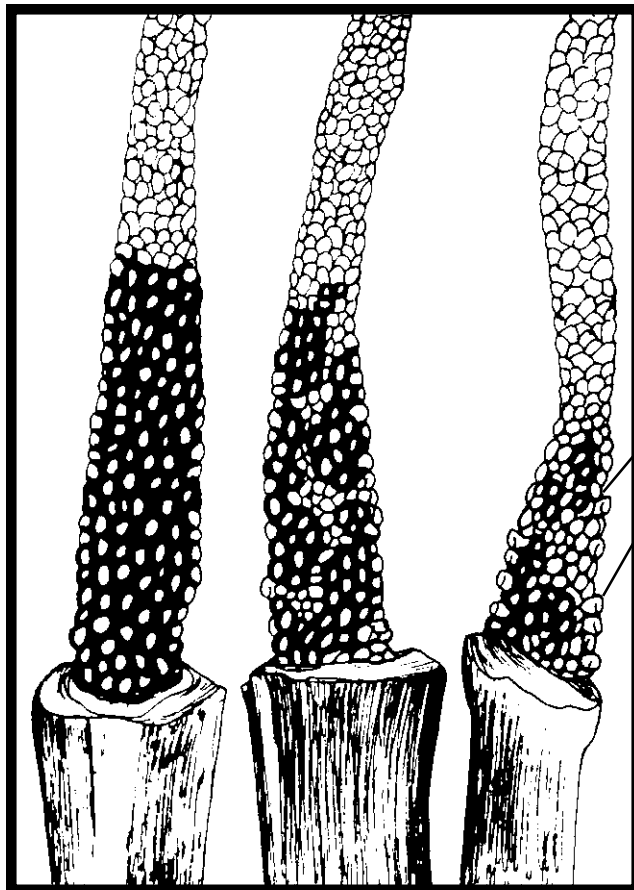
Inflorescence with part of
the spathe removed



The small, sessile (without a stalk) flowers occur in inflorescences. Each inflorescence consists of a spadix enclosed in a spathe. The male (staminate) and female (pistillate) flowers are in different locations on the spadix and are separated by a constricted band of sterile flowers (see sketch below). There is a sterile tip at the very top of the spadix, and there are also sterile flowers, in varying numbers, scattered among the fertile female flowers. You can easily distinguish the fertile and sterile female flowers. The fertile female flowers are green with distinctive stigmas, whereas the sterile flowers are ivory-coloured and usually taller than the fertile ones.

Depending on the location and clone, female flowers may be receptive (ready to be pollinated) one day before the male flowers in the same inflorescence shed their pollen (pollen shed), or the same day as pollen shed, or one day after pollen shed.

Here in the Pacific, female flowers are usually most receptive one day before pollen shed, and this is the best day to hand-pollinate. On this day the inflorescence has a strong aroma. Also, the base of the spathe is cracked open, and the constricted part of the spathe becomes loose around the band of sterile flowers. In nature this allows insects to reach the female flowers by flying through the crack or by crawling down from the male part of the spadix, past the band of sterile flowers. We call this the 'crack' stage. The following day (the day of pollen shed), the crack closes, and the spathe becomes tight around the band of sterile flowers.



sterile flowers

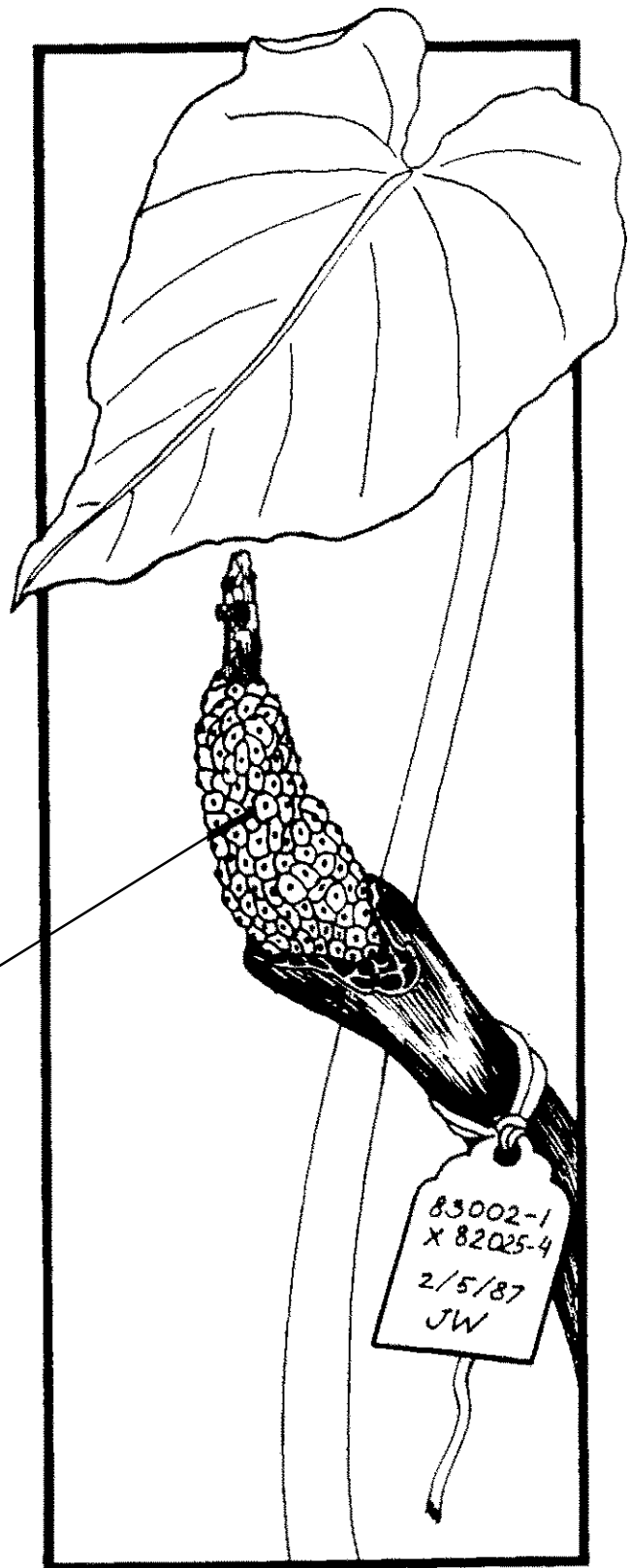
The female flowers are located at the bottom of the spadix and are mixed with a varying number of sterile flowers. In this sketch the spadix on the left has no sterile flowers in the band of female flowers, but the spadix on the right has many sterile flowers scattered among the females. The spadix in the centre is intermediate for number of sterile flowers. Because of the greater numbers of sterile flowers, the spadix on the right will produce the least seeds.

Pollinating insects occur in those countries where naturally-set seeds are common in farmers' fields (for example, Solomon Islands). The most likely natural pollinators are small flies, which are attracted to inflorescences by the distinctive aroma. In other countries (for example, Western Samoa), pollinating insects do not appear to be active, and the small quantities of naturally-set seeds that occur there are probably produced when rain washes pollen down onto the female flowers.

The fruit head is a cluster of densely packed berries. Each berry generally contains 1 to 10 seeds, but you may find as many as 35 seeds.

Seeds are tiny, usually less than 2 mm. long. When mature, they are ovate in shape, hard, and conspicuously ridged longitudinally. They germinate in 7 to 14 days with no apparent dormancy.

berry containing seeds



The fruit head is a cluster of berries

Controlled Hand-pollination

To carry out a controlled hand-pollination in taro, there are 6 steps:

1. preventing insect-pollination before hand-pollination,
2. emasculating,
3. pollinating,
4. preventing insect pollination after hand-pollination,
5. labelling, and
6. removing pollinating bag and replacing it with a fruit bag.

The purpose of Step 1 is to insure that the inflorescences that you plan to hand-pollinate are protected from Insect-pollination. Therefore, you should carry out Step 1 if you are working in a location where insect pollinators are present.

Why is it necessary to prevent insect-pollination? Because insects can self-pollinate by carrying pollen between inflorescences on the same plant and between inflorescence on different plants of the same clone. And in taro breeding, self-pollination is generally undesirable.

Even in countries where Step 1 is not necessary to prevent insect-pollination, bagging the male parent can help prevent light rains from washing off pollen. Therefore, you may want to carry out this step if early morning rains are frequent in your location.

NOTE: If you are producing seeds for a genetic study, it is important that you eliminate ALL possibility of insect-pollination. Therefore, you should bag inflorescences before and after hand-pollination, even if insect-pollination appears to be rare in your location.

Protect the inflorescences on both the female and male parent plants. To do this, select inflorescences that are large and full, but that still have their spathes closed around the male portion of the spadix. Cover these inflorescences with an insect-proof, cloth bag (pollinating bag) and close it at the bottom by tying it around the peduncle with a twist-tie or string.

Bagged inflorescences are easier to find at pollinating time if you mark plants with brightly-coloured ribbons, which you remove after pollinating.

Sew your own pollinating bags from light-weight, but stiff cloth or very, very fine mesh. Remember that the insect pollinators are SMALL flies. The very best material is the thrip-proof mesh that is often used to construct quarantine houses and insect rearing cages. Ask the entomologist in your research station for some.

Emasculate means to remove the male part of the spadix before pollen is shed. Emasculating and pollinating, are carried out at the same time.

The best time to pollinate is in the morning between seven and noon, although on cool, cloudy, or rainy days, you may have to start later in the morning because pollen is shed later.

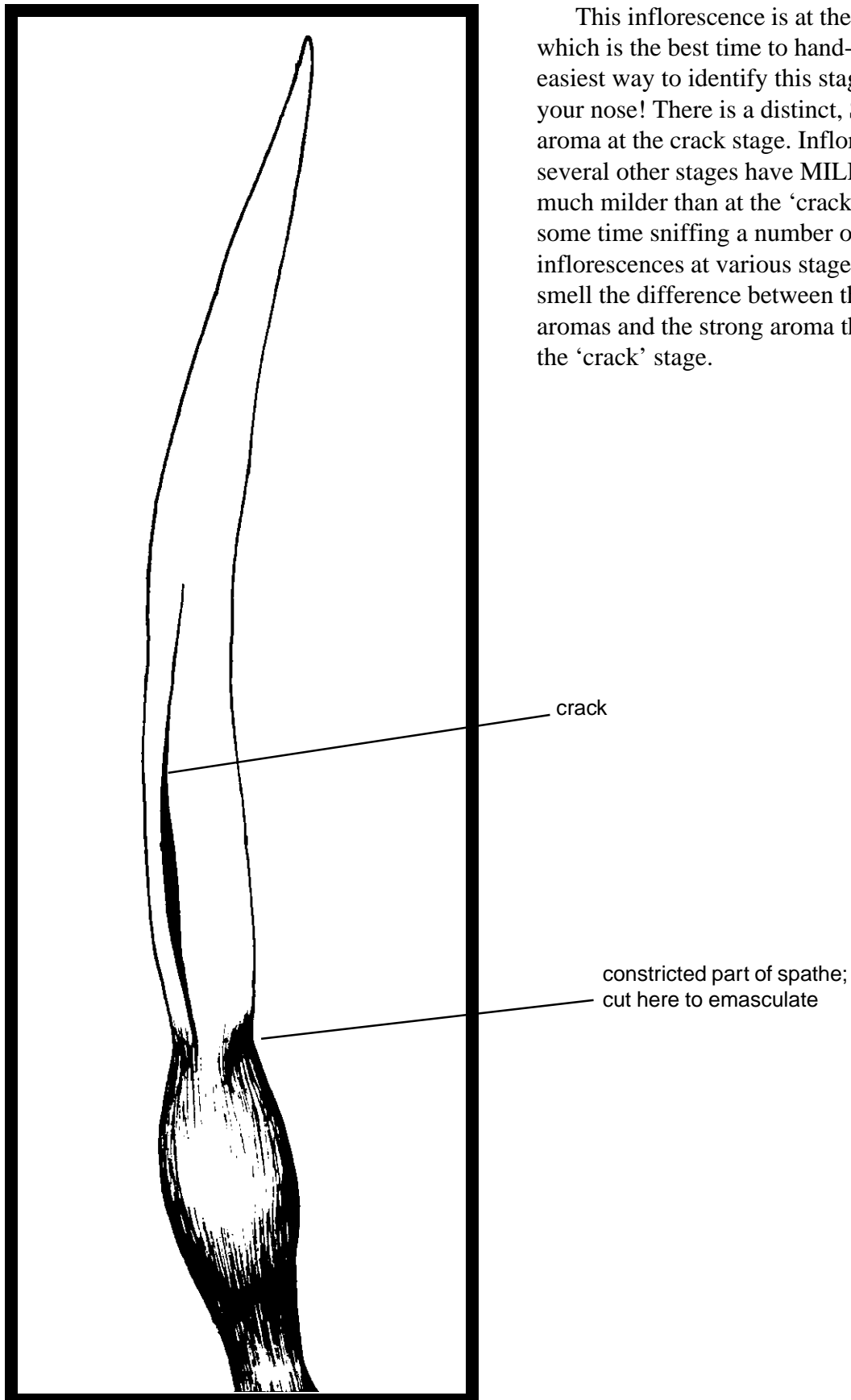
On a male-parent plant, find a bagged inflorescence that has pollen. Taro pollen is extruded in clumps and is easy to see. Cut off the entire inflorescence and carry it to the female-parent plant. Carry it carefully so that you do not shake off the pollen.

On a female-parent plant, choose an inflorescence that is at the ‘crack’ stage and gently remove the bag covering it. Then emasculate this female inflorescence. To do this, cut off the male portion of the spadix by cutting through the band of sterile flowers that separates the male flowers from the female flowers. You can easily locate this band of sterile flowers without removing the spathe, because it is under the constricted area where the green basal tube of the spathe joins the yellow top of the spathe.

Next, carefully cut away the spathe surrounding the female portion of the spadix. Be careful not to damage the peduncle. Remove the bag from the male-parent inflorescence and cut off the male portion of the spadix (in the same way that you emasculated the female inflorescence). Hold the male portion by the sterile tip and carefully remove it from the spathe. Then gently rub it over the female flowers. Since sterile flowers are usually taller than fertile females, concentrate on applying pollen to the fertile female flowers. Apply the pollen evenly to cover all the fertile female flowers, since a fruit with only a few berries will not develop. Check inside the spathe section that you removed from the male spadix. Often it contains pollen that you can also dust over the female flowers.

For emasculating and pollinating, you will need a knife with a small, sharp blade.

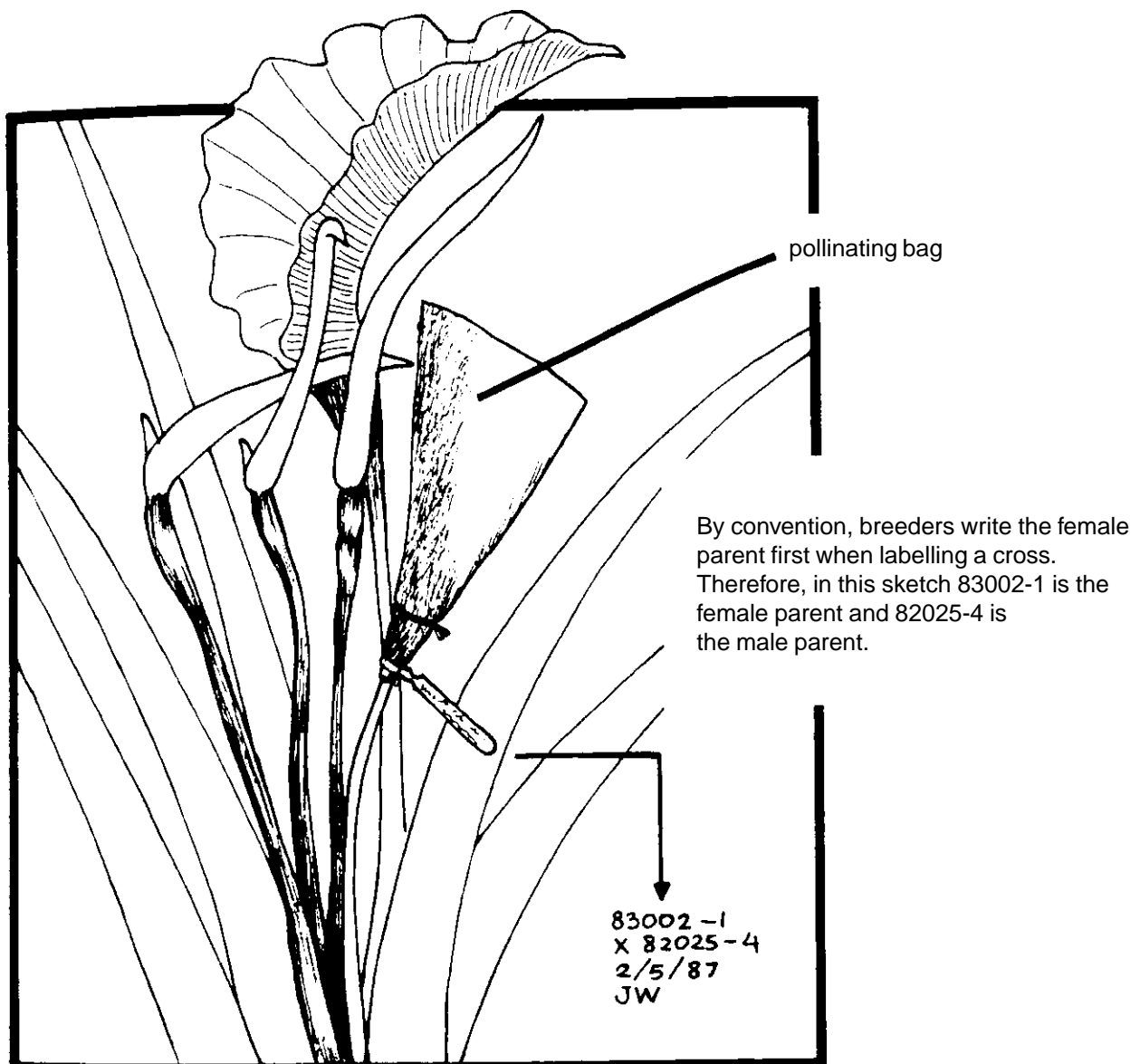
This inflorescence is at the 'crack' stage, which is the best time to hand-pollinate. The easiest way to identify this stage is to use your nose! There is a distinct, **STRONG** aroma at the crack stage. Inflorescences at several other stages have **MILD** aromas, but much milder than at the 'crack' stage. Spend some time sniffing a number of inflorescences at various stages until you can smell the difference between these milder aromas and the strong aroma that identifies the 'crack' stage.



After you have finished a pollination, carefully cover the female inflorescence with the pollinating bag. This prevents insect pollination and helps keep light rain from washing off the pollen you have applied. It also helps to maintain high humidity around the female flowers, and this high humidity increases the percentage of successful pollinations. Therefore, you should carry out this step whether or not you have insect pollinators.

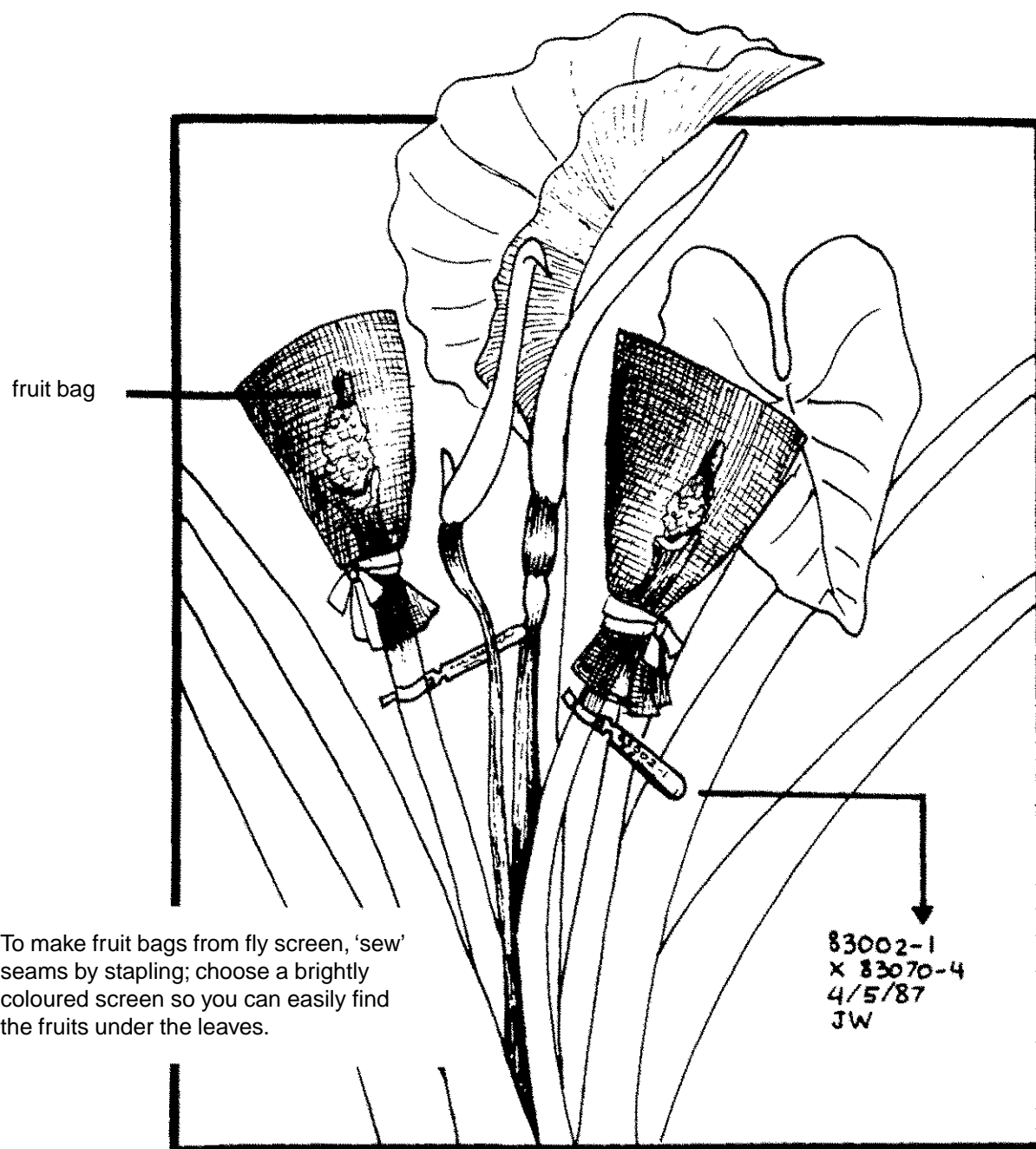
Label each pollination with the date and the names or numbers of the parents. Attach the label to the peduncle of the inflorescence that you pollinated. For labeling we use plastic Diamond-Lox labels because they are easy to attach and are long-lasting in all weather (see Supplies).

To reduce contamination by undesired pollen, wash your hands or clean them with a damp cloth each time you change to a different male parent.



Three days after pollinating, the female flowers are no longer receptive, and you can remove the pollinating bag. You should not leave on the pollinating bag longer than 5 days because it keeps the developing fruit too hot and damp.

In Western Samoa we have problems with armyworms eating the developing fruits. Therefore, when we remove the pollinating bag, we replace it with a fruit bag made from plastic fly screen. This fruit bag keeps out most (although not all) armyworms and still allows enough air. And you can see or feel through the fly screen to determine when the fruit is ready for harvest.



Your success rate for hand-pollination is affected by the weather, the health of the plants, the parents used, and your skill at pollinating. In the IRETA programme, usually more than 75% of the inflorescences we pollinate develop into fruit heads. Here are some hints for improving your pollinating success, especially when conditions are not perfect:

1. When first learning to pollinate, write on the pollinating label the initials of the person pollinating, time of day, remarks about the weather (very hot, rainy, etc.) and other comments that will help you improve your pollinating skill.
2. Unless you want a particular maternally-inherited character, you can try using each clone as both a male parent and a female parent. However, clones that are very poor pollen producers should be used as female parents only.
3. If you do not have enough inflorescences, you can use the same inflorescence as both a male and a female parent. When you collect pollen, cut off only the male portion of the spadix (rather than the whole inflorescence), and use the remaining female portion of the spadix as a female parent for another pollination. The female flowers will still have some receptivity even though they are one day older than the 'crack' stage. NOTE however, that some self-pollination may have occurred before you cut off the male portion.
4. When you emasculate inflorescences on female parents, you can save the male portion of the spadix as a source of pollen for the next day. Label the male portion of the spadix with the clone number, and keep it inside its spathe covering by pulling the label tight around the spathe. Take these male spadices into the lab, wrap each one with a damp paper towel and place in a plastic bag to maintain high

relative humidity. Some, but not all, of them will shed pollen the next morning.

5. Some inflorescences produce very little pollen or no pollen. Such poor pollen production also occurs sometimes in naturally produced inflorescences and therefore is probably not related to GA application. Some poor pollen production may be genetic, but some is definitely related to environmental stress, especially drought stress and low relative humidity. When relative humidity is low, many clones do not shed pollen even when soil moisture is adequate.

We know that in some ornamental aroids, maximum pollen germination and seed set is achieved when both pollen and female flowers are maintained at high relative humidity before and after pollination. This is probably true for taro also. During periods of low relative humidity, you can try exposing pollen to high humidity by harvesting inflorescences from male parents one or two days before pollen shed. Take them into the lab and place the peduncles in a container of water. Wrap each inflorescence with a damp paper towel and cover with a plastic bag. Similarly, you can increase the relative humidity around the female flowers after pollinating by wrapping a damp paper towel around the female portion of the spadix before covering it with a **pollinating** bag. NOTE that **plastic** bags would keep the relative humidity higher, but they get too hot inside when used in the field.

6. Fruit heads will not develop unless a number of berries have been fertilised. Therefore, it is important that you have enough pollen to cover each female flower. If inflorescences on your male parent each have only a small amount of pollen, use several of them to pollinate one inflorescence on the female parent.
7. In contrast, if a male-parent inflorescence is covered with a large quantity of pollen, you can use it to pollinate 2 female spadices.

Harvesting Seeds

A fruit head is ripe and ready to harvest when the berries become soft and the peduncle turns yellow and shrivels. This is usually 30 to 45 days after pollination. The young berries are usually dark green and change to a lighter green or yellow-green as they ripen. However, the berries on a few clones ripen orange.

If the peduncle becomes soft and fall over in less than 2 weeks, then your pollination was not successful.

It is important that you check your Crossing Block for ripe fruit heads every day, because a heavy rain can wash all the seeds from soft berries onto the ground. To avoid losing seeds this way, we harvest fruit heads when the berries are just beginning to soften and place them in the lab to finish ripening. We harvest each fruit head with a long peduncle, which we place in water like a bouquet.

Another danger is to let the ripe fruit heads dry up. It is very difficult to wash the seeds out of dry, hard berries.

Pick each hand-pollinated fruit head with its label. If you are using open-pollinated fruit heads, label them with the same name or number of the female parent.

In the lab, extract the seeds by washing in water. We use the following method: Remove the berries from the core of the fruit and place them in a very fine screen or strainer. **Caution: The Screen Must Be So Fine That The Small Seeds Do Not Wash Through.** We use a very fine tea strainer made with plastic mesh. Crush the berries by rubbing them GENTLY (do not crush the seeds!) against the sides and bottom of the screen. Hold the screen under the cold-water tap and stir the crushed berries with your finger to wash out the fruit pulp. Dump the seeds and remaining fruit pulp into a small glass container and add water. The heavy, viable seeds will sink to the bottom. The lightweight seeds and most of the fruit pulp will float to the top, and you can pour them off and discard. In our experience most of these lightweight seeds will not germinate. A few of the are viable, but it is usually not worth the time it takes to separate them from the fruit pulp unless you are very short of seeds.

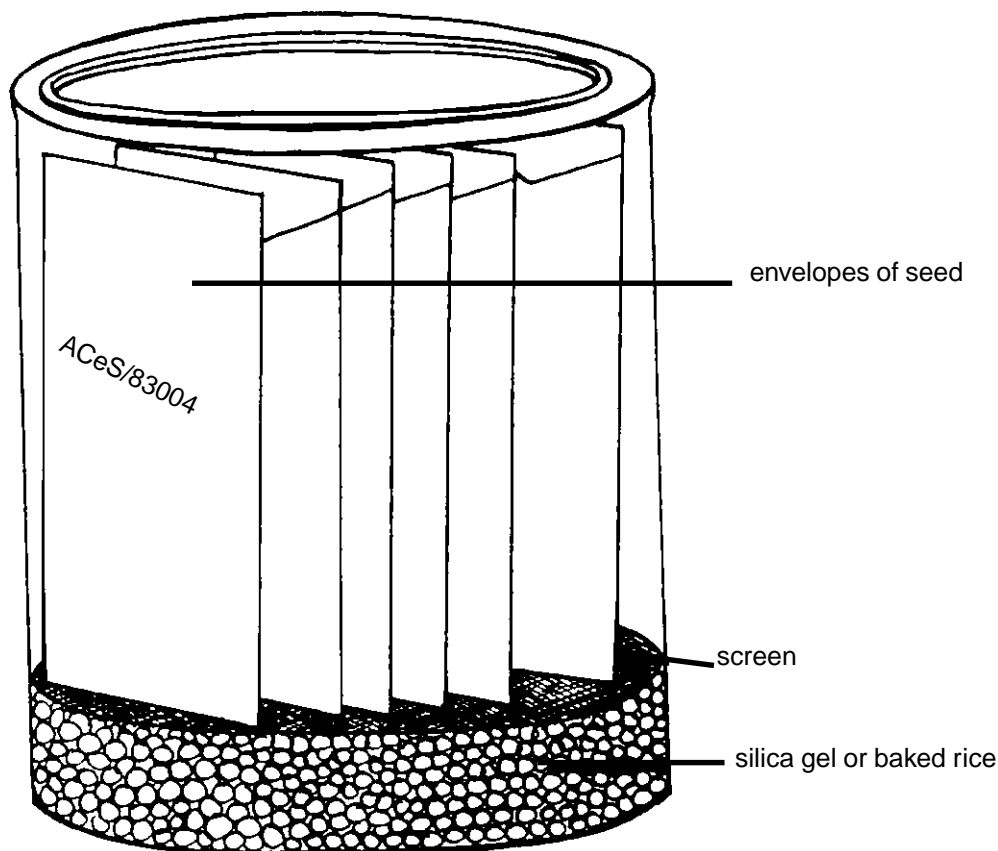
Repeat the steps of crushing and floating several times until the seeds are clean. Then pour the heavy seeds that sink to the bottom into the screen, tap gently to shake off as much water as possible, and place seeds on filter paper in an uncovered petri dish. Leave the petri dish in a well aerated location in the lab until seeds are dry. Remember to place the pollinating label in the petri dish of seed.

Put the dry seeds into labeled envelopes and store. You can put seeds from different hand-pollinated inflorescence into one envelope if they have the same female and male parents, or, in the case of open-pollinated seeds, if they have the same female parent.

Seed Storage

Taro seeds will store at least 2 years in a desiccator in the refrigerator. We make an inexpensive desiccator from a tin or glass jar with a tight fitting lid. In the bottom of the tin or jar we place a layer of the desiccant, silica gel. The indicating type is best, since you can see by the change in colour from blue to pink that it needs drying.

If you do not have silica gel, you can use uncooked rice that has been baked in a low-temperature oven until very dry and light brown. Try to find at least a small quantity of indicating silica gel to mix with the baked rice so you can see when the rice needs re-drying. Place a piece of screen over the desiccant before adding the envelopes of seeds.



You can make an inexpensive desiccator for storing seeds

Record Keeping

Record keeping is an important part of your breeding programme. With some methods of breeding, for example pedigree breeding, it is essential that you be able to trace the pedigree of a clone back through many generations. This is generally not true when using recurrent selection to breed most crops. However, since taro breeding is a new science, we need to learn as much about taro genetics as possible. Keeping records of pedigrees helps us to do this, and that is why we keep individual crosses separate and labelled.

Different breeders prefer different methods of recording pedigrees. Here is the one that we use:

When seeds are harvested from the Crossing Block, each individual cross is assigned a family number, for example, ACeS/86001. ACeS indicates seeds(S) or taro (Ce=*Colocasia esculenta*) produced at Alafua (A), and 86001 is the family number (86 = 1986, the year the seeds were harvested). When we harvest the seedlings in the Hill Trial, we assign a clone number to each seedling that is selected to go into the Preliminary Trail. This clone number consists of the family number followed by -1, -2, -3, etc., for example, 86001-1. This clone number is a PERMANENT number, and does NOT change from year to year.

Keep handwritten records in a bound record book – do NOT risk typing errors.

<u>FAMILY NO.</u>	<u>PARENTS</u>	<u>DATES POLLINATION</u>
<u>1986</u>		
ACeS/86001	82014-31 x 82006-137	3/6/86
ACeS/86002	82015-53 x 83012-134	4/6/86
ACeS/86003	82006-177 x 82007-100	29/5/86
ACeS/86004	82004-28 x 82015-53	30/5/86
ACeS/86005	Niue x 82014-88	12/6/86
ACeS/86006	82025-11 x 83006-134	3/6/86
ACeS/86007	83011-1 x 82014-116	3/6/86
ACeS/86008	82014-166 x Paepae	13/6/86
ACeS/86009	84014-83 x 82012-138	12/6/86
<u>1987</u>		
ACeS/87001	83002-3 x Ce 48	29/4/87
ACeS/87002	84018-1 x 83002-22	6/4/87
ACeS/87003	Manua x 83002-56	7/4/87
ACeS/87004	83004-10 x 83003-24	19/5/87
ACeS/87005	83004-10 x 84013-24	14/4/87

An example of a breeding record

Step 2—Plant Seeds And Rear Seedlings

Taro seeds are very small, and young seedlings are delicate and very slow growing. Careful attention to them is necessary for success.

Sow seeds about 4 months before the beginning of the rainy season. Petri dishes or small pots covered with glass can be used as containers for planting seeds. We make inexpensive pots from aluminum beer tins. We cut off the top of each tin, then punch a drainage hole in the bottom, and cover with one half of a petri dish.

Soak containers and lids in diluted Clorox or other household bleach containing sodium hypochlorite to sterilize them.

Fill containers to within 1 or 2 cm of the top with STERILIZED, free-draining potting mixture to which you have added fungicide to retard damp-off. For potting mixture, we use a mixture of top soil, washed RIVER (not beach) sand, and peat.

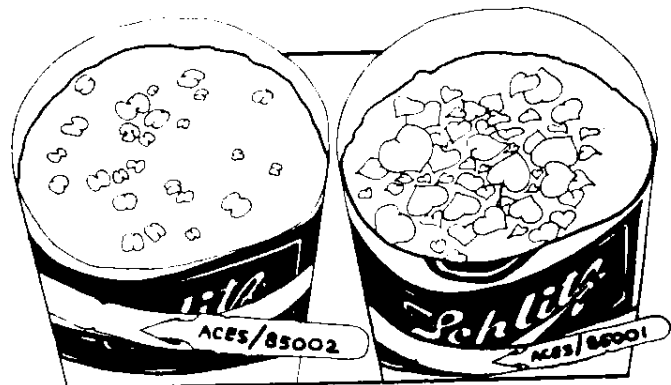
Dust seeds with fungicide. Scatter the seeds onto the soil surface (do not cover with soil), gently water, and cover containers with lids. Lids are important because they keep the uncovered seeds from drying out. Place the

covered containers in a warm place with light for part of the day. Temperatures of 25-28°C and 12 hours light give us good germination. Germination begins about 7 days after sowing.

To help reduce damping-off of seedlings, water with sterile water. Sterilize by boiling, then cool. Keep soil damp, not wet.

Seedlings are ready for transplanting when their roots are 1 to 1.5 cm long and cotyledons are fully expanded, generally 14 to 21 days after sowing. Transplant them into “Jiffy-7” pellets or small pots filled with sterile soil. Place them in a warm, shady location, and water as necessary. Gradually remove shade so that seedlings are adjusted to full sunlight before they are transplanted into the field.

Aluminium beer tins make good containers for germinating seeds



Step 3–Transplant Seedlings To The Field

Seedlings are ready for transplanting into the field when they are 10 to 15 cm high and have 3 to 5 leaves, which is about 4 months after sowing seeds. You should remove nets from “Jiffy-7” pellets as you transplant to prevent restricted corm development.

Transplant seedlings to the field at the spacing most commonly used by farmers in your location.

Steps 4 through 7–Evaluate And Select Clones

In these steps, you evaluate the breeding clones in a series of 3 trials located on the research station, followed by trials in farmers’ fields.

At the end of each trial, you must make decisions whether to select a clone for further trial, or to discard it, or to use it as a parent in the Crossing Block. Usually, you select 10 to 50% of the clones for further trial.

In Preliminary Trials you have large numbers of clones, but each clone is represented by only a few plants. In Intermediate and Advanced Trials you have fewer clones, but more plants in each clone. For instance, in a Preliminary Trial you might have 500 clones with 3 plants/clone, compared to an Advanced Trial with 15 clones and 5 plants/clone/replication, 5 replications. With the small number of plants/clone in Preliminary Trials, it is not possible to judge very accurately such characteristics as yield. That is why we use subjective ratings during these trials and do not begin to actually count and weigh yield until the Intermediate Trials.

Which characters should you evaluate when selecting clones? This will depend on the goals of your breeding programme, but to give you some ideas, I have included in Table 1 the characters that we evaluate in each trial in the IRETA breeding programme.

NOTE that the number of plants/clone given in Table I are minimum numbers. It would be MUCH better to have larger numbers of plants/clone in each trial, for example in the Advanced Trial, 10 plants/rep (planted in 2 adjacent rows of 5). But this is possible only if you have labour and supplemental water for extra manipulation.

Conducting Trials

Here are some pointers for conducting these trials:

1. Trial Conditions. Ideally, trials should be carried out in as many sites as possible, but practically we are often limited to one or two sites. Therefore, choose your trial sites carefully to include as many as possible of the relevant biological and physical constraints faced by farmers. In other words, you should carry out your trials under conditions similar to those faced by farmers.

Do not make the common mistake of conducting your trials under optimum conditions by adding fertiliser and water, controlling all pests and diseases, etc. If you do, you will end up selecting breeding clones that perform well under optimum conditions but may perform poorly under the farmers' less-than-optimum conditions. For instance, if farmers do not irrigate their taro, you should not irrigate your trials. If you predict that in 5 or 10 years many farmers will be forced to grow their taro on low fertility soil, then you should grow your trials without adding fertilizer.

Obviously, there are many times when you must break this rule in order to accomplish your breeding goals. For example, if you are selecting for *Phytophthora* resistance, you might need to apply small quantities of overhead irrigation to wet the leaves and maintain high relative humidity, in order to encourage disease spread.

2. Spacing. In your trials, you should use the spacing most commonly used by farmers in your location. For example,

most farmers in Western Samoa plant at 1 x 1 m or 1.5 x 1.5 m, whereas some commercial farmers in Fiji, plant at a closer spacing.

3. Wetland Conditions. Do not assume that breeding clones that perform well in upland/rainfed conditions will also perform well in wetland conditions. In locations, such as the Cook Islands, where a significant amount of the taro is grown in wetland conditions, you should plant trials in wetland as well as upland/rainfed conditions.

4. Disease and Pest Control. In your trials, you should normally NOT control the disease, insects, or nematodes to which you are selecting resistance, even if farmers do use control measures. However, if you are NOT evaluating your breeding clones for certain pests and diseases, you should control them in your trials if the damage they cause will obscure the characters you are evaluating. For example, we control armyworm and hornworms when populations are high.

If you are evaluating for dasheen mosaic virus resistance, do not spray your plots with any insecticides that will control Aphids, which are the insect vectors of this virus. Likewise, if you are evaluating for alomae and bobone, do not control planthoppers (*Tarophagus proserpina*) or mealybugs (*Planococcus citri*).

NOTE that the rules for Crossing Blocks and trials are different. You SHOULD protect plants in your Crossing Blocks against all damaging diseases and pests. But in trials, you should NOT control diseases and pests to which you are selecting resistance.

Table 1. Characters that we evaluate in each trial in the IRETA taro breeding programme.

TRIAL	PLANTING PATTERN	CHARACTERS
Seedling Nursery (SN)	“Jiffy-7” pots in trays; 1 plant/clone.	plant vigour (do not transplant weak seedlings into field); artificial inoculation to evaluate seedlings for <i>Phytophthora</i> resistance is possible in those countries where this disease occurs; it would be very useful to develop a method of artificial inoculation to evaluate seedlings for <i>Pythium</i> resistance.
Hill Trial (HT)	1 x 1 m between plants; 1 plant/clone.	plant vigour, dasheen mosaic virus score (average over season), golden virus score (average over season), corm rot (at harvest), rose beetle score, sucker number (immediately before harvest), stolon production (absent or present), corm bud colour, basal ring colour, corm yield (high, medium, low), petiole colour of clones selected in field.
Preliminary Trial (PT)	1 x 1 m between plants; 3 plants/clone	plant vigour, dasheen mosaic virus score (average over season), golden virus score (average over season), corm rot (at harvest), rose beetle score, sucker number (immediately before harvest), stolon production (absent or present), petiole colour, maturity (early, medium, late), corm bud colour, basal ring colour, corm yield (high, medium, low), corm smoothness, corm shape, specific gravity of clones selected in field.

Table 1 continued

Intermediate Trial (IT)	1 x 1 m between plants 3 plants/rep; 3 reps.	plant vigour, dasheen mosaic virus score (average over season), golden virus score (average over season), corm rot (at harvest), rose beetle score, sucker number (immediately before harvest), stolon production (absent or present), petiole colour, maturity (early, medium, late), corm bud colour, basal ring colour, number edible or marketable corms (count), weight edible or marketable corms (weigh), corm smoothness, corm shape, field selection, specific gravity, taste acidity, cooked flesh colour.
Advanced Trial (AT)	1 x 1 m between plants 5 plants/rep; 5 reps	same as IT except substitute corm dry weight for specific gravity; if possible nutritional factors should be measured at this stage.
On-Farm Trials	spacing & planting pattern determined by farmer; number of plants and reps determined by availability of planting material and land; best located in the middle of farmer's own taro production field.	plant vigour, dasheen mosaic virus score, (immediately before harvest), golden virus score (immediately before harvest), corm rot (at harvest), sucker number (immediately before harvest), maturity (early, medium, late), number edible or marketable corms (count), weight edible or marketable corms (weigh), with farmer deciding which corms are edible or marketable, ease/difficulty of harvesting as decided by farmer, eating quality as judged by farmer and family, farmer's overall opinion of breeding clones and farmer's choice of which ones he/she will grow again.

5. Local Checks. You must always include in your trials one or more local check cultivars. A local check is a cultivar that is presently popular and grown by many farmers in your location, or a cultivar that is presently recommended by the Extension Division. In our IRETA trials we include 3 local check cultivars, Niue, Paepae, and Manua. Why is it necessary to include a local check? Because the purpose of your trials is to identify breeding clones that are as good as, or better than, the cultivars that farmers are already growing. Local checks are treated like breeding clones in that they are randomised and included in all replications.

6. Susceptible and Resistant Checks. If you are evaluating your breeding clones for disease, insect, or nematode resistance, you should also include in your trials a susceptible check cultivar and a resistant check cultivar for each of these constraints.

A susceptible check is one that you know is susceptible to the disease (or insect or nematode). It helps you to determine whether the disease (or insect or nematode) is present in your trial and at what level. For *Phytophthora*, for instance, if your susceptible check is severely infected with the disease, then breeding clones in the same trial that show mild or no infection are most likely resistant to this disease, and you can select them for further trial. However, if your susceptible check does not become infected with *Phytophthora*, then you cannot evaluate the breeding clones for resistance, because the disease is not present in your trial, or the environment is not favourable for disease spread. If all rows of the susceptible check in the different replications show symptoms of the same intensity, then you know that the disease is uniformly spread in the trial.

A resistant check helps you to determine the LEVEL of resistance of each breeding clone. Is it the same, higher than, or lower than the resistant check cultivar?

In Intermediate, Advanced, and On-Farm Trials, treat the susceptible and resistant checks the same as the breeding clones by randomising them in each replication. In Hill and Preliminary Trials containing large numbers of breeding clones, repeat the susceptible and resistant check (and local checks) several times about once for every 10 breeding clones.

7. Spreader Rows. When evaluating for resistance, it is important to have high levels of the disease, insect, or nematode present in your trials so that you can distinguish between resistant and susceptible breeding clones. Therefore, locate your trials at sites where the disease, insect, or nematode is naturally epidemic.

You can also increase the amount of disease inoculum available to infect the trial by planting ‘spreader rows’ – rows of infected plants of a susceptible cultivar. But, be very careful to plant these rows so that all clones in the trial are an equal distance from the spreader rows. See Figures 4, 5, 6, and 7 for examples. Similarly, you can increase the number of insect pests in your trial with spreader rows of infected plants or plant parts, but this is usually not necessary with taro pests.

When you transplant your seedlings to the field, it is VERY important that you plant spreader rows for dasheen mosaic virus and ‘golden virus’. Dasheen mosaic virus and ‘golden virus’ are not carried in taro seeds, and all seedlings are free of virus until they have been infected by insect transmission. You can insure that there is plenty of inoculum nearby for the insects to vector to your seedlings by planting spreader rows of suckers and headsets of local cultivars which are infected with dasheen mosaic virus and ‘golden virus’.

8. Guard Rows. In all field trials, guard rows (often called border rows) are essential. All data plants (plants that you will observe, measure, and collect data from) must be surrounded by 4 other plants in order to eliminate the ‘edge effect’. See Figures 4, 5, 6, and 7 for examples. If you do not take the precaution of planting guard rows, then data plants on the edge of the plot will have more space and will be more vigorous and higher-yielding than plants in a typical field situation.

Extra guard rows can also be planted to ‘guard’ the trial from damage by tractors, trucks, and foot traffic. For guard rows, use planting setts that are the same size as most clones in that replication. For the Hill Trial, use SMALL planting setts of local cultivars so that the guard rows will not be too much more vigorous than the seedlings.

9. Fill-ins. For the same reasons that you plant guard rows, you should ‘fill in’ all missing plants that died soon after planting. For fill-ins, use a clone of *Colocasia* taro that is so distinctive it cannot be confused with your breeding clones or check cultivars. Or use *Xanthosoma*. Do NOT replant the breeding clone itself unless it died from ‘unnatural’ causes, like pigs or hoe-damage. And, of course, do not take data on the ‘fill-in’ plant.

10. Labelling and Mapping. At planting time, one of the most important precautions you should take to avoid errors is to properly label all clones and to map the seedlings, trials, multiplication blocks, and crossing blocks IMMEDIATELY after planting. Label stakes may be lost because a farm worker needs wood to start a cooking fire or a stake to scrape mud off his shoes! Make a permanent map of the trial layout and keep it in a safe place, so that clones can be accurately located even if every label is moved or destroyed. For orientation, include compass directions and permanent landmarks such as buildings or large trees.

In this permanent record, also write planting dates, harvest dates, dates of important operations like fertiliser and pesticide applications, dates when data were taken, spacing, number of plants per row, etc.

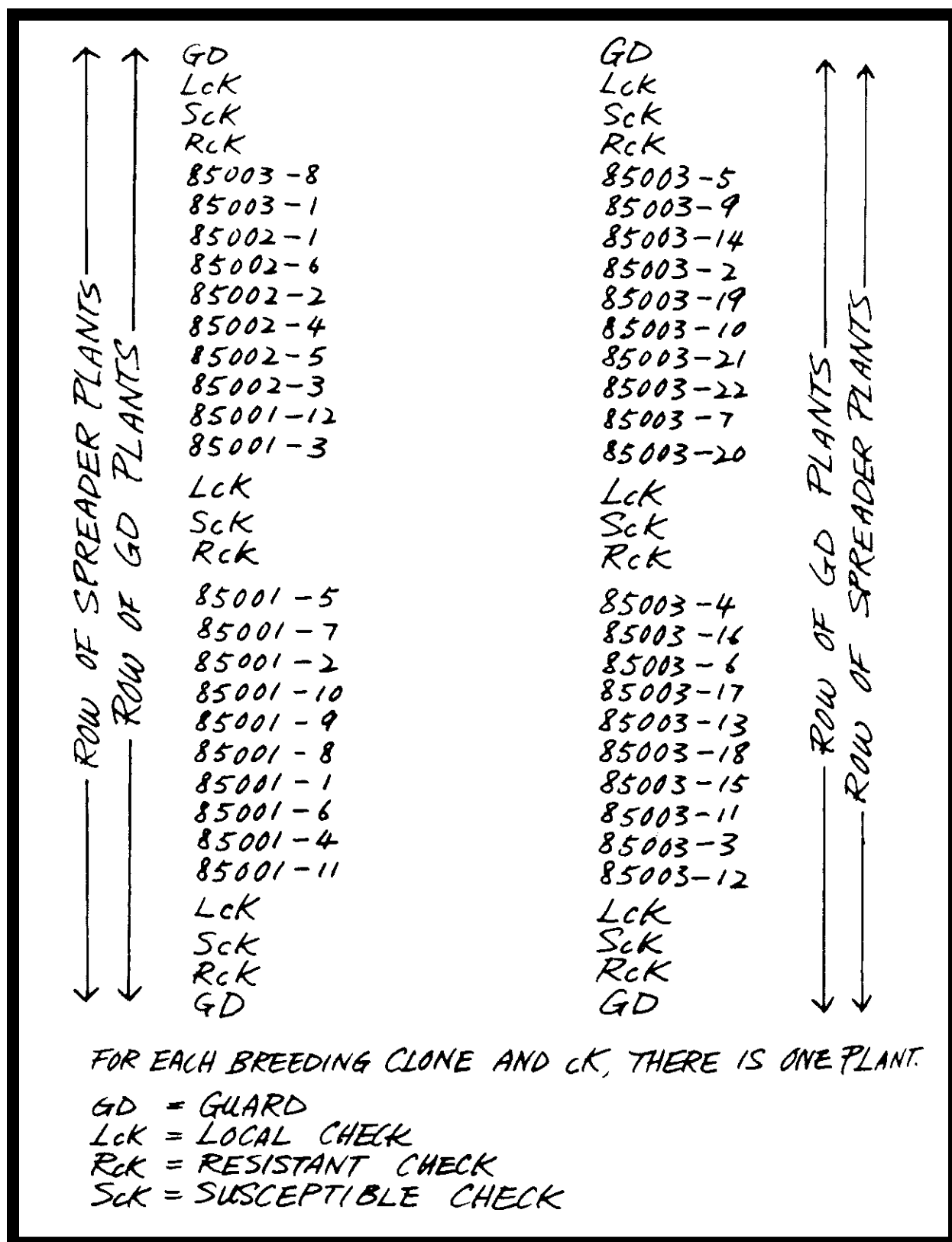


Figure 4. Example of the layout of **part** of a Hill Trial. Note positions of guard rows and spreader rows.

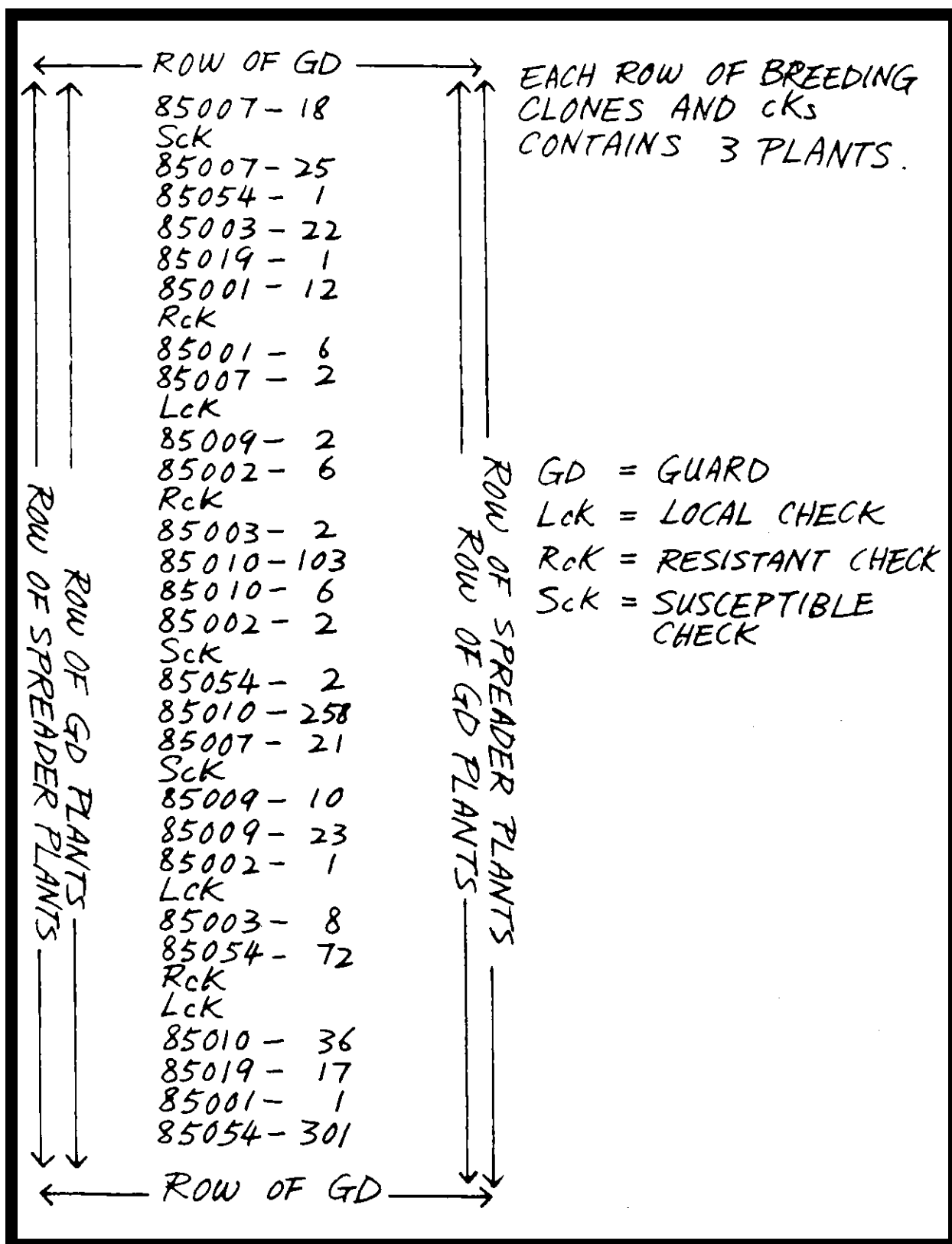


Figure 5. Example of the layout of a Preliminary Trial. Note positions of guard rows and spreader rows. Most of your Preliminary Trials will be larger than this one.

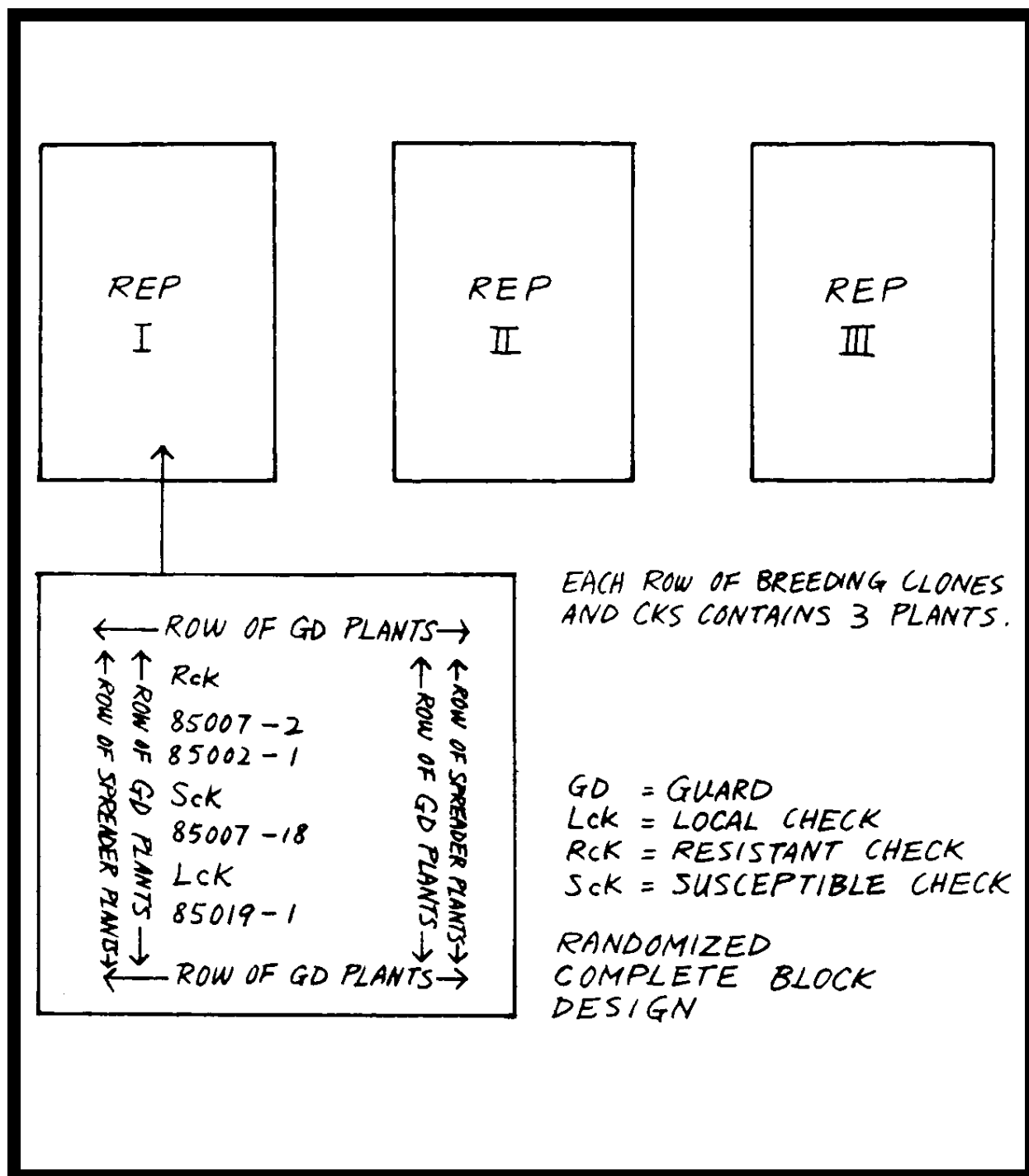


Figure 6. Example of the layout of an Intermediate Trial. Note positions of guard rows and spreader rows. Most of your Intermediate Trials will be larger than this one.

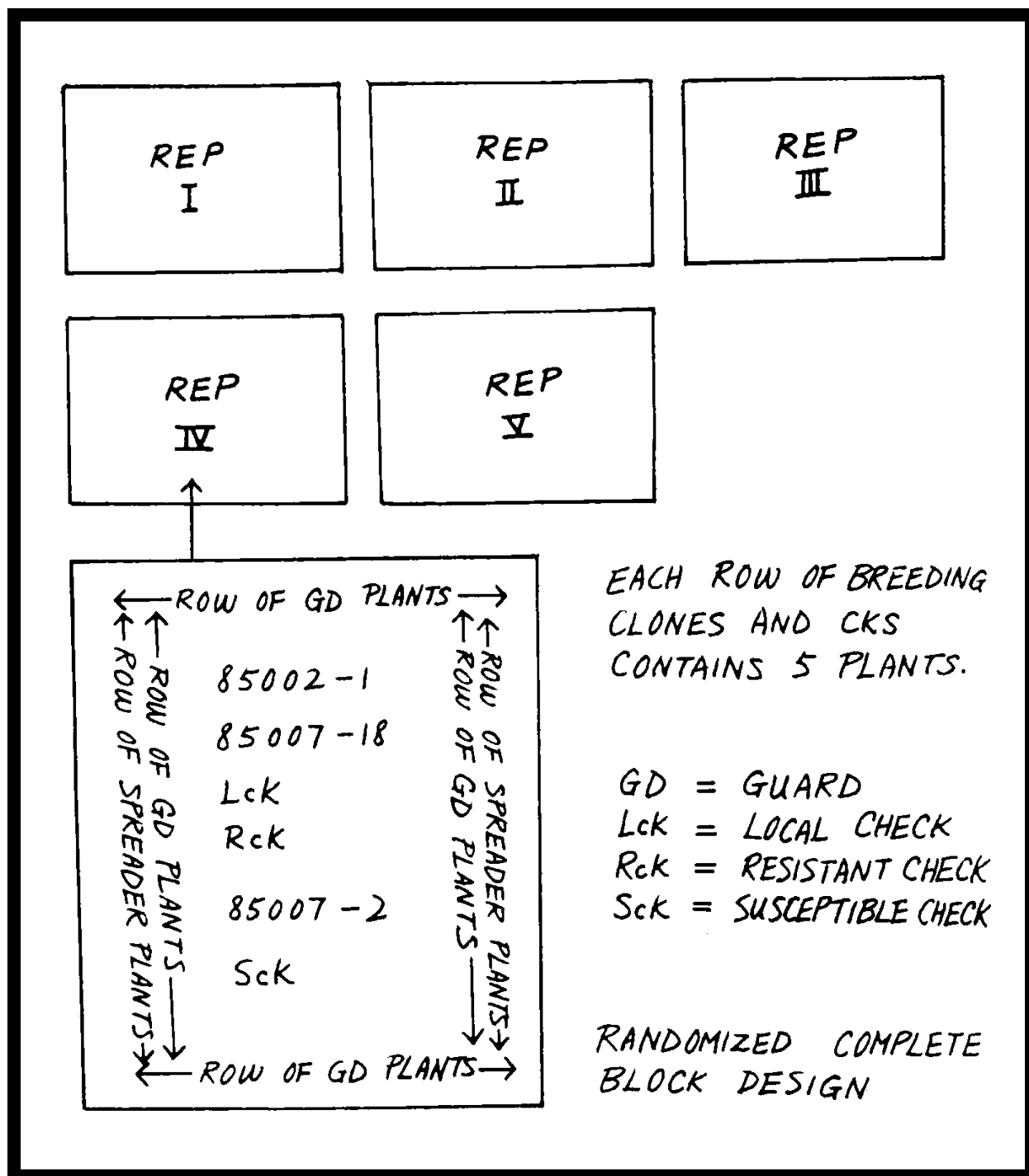


Figure 7. Example of the layout of an Advanced Trial. Note positions of guard rows and spreader rows. Most of your Advanced Trials will be larger than this one.

11. Selection. To save land and labour, it is essential that you discard undesirable clones as early in the trial sequence as you can accurately identify them. However, in the Hill and Preliminary Trials in which there are no replications and only one or a few plants of each clone, you must be careful when evaluating characters such as yield, which are strongly influenced by the environment. Keeping this caution in mind, you should try to identify clones that have poor yields and discard them, especially when your decision is reinforced by other negative characters such as disease susceptibility or too many suckers.

In these unreplicated trials, concentrate more on highly heritable characters such as bud colour, flesh colour, and broad categories of sucker number, such as too few, ok range, and too many.

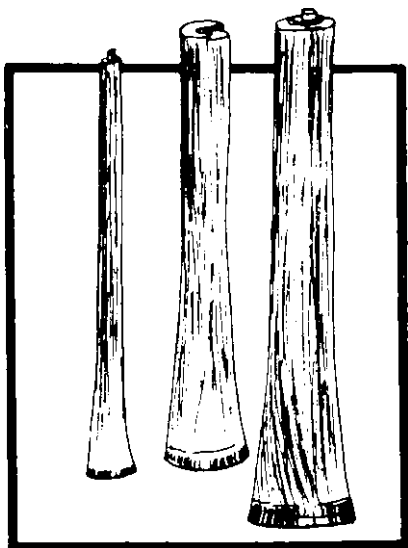
Concentrate also on discarding the poorest clones rather than selecting the best. For example, you may not be able to accurately identify clones that are resistant to *Pythium*, but you can discard any that show symptoms of this disease. Clones with obviously poor corm shape, deep sucker scars, or otherwise unacceptable corm appearance can be discarded in these early trials.

From each trial, you usually select 10 to 15% of the clones for planting in the next trial. Therefore, you must start with a large number of seedlings. For example:

2000	seedlings
1500	clones in HT
150	clones in PT
15	clones in IT
7	clones in AT
2	clones in On-Farm

12. Experimental Error. There are several ways you can reduce variability and thus experimental error in your trials.

When planting trials, use uniform planting material taken from plants that are the same age and are growing in the same location. Ideally, you would also use all headsetts or all suckers depending on which are preferred by your farmers. This is usually not possible, however, because of the slow rate of multiplication. Sort planting material into piles according to vigour and size, with size judged by the diameter at the base of the petioles. Plant the 'largest' in replication 1, the 'second largest' in replication 2, the 'third largest' in replication 3, etc.



small, medium, and large headsets

Throughout the growing season, apply all treatments uniformly to all clones in a replication. This includes treatments such as planting depth and style, fertiliser, pesticides, irrigating, and weeding.

Carry out operations like weeding by replication, and if you can not complete the entire trial at one time, break after completing a replication, not in the middle of a replication.

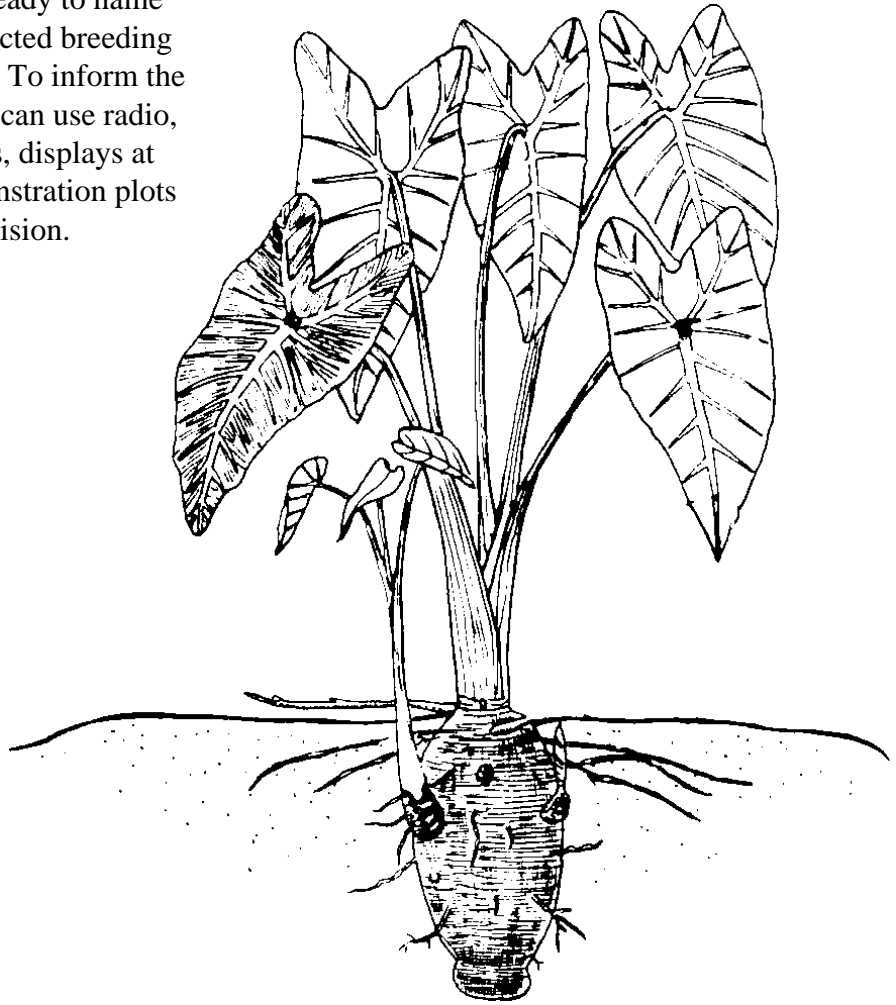
Each field worker treats taro a little differently, in terms of cutting planting material, planting, weeding, applying fertiliser, etc., and therefore, if more than one worker is applying a treatment, assign one worker to complete one replication. For example, when we plant our trials, one worker plants all of replication 1, another worker plants all of replication 2, etc. You must also take the same precautions when collecting data. If it begins to rain, for example, finish the replication before you stop. If more than one worker is collecting data, each worker must complete a replication; NEVER have different workers evaluate different clones within the same replication.



Small, medium, and large suckers

Step 8–Name And Release The Best Clones

After you have made your final selections in the On-Farm trials, you are ready to name and officially release the selected breeding clones as improved cultivars. To inform the public about this release you can use radio, newspaper, extension leaflets, displays at agriculture shows, and demonstration plots planted by the Extension Division.



Step 9–Distribute New Cultivars to Farmers

The breeder's job is NOT completed until the new cultivar has been distributed to farmers. This step requires large-scale multiplication of high quality planting material and collaboration with the Extension Division, farmer groups, schools, etc.

Multiplication

During each season it is necessary to multiply enough planting material for the next season's trials. And after a cultivar has been released, large amounts of planting material need to be multiplied for distribution to farmers.

Often it is necessary to depend on suckers produced in the trials for multiplication. Therefore, it is necessary to 'store' and 'grow' suckers and headsets in the soil from the time you harvest one trial until the time you plant the next trial. This varies from 2 to 6 months. Unfortunately, this storage time is usually during the dry season, and suckers may suffer from drought unless you can irrigate them.

When you harvest a trial, carefully pull the central corm, so that you disturb the suckers as little as possible. Resettle the suckers by pressing them into the soil with your feet, and then mound soil up around their bases. Obviously, the suckers will survive better and grow faster if you harvest when the soil is damp or when rain is expected shortly after harvest. Remove the headset from each harvested corm and plant it near its mound of suckers.

Here are some ways you can increase the rate of multiplication if you have the necessary resources, mainly labour and irrigation. Note that these methods are excellent for multiplying planting material to distribute to farmers, but some of them are not very good for multiplying for trials because the resulting planting material is not uniform in terms of age and location.

1. After harvesting corms and mounding suckers, irrigate suckers whenever necessary to promote vigorous growth.
2. After harvesting corms, pull all suckers and replant them and the headsets in a nursery where they can be regularly watered.
3. If you have limited nursery space, pull only the smallest suckers and replant them in the nursery, leaving the larger suckers and headsets in the field.

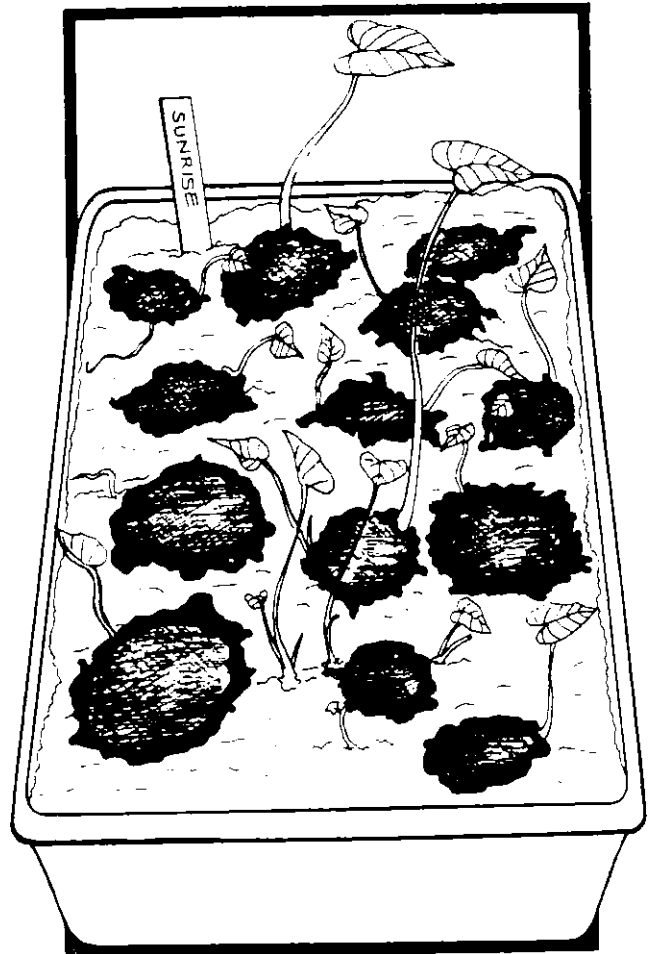
Note that there is one danger in using irrigation and nurseries to assist with multiplication. When you do so, there is no opportunity for natural selection to eliminate clones that do not have enough drought tolerance for their suckers to survive and grow in the dry season under farmers' non-irrigated conditions.

4. You can produce suckers from corms left after determining dry weight and eating quality and from corms that you used for determining specific gravity (just wash off the salt before planting).

To plant corms, remove and plant any headsetts that were not removed in the field at harvest. Plant corms in nursery beds, pots, or trays filled with vermiculite, Permalite, sand, light top soil, or other free draining material. We prefer vermiculite and Permalite, because these light media make it easy to remove the roots of the suckers. Plant each corm upright so that the cut surface left after removing the headsett is just above the growing medium and will dry out in between waterings. Cover all the rest of the corm with the growing medium, so it will not dry out and rot. Water as necessary to keep the planting medium damp but not wet.

The lateral buds on the corm will sprout and grow into small suckers. Once each week harvest all of the suckers that have grown to 10–15 cm tall, and plant them in a nursery in the screen house or field (water must be available). When you are pulling off the suckers, disturb the corm as little as possible, and it will continue to produce suckers for many weeks.

5. Once you have reached Step 9 and are multiplying planting material to distribute to farmers, it will definitely be necessary to grow multiplication plots in the field during normal taro growing season. In the multiplication plots you are growing plants just for multiplication, not for evaluation, and therefore, you should alter the growing conditions to favour sucker production, not corm production. How? By using wide spacing, shallow planting, and high nitrogen, which all increase the number of suckers produced.



For rapid multiplication, corms can be planted in trays in the screen house.

Recurrent Selection

There are 3 steps in a recurrent-selection breeding programme:

1. Create a base population by selecting parent clones and intercrossing them in as many combinations as possible.
2. Grow, evaluate, and select the seedling-derived clones grown from seeds produced in the above step, and intercross selected clones in as many combinations as possible.
3. Include new germplasm in the Crossing Block when available (this is called introgression).

In a recurrent-selection breeding programme, the first time you select and intercross parent clones you are creating what is called the base population or the original source population. It is important to begin with a wide genetic base. To do this, choose at least 20 parent clones that are unrelated and have a wide range of characters.

To widen the genetic base, or to obtain specific characters not available in the local germplasm, it is often necessary to import seeds or vegetative material from other countries. However, this importation must be done in such a way that there is not risk of introducing new diseases and pests.

Seeds and PATHOGEN-TESTED (virus-indexed) plantlets growing as tissue cultures are safe ways to import materials if you follow recommended quarantine procedures. The first step in the importation process is to obtain an Import Permit from your Quarantine Division and then to cooperate fully with the requirements for phytosanitary certificates, post-entry quarantine, etc.

For taro it takes about 4 years from Crossing Block until harvest of the Intermediate Trial. Therefore, if you plant a Crossing Block once each year, you will in fact have 4 recurrent-selection populations running at the same time.

How do you select seedling-derived clones for each cycle of intercrossing? You can base your selection on the phenotype of the seedling itself. However, at the seedling stage, you have only one plant of each clone, grown from a different kind of propagule than farmers use (seed rather than headsett or sucker). Therefore, it is not possible to make accurate judgements on many characters at the seedling stage. After cloning the seedlings and evaluating the seedling-derived clones in the trial sequence, your judgement of their performance becomes increasingly accurate as you advance from Hill Trial through Preliminary Trial, Intermediate Trial, Advanced Trial, and finally On-Farm Trials.

You can also base your selection on the breeding value of a seedling-derived clone, as judged by the performance of its progeny (progeny testing). This is often a better criterion than the phenotype of the seedling-derived clone itself. However, progeny testing adds a number of lengthy steps to the breeding programme, and for this reason we are not using it in our taro breeding programme.

During the first 2 or 3 cycles of your recurrent-selection programme, apply only light selection pressure to allow maximum recombination to occur. For example, in the first cycle you could select and intercross all the seedling-derived clones that you select from the Hill Trial for planting in the Preliminary Trial. In the second and third cycles, you could select and intercross all the seedling-derived clones that you select from the Preliminary Trial for planting in the Intermediate Trial.

After completing these early recombination cycles, you should increase the selection pressure. We do this by selecting and intercrossing all seedling-derived clones that we have selected from the Intermediate Trial for advancement to the Advanced Trial (see Figure 1). We may also include in the Crossing Block a few clones from earlier trials that have good characters but are not good enough overall to be

selected for further trial. For example, a clone that has a very high level of *Pythium* resistance but has poor corm shape, or a clone with exceptionally high yield and eating quality but too few suckers. In these later recombination cycles, use 30 or more parent clones.

Newly introduced germplasm can be used in the base population for introgressed (crossed) at any later time.

With each cycle of recurrent selection your breeding population will improve. This means that the frequency of desirable genes will increase, and your chances of finding clones with all the characters you want will increase.

If you have a clone with one or a few good characters but many undesirable characters, you can introgress it into your improved population without adding the genes for the undesirable characters to your improved population. Plant the clone to be introgressed in a border row of your Crossing Block. Use it in crosses as a FEMALE PARENT ONLY. If you are collecting open-pollinated (insect-pollinated) seeds from your Crossing Block, prevent its pollen from contaminating your improved population by emasculating all its inflorescences before they shed pollen. Evaluate the progenies from these crosses in the trial sequence and repeat the procedure with the selections until they are improved enough for most characters to be included as normal parents in the recurrent-selection crossing block.

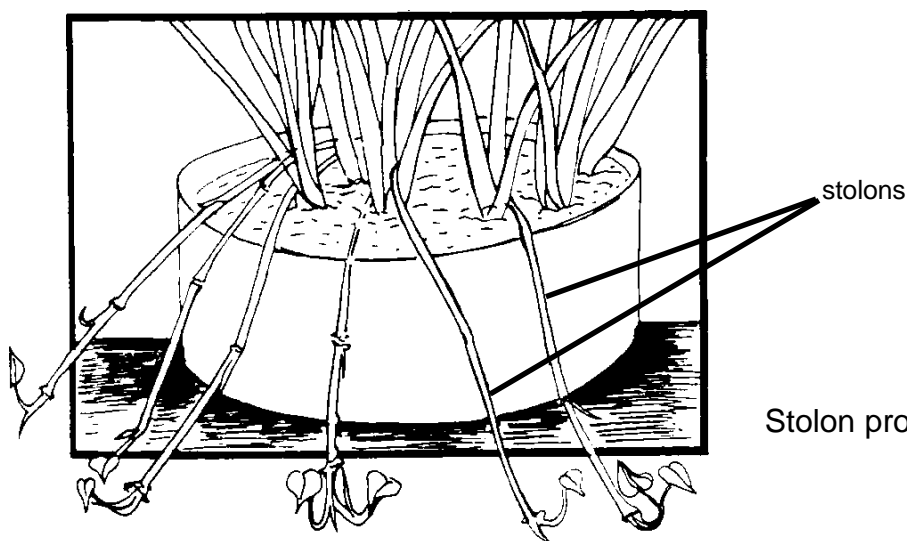
Genetics

Some taro clones are diploid ($2n$) and contain a total of 28 chromosomes. Other clones are triploid ($3n$) and contain a total of 42 chromosomes. All the clones in our breeding programme have acted like diploids. Taro is also heterozygous, and consequently segregation of characters always occurs in the offspring (progeny). Taro has both qualitative and quantitative characters. Qualitative characters are distinct and discontinuous and are easily distinguished from each other. For example, stolon production is a qualitative character. Generally only 1 or 2 sets of genes control each qualitative character. In contrast, quantitative characters are indistinct and continuous and gradually grade into each other, and usually many sets of genes are involved. For example, the shape and yield of corms are quantitative characters.

For some characters, improvement through selection is rapid, but for other characters it is slow. This is determined by the heritability of the character. If a character has high heritability, the progeny will resemble the parents, and improvement through selection will be rapid. For example, sucker number appears to have high heritability.

Other characters have lower heritabilities such as yield, fibre content, corm shape, and eating quality.

If a character has low heritability, improvement through selection will often be slow. It is sometimes possible to increase low heritabilities by increasing the number of replications in trials and using better screening techniques, such as artificial inoculation. Also, when heritabilities are low, it may be better to base your selection on progeny testing rather than on the parents.



Evaluating Specific Characters

Plant Characters

There are 2 basic **plant types** in taro. The dasheen type has a large central corm, with suckers, stolons, or a few small cormels that are generally not eaten. The eddoe type has a smaller central corm that is surrounded by a large number of well-developed cormels. These cormels are the main harvestable yield. The dasheen type is classified as *Colocasia esculenta* var. *esculenta*, and the eddoe type is classified as *Colocasia esculenta* var. *antiquorum*. In the Pacific, most taro cultivars are the dasheen type, and your breeding programme should concentrate on this type. However, eddoe-type cultivars do have certain advantages: they are more drought tolerant than dasheens and the cormels have longer storage life than dasheen corms. For these reasons, eddoes may deserve some attention in your breeding programme.

Some cultivars of taro produce suckers. Others produce *stolons*. With very few exceptions, stolon production is an undesirable character, and you should discard progeny with stolons.

Petiole colour is very variable, but it is usually not important to farmers unless they associate certain petiole colours with desirable or undesirable characters in the local cultivars that they grow. For export taro, the colour of the base of the petiole is often important because consumers use this character to identify the cultivars they prefer to buy. For instance, many consumers in New Zealand prefer ‘Samoa Pink’ (which in Western Samoa is the cultivar ‘Niue’) and they look for the pink petiole bases and buds when they are buying taro.

Even if we are not selecting for a certain petiole colour, we always note the petiole colour of each clone in our field evaluation book. Having records of this character helps us to sort out ‘mixtures’ or find a lost clone number. With care, ‘mixtures’ and lost numbers are rare, but they do happen!

Plant Vigour

Plant vigour is related to yield as well as erosion and weed control. The best time to evaluate plant vigour is at the so-called ‘grand growth stage’, when plants have reached their maximum height. We classify vigour as LOW, MEDIUM, and HIGH. Clones with low vigour usually produce low yields. Clones with medium vigour usually produce medium yields. However, clones with high vigour can produce either high yields or low yields. How? Some clones put almost all of their energy into very vigorous leaf growth and consequently have poor corm growth. Therefore, an ideal clone must have both high vigour and high corm yield.

Sucker Number and Attachment

Sucker number varies from none to a few to 30 or more. The ideal sucker number is determined by the farmers' system of planting and marketing. A cultivar must provide enough planting material to permit farmers to replant and expand their fields. In those locations where farmers use a mixture of headsets and suckers for planting material, 2 to 3 suckers/plant is adequate. In other locations, farmers use only suckers, either because they prefer them to headsets or because they market their taro with the headsets attached and thus have only suckers left for planting. These farmers need 3 to 5 suckers/plant. Therefore, we select clones that on the average produce 3 to 5 suckers **that are large enough for planting.**

Clones that produce too many suckers are undesirable because they are too difficult to harvest. Also, corms from these clones are unsightly because they are covered with wounds where the suckers have broken off, and these wounds make corms more susceptible to post-harvest rot and desiccation.

We have found that the ease of harvesting and the size of wounds on corms is also determined by the sucker attachment. Suckers with wide bases where they are attached to the corm are hard to break off, and they leave large, deep wounds on the corm. Suckers with narrow bases are easier to break off, and they leave smaller, shallower wounds on the corms. Therefore, we select for narrow-based suckers.

In very few taro production systems, high sucker number is a desirable rather than undesirable character. This is the case when taro is grown in flooded conditions as a long duration crop (12 or more months) and small corms are acceptable to farmers and consumers. In such a system, sucker corms contribute significantly to the marketable yield. Hawaii paddy taro grown for marking poi is an example.

Remember that sucker number is very much affected by plant spacing. Therefore, it is important that you select sucker number when plants are grown at the spacing most commonly used by farmers. Also, we have found that when we are evaluating the Hill Trial, we can safely discard seedlings that have 10 or more suckers. However, many seedlings that have 'too few' suckers (none, 1, or 2) will produce 5 or more suckers when they are cloned and grown from vegetative planting material.

Disease, Insect, and Nematode Resistance

It is important that you develop a reliable scoring system that can distinguish resistant from susceptible clones. Your scoring system should have at least 3 classes, but it must not be so complex that it is difficult to use on a large number of clones in the field.

For **dasheen mosaic virus**, we evaluate each plant separately using a score of 0 to 3, with 0 meaning no leaves showing symptoms of the disease 1 meaning mild symptoms on one or a few leaves, 2 meaning severe, conspicuous symptoms covering most of one or more leaves or mild symptoms on many leaves, and 3 meaning some leaves distorted in shape by the virus. Since plants produce about one new leaf/month, we score plants at one month intervals through out the growing season.

We also evaluate each plant for what we call '**golden virus**' (veins near leaf edges are etched a golden yellow colour). It is possible that 'golden virus' is another symptom of dasheen mosaic virus, but until the casual agent is confirmed by pathologists, we evaluate it separately. We use the same scoring system as for dasheen mosaic virus, but omit score 3, because 'golden virus' does not cause distortion of leaves.

Remember that seedlings are virus-free until infected by insect vectors. We do not yet know how many years it takes for seedling-derived clones to accumulate a maximum load of virus. We do know that seedlings show symptoms during the first season they are planted in the field in Hill

Trials (if inoculum and insect vectors are present in that field). We also know that many seedling-derived clones tend to lose vigour and yield (that is they 'run down') as they progress from Hill Trial to Preliminary Trial to Intermediate Trial to Advanced Trial to On-Farm Trials. We assume that clones that lose vigour and yield fastest are susceptible to virus and clones that are still more vigourous and higher yielding than local checks in Advanced Trials are resistant to virus. However, it is possible that the improved cultivars we release, may gradually 'run down' as they are grown for a number of years by farmers. We hope that this does not happen, but we will know for sure only after released cultivars have been grown for many years.

For *Pythium*, we determine the percentage of the corms of each cultivar rotted at harvest.

Most, if not all, local cultivars of taro are highly resistant to **rose beetle**. However, we have found that seedling populations contain a low percentage of plants that are susceptible. These susceptible plants are easily identified during the Hill Trial and should be discarded.

Time from Planting to Harvest

Production of upland/rainfed taro is often seasonal because there is only one 'best' time for planting taro (at the beginning of the rainy season) and because most local cultivars mature in about the same number of months. One way to provide a longer harvest season is to breed a series of different cultivars that have a wide range of maturities. Farmers could plant the different cultivars at the same time but harvest at different times. For example, if farmers had 7 cultivars that mature in 4, 6, 8, 10, 12, 14, and 16 months, they could plant them all in September and harvest every month of the year. We have not yet been able to find this wide range of maturities in our breeding material, but conscientious selection and recrossing of early X early and late X late should gradually create more variability for maturity in breeding populations. As soon as you have more variability for maturity, you will need to divide your Preliminary, Intermediate, and Advanced Trials into different sets of trials, e.g. early maturing trials, medium maturing trials, and late maturing trials and to harvest each set at the appropriate time.

Another important character is the ability to 'hold in the field', meaning that a cultivar can be left in the soil for several months after it is ready to harvest without rotting or losing its eating quality. For example, in Western Samoa, farmers know that cultivar 'Manua' holds better than 'Niue'.

Yield

TOTAL YIELD of corms is made up of EDIBLE YIELD plus REJECTS (nonedible, mostly rotten and very small corms). Edible yield is made up of corms that are good enough to be sold (MARKETABLE YIELD) and corms that cannot be marketed but can be eaten by farm families. Which yields should you measure? If you are breeding new cultivars for subsistence farmers, then edible yield is the most important. If you are breeding for commercial farmers, then marketable yield is the most important to measure. However, we have found that for taro edible yield and marketable yield are usually the same. Therefore, it is necessary to measure only one or the other. Total yield is usually not a very relevant measurement.

The yield of corms at the main (first) harvest is more important to farmers than the yield of sucker corms from the ratoon crop. But clones that produce high, reliable yields in the ratoon crop have another point in their favour.

Remember that you should calculate yield based on the land area occupied by the number of plants of each clone you **planted**, not the number that survived until harvest. Why? Because survival, especially the ability to establish at planting, is a very important component of yield. For example: you plant 5 headsetts of a clone at 1 x 1 m spacing, and 4 plants survive until harvest producing 4 corms weighing 1.2, 1.1, 0.9, and 1.5 kg. The mean yield for this clone is $4.7 \text{ kg}/5 \text{ m} = 0.9 \text{ kg/m}^2$, NOT $4.7\text{kg}/4\text{m} = 1.2 \text{ kg/m}^2$. The only exception to this rule is when the missing plant(s) are missing because of unnatural causes such as shortage of planting material, theft, hoe or weeding damage, or pig damage.

If farmers in your location market corms with petioles attached, you may want to weigh your trial corms with petioles attached (use the same length as the farmers do), but when reporting your yields, always indicate that you have included petiole weight.

Corm Characters

Is there a preference for a certain **corm shape** in your location? If there is, then you should select breeding clones with that shape. Clones that produce more than one head on a corm are usually undesirable. We classify corm shape as ROUND, ELONGATE-ROUND (oval), ELONGATE, and MORE THAN ONE HEAD.

Smoothness indicates how much cleaning (removing roots and 'mat') a corm requires for marketing, as well as the number and appearance of sucker scars. Deep and ragged sucker scars are unattractive. We use the categories SMOOTH, MEDIUM, and ROUGH.

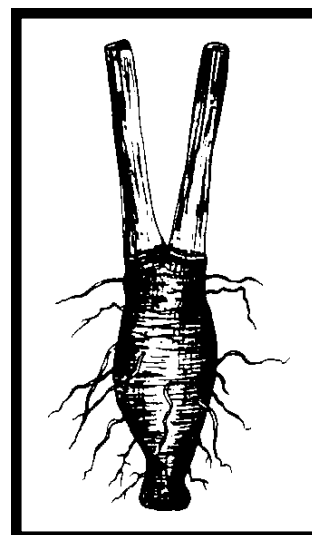
Farmers and consumers may have a strong preference for certain **colours of the buds, basal rings, petiole bases, and flesh**, or they may accept many different colours. Be certain that you understand the situation in your location before you begin your breeding programme.

Double or multiple heads are usually undesirable.

Field Selection

Plant breeding is both a science and an art. A breeder makes decisions about which clones to keep or discard based on both data (science) and on a gut reaction to 'the look' of a clone (art). Sometimes we just know that a clone is worth keeping, even though we cannot measure why.

In Hill and Preliminary Trials, it is easy to take into account our gut reaction to 'the look' of a clone because we make our decisions about which clones to keep or discard **IN THE FIELD** at the time of harvest. (The only character evaluated after harvest is specific gravity.) However, in Intermediate and Advanced Trials, we must analyze yield and quality data before making decisions. Therefore, it is necessary to record our gut reaction to 'the look' of a clone at the time of harvest so that this gut reaction can be considered together with the data when we make our decisions in the office. We call this gut reaction 'field selection' and record YES or NO, with yes meaning that our gut reaction to this clone is a positive one.



Eating Quality

Generally, Pacific Islanders prefer dry, firm-textured taro. Therefore, **percent dry weight** is one measure of eating quality. In Western Samoa for example, cultivars having dry weights higher than 30% are preferred to those with dry weights lower than 30%. However, some clones with dry weights higher than 40% may be considered poor eating quality because they are too dry ('hard', especially when cold).

We measure percent dry weight of all clones in Advanced Trials. To do this, we select 3 to 5 sound corms of each cultivar from each replication. We treat each corm as a separate sample. We peel it in the traditional way, cut off the petioles and corm base as for cooking, cut out a centre, longitudinal slice 3 cm wide, and chop this slice into cubes 1 cm square or smaller, and place these cubes into a paper bag or small aluminium foil baking pan. We then weigh each sample to determine its fresh weight, dry it in a laboratory oven at 100°C until it has reached constant weight (that is, when further drying does not lower the weight), and finally weigh it again to determine dry weight. We have found that merchandise tags (with strings removed) survive the drying temperature and thus work well for labelling samples.

You calculate percent dry weight as:

$$\% \text{ dry weight} = \frac{\text{dry weight}}{\text{fresh weight}} \times 100$$

Do not forget to “tare” (deduct) the weight of the paper bag or baking pan when you weigh fresh and dry samples. And when relative humidity is high, you must weigh dry samples IMMEDIATELY after removing them from the oven because they quickly absorb moisture.

Often there is not enough oven space and labour to determine percent dry weight of the large number of breeding clones in Preliminary and Intermediate Trials. When this occurs, **specific gravity** can be used to estimate dry weight and eating quality.

We estimate specific gravity by determining whether a corm sinks or floats in a solution of common table salt dissolved in water. For Intermediate Trials we select all sound corms from each replication. For unreplicated Preliminary Trials we select all sound corms of each clone that has performed well for all other characters.

To estimate specific gravity, make up 1 bucket for each specific gravity rating by adding a specific amount of salt to 6 litres of water (see Table 2). Treat each corm as a separate sample. Wash it in water. (It is not necessary to peel off the skin unless you are using the same corm for taste testing.) Then place it in Bucket 0. If it sinks, move it to Bucket 0.5, then Bucket 1.0, then Bucket 2.0, etc, until the corm floats to the surface of the salt solution. Give the sample the specific gravity rating of the bucket in which it first floats, and then average the ratings of the corms to obtain a mean rating for the replication (Intermediate Trials) or clone (Preliminary and Hill Trials).

When specific gravity ratings are compared against Western Samoan taste-test scores, the results are not as consistent as

they are for other crops such as sweet potato in Tonga. In other words, specific gravity is not always a good predictor of eating quality, at least in Western Samoa. But we have found that almost all clones with specific gravity ratings lower than 1.0 have poor eating quality. Also, that most clones with good eating quality have specific gravity ratings of 1.0 or higher. But, that not all clones with specific gravity ratings of 1.0 and higher have good eating quality. This means that we can safely discard clones with specific gravity ratings lower than 1.0. When doing so, we may discard a very few clones that have good eating quality, but the number of ‘mistakes’ is too small to worry about. In your location, you will need to evaluate specific gravity and eating quality of many breeding clones and local cultivars for several years to determine how they are related.

Table 2. How to prepare a series of salt solutions to estimate the specific gravity of taro corms

Specific gravity rating	Amount of salt (grams) to dissolve in 6 liters of water	Actual specific gravity
0	0	1.0000
0.5	150	1.0173
1	300	1.0347
2	600	1.0680
3	900	1.1002
4	1200	1.1316
5	1500	1.1623
6	1800	1.1926

Of course, the best method to determine the eating quality of breeding clones is to evaluate them in **taste tests**. And this is the only method to determine **acridity**, a very important quality character in taro. However, taste tests are time consuming and only a few clones can be accurately ‘tasted’ at any one time. Therefore, taste tests must usually be delayed until Intermediate, Advanced, and On-Farm Trials.

There are several methods of conducting taste tests, some of them very complicated. However, we have found that a relatively simple test is accurate enough.

From each replication of the Intermediate and Advanced Trials, we select 2 average corms of each breeding clone and each check cultivar. We peel these corms, then cook them in the ‘umu’, since this is the most common method of cooking taro in Western Samoa. Prepare your corms using the most common cooking method in your location. We cut the cooked corms into small pieces, and put each clone (mix the corms) on a separate plate that has been labelled with a code number (not the actual number that some tasters might recognize). We invite at least 20 Western Samoans to taste several pieces from each plate and fill out an evaluation form. On this form we ask them to rate each clone as 4 (excellent, I like it very much), 3 (good), 2 (OK), or 1 (poor, I do not like it). We also ask them to rate acridity as absent (-) or present (+). And we also ask them to write remarks about each sample, explaining why they do or do not like it.

Acridity means irritation or scratchiness to the mouth and throat.

Of course, taste is not the only factor that determines the ratings that our tasters give to a sample. They are also influenced by how the sample looks (colour, ‘wet’), its texture, and the presence of fibres. All these factors are important in determining eating quality.

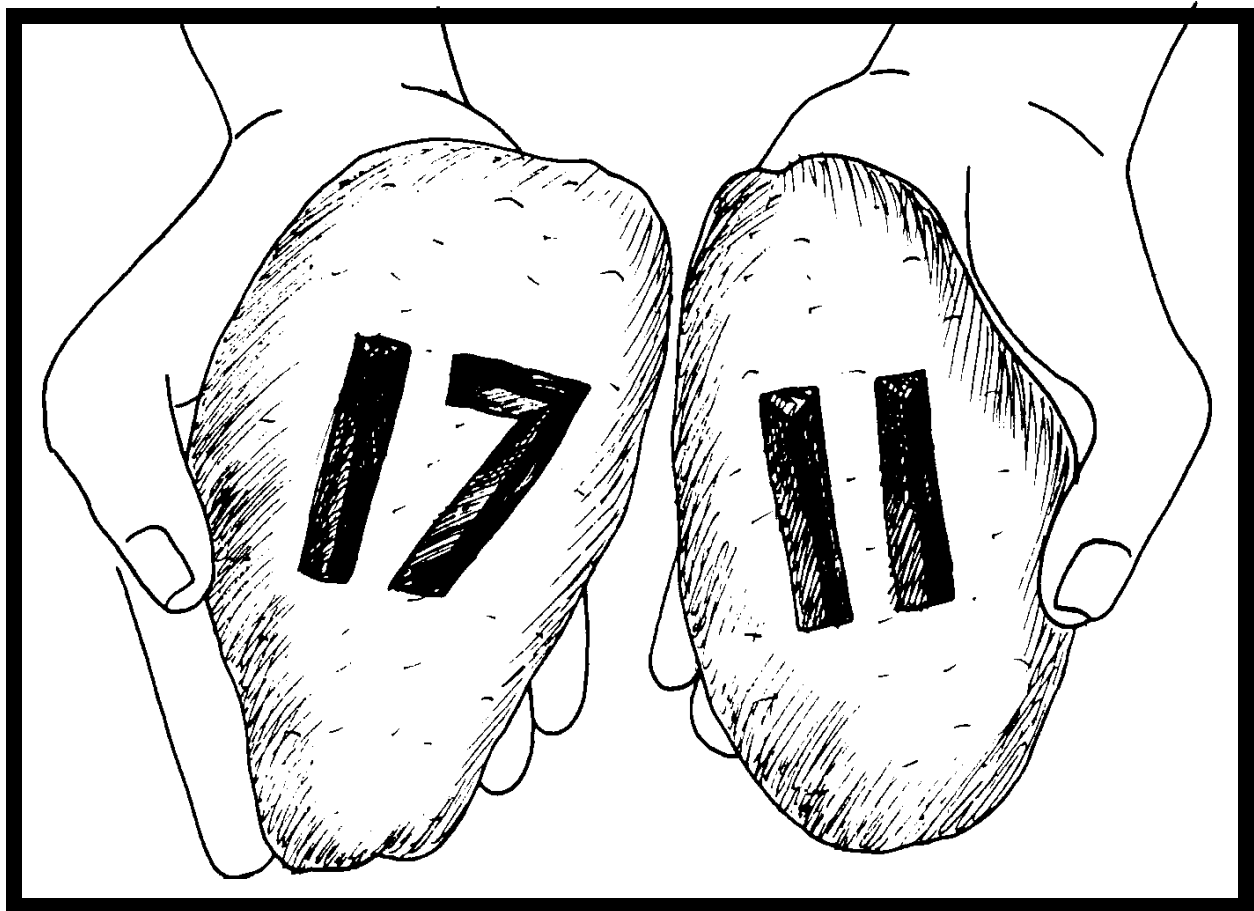
When we asked USP Alafua students from several different countries to join a taste test, we learned an important lesson. Judgements about eating quality vary greatly from country to country. For example, a taro clone rated as excellent tasting by a Western Samoan, may be rated as poor tasting by a Solomon Islander. This means that tests must be performed by people from the location for which the taro is being bred.

Since taro leaves are a popular vegetable in most islands, eating quality of the leaf is also important. Therefore, you should taste-test the leaves of all clones in the Advanced Trial that perform well for other characters. Harvest leaves at the correct stage, prepare them in a traditional recipe (choose a recipe in which the other ingredients do not disguise the taste of the taro leaves), and evaluate in a taste test, particularly for acridity and tenderness.

Nutritional Value

Protein content, protein-inhibitor content, and vitamin content are very important nutritional factors that should be evaluated in your taro breeding programme. However, most breeding programmes cannot afford the expensive equipment and highly trained technicians required to measure these

nutritional factors. If possible, you should establish a collaborative project with an overseas institution where you can send samples of clones from Advanced Trials for analysis.



Be sure that you use 'heat-proof' labels to identify clones during cooking. We carve a code number into each corm. Also metal labels and some marking pens will last through the 'umu'. For boiling, you can cut the corms into different shapes for identification.

SUPPLIES

Merchandise Tags for labelling dry weights

Standard quality, white, 1-15/16 x 1-1/4 in., No. 6, No. 12-203, 1000 in a box; from Denney-Reyburn Company, West Chester, Pennsylvania 19380, USA.

White Plastic Labels for labelling pollinations and baskets

Diamond-Lox, white, 5-1/2 x 1/2 in., 1000 in a box; from A.M. Leonard, Inc., P.O. Box 816, Piqua, Ohio 45356-0816, USA.

Flagging Ribbon for marking

Flagging, polyethelene or vinyl, 1-3/16 in. wide, many colours, 100 yds/roll; from Forestry Suppliers, Inc., 205 West Rankin St., P.O. Box 8397, Jackson Mississippi 39204-0397, USA.

Aluminum Labels for marking field stakes

Al Tags, 3/4 x 3 in., 9 in. wire, can be permanently embossed with pen or pencil, 1000 in a box; from Forestry Suppliers, Inc., 205 West Rankin St., P.O. Box 8397, Jackson Mississippi 39204-0397, USA.

Field Record Books

Lietz Level Book, No. 8152-55, 4-1/2 x 7-1/4 in., water repellent; from Forestry Suppliers, Inc., 205 West Rankin St., P.O. Box 8397, Jackson Mississippi 39204-0397, USA.

Plastic Net Bags for small lots of corms

Sold for packaging onions, potatoes, etc., available in rolls of long tubes that can be cut to any length, and in many bright colours.

Nursery Marking Pens

Permanent, sunproof, waterproof, fine point, No. UH0960; from The John Henry Company, 5800 W. Grand River, P.O. Box 17099, Lansing, Michigan 48901-7099, USA.

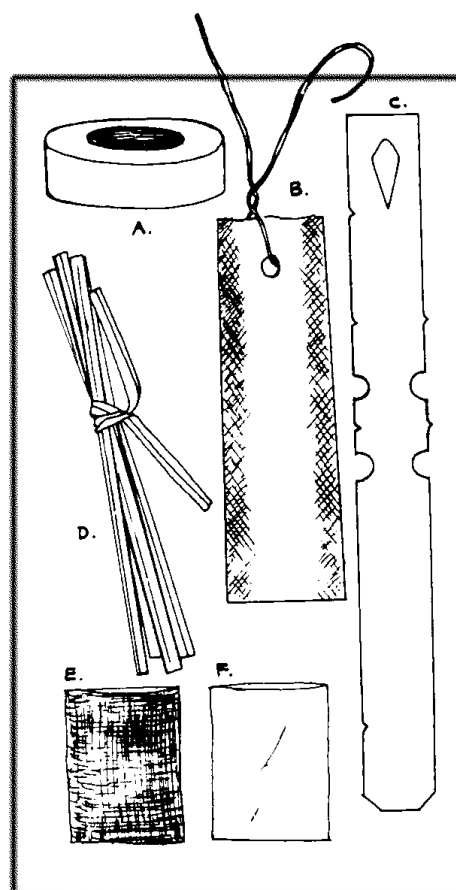
Gibberellic Acid

Pro-Gibb Plus (20% powder) manufactured by Abbott Lab; stock no. 582601, 160 g bottle; available from United Agri Products, 1660 Waiwai Loop, Honolulu, Hawaii 96819, USA.

Technical grade, 90% gibberellins, product no G7645; 1, 5 or 10 g; from SIGMA Chemical Company, P.O. Box 14508, St. Louis, Missouri 63178, USA.

Twist-ties for pollinating

Twist-ems, 6 and 8 in. long, 1000 in a bundle; from Forestry Suppliers, Inc., 205 West Rankin St., P.O. Box 8397, Jackson Mississippi 39204-0397, USA.



A - flagging ribbon
D - twist-ties

B- al tag
E - net fruit bag

C- diamond-lox label
F - cloth pollinating bag