Drying of transplants after insecticide treatment

Experimental work on behalf of the Forestry Commission

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SUMMARY

Appropriate parameters for drying Sitka transplants were found to be:

air speed	5 m/s
air temperature	40 ºC
drying time	5 minutes

The risk of carrying insecticide droplets to the environment increases sharply with air speeds greater than about 5 m/s. Air speeds of 6 - 7 m/s did not markedly increase the drying rate. The inference is that 5 m/s would be an appropriate air speed for drying the transplants.

No physiological damage was reported after Sitka transplants had been dried at 40 ºC with an air speed of 5 m/s for periods up to 15 minutes. An air temperature of 40 ºC resulted in considerably faster drying than 30 ºC or 35 ºC. Further tests could be conducted to find out whether higher temperatures and shorter drying times were feasible.

When transplants were dipped in water, droplets accumulated on the needle tips and where the stems branched. These droplets were invariably very slow to dry. Vigorous shaking can remove some of the droplets; a "whipping" action is much more effective, but would be very difficult to incorporate into a machine.

Transplants dipped in insecticide were almost entirely free from droplets, and it would appear that adjuvents used in the insecticide formulations were extremely effective.

Patches contaminated with soil remained damp long after the remainder of the transplants were dry: washing before treatment would probably be essential unless the aerial parts of transplants could be kept free from soil.

Some design considerations for a high-throughput system are discussed. It is recommended that a full scale system should convey groups of transplants in line abreast through the dipping and drying equipment. This may be achievable using a development of root crop handling technology.

1 Background

The experiments referred to in this report were commissioned by the Forestry Commission (FC) as part of an investigation into methods for treating transplants with insecticide.

Future requirement is for a system where the operators are not exposed to the chemical, and the transplants are dry externally before they are bagged. In addition, it is important that any new technique should be no less effective and reliable than the present method of hand dipping.

It is envisaged that any chemical used in future will be a suspension of a non-volatile active ingredient (ai) in water, and that it should be possible to evaporate the water so that the external surfaces of the transplant are dried, while all the ai remains on the plant.

A feasibility study carried out by SAC in January 2000 explored some possible configurations for the treatment equipment. Following that feasibility study, FC and SAC agreed that development of a continuous flow treatment system should be postponed, and that a simple batch system should be constructed. The batch system would be used to :

- assess appropriate air velocities and air temperatures for drying the transplants;
- produce 18 000 treated transplants in time for planting trials in spring 2000.

This follow-up study was organised in phases, as outlined below.

2 Preliminary trials

Preliminary trials were undertaken to find the maximum air speed that could be used without carrying away liquid in the air stream. The requirement is to evaporate moisture, leaving all the ai on the plant. Higher air speeds result in faster drying, but involve a risk that droplets of liquid might be blown from the plant and reach the atmosphere, with possible environmental damage or hazards to health of operators.

A existing small wind tunnel was modified so that a single transplant could be gripped at the root collar and suspended in the air steam (Fig 1). The wind tunnel was supplied with air from a 0.5 kW single stage axial flow fan. Sitka transplants were dipped in water and placed in this wind tunnel at a range of air speeds. Table 1 shows the distances at which water droplets were easily visible downwind of the transplant.

Table1 Transport of water droplets at different air speeds

Air speed m/s	Maximum downwind transport distance m
3	0.44
4	0.44
5	1.03
6	1.5
7	1.8
8	2.6
9	> 3.0

On the basis of these results it was decided that the maximum air speed for the batch transplant drier should be 9 m/s.

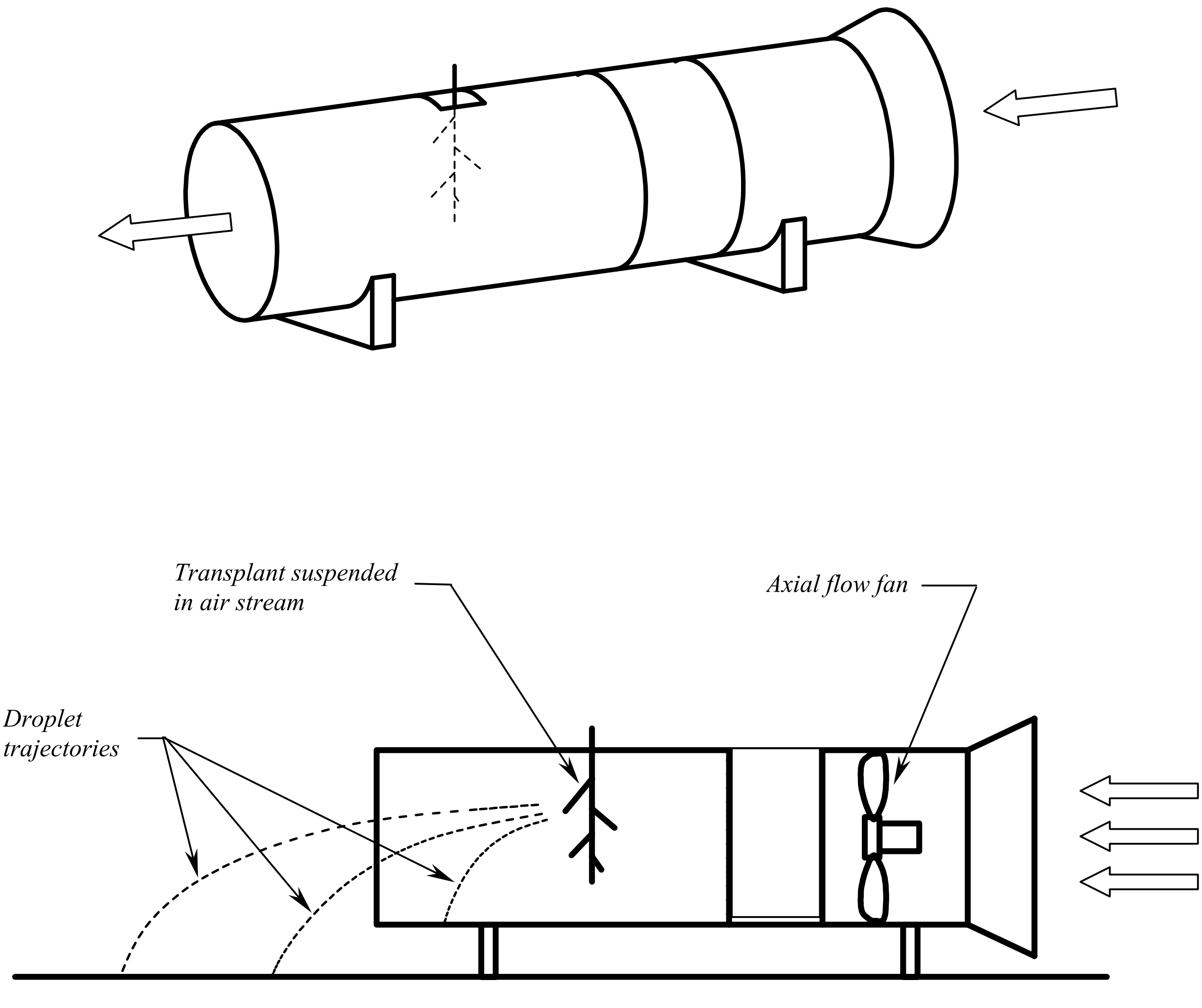

Fig 1 Simple wind tunnel adapted for preliminary trials

3 Design and construction of drying tunnel

The next phase of the work was to design and construct a wind tunnel for drying the transplants, capable of producing an air stream of variable speed up to the 9 m/s maximum established in the preliminary trials, with air temperature variable between ambient and 40 °C. The contract required that this drying tunnel should be suitable for use in trials with approximately 18 000 transplants, and that the plant roots should be protected as far as possible from the drying effects of the air stream.

A tunnel of 530 mm x 530 mm cross section was built and connected to a 4.3 kW two stage axial fan. For initial tests the drying tunnel was placed downwind from the fan, to allow easy access for observations and modifications. The equipment was then re-assembled with the drying tunnel upwind of the fan, to avoid risk of chemical being blown onto the operators when loading or unloading the transplants. Discharge from the fan was directed along a sealed duct and through a bio-filter unit loaded with wood chips, in order to capture any chemical that might otherwise have reached the atmosphere (Fig 2).

Electric heater banks were fitted to provide a simple means of controlling the air temperature, with minimum installation costs. Maximum heat available was 64 kW, switchable in 2 kW steps. Air velocities were measured using an Airflow AV2 vane anemometer with 35 mm diameter sensor, calibrated by the manufacturer, and were checked by pitot tube. Air temperature within the drying tunnel was monitored using a Digitron instrument and a type J thermocouple, checked against a mercury in glass thermometer calibrated to NAMAS standards (Appendix 1).

Carriers were designed and constructed to hold the transplants. For initial trials the transplants were inserted into slots cut from soft rubber sheeting, the rubber being fixed by adhesive to a folded steel sheet. This design was chosen because it could be produced rapidly from materials already in stock.

Each of the first type carriers held 15 transplants at 65 mm spacing, and four carriers could be fitted across the width of the tunnel. Early tests revealed that some transplants at the downwind end of the carriers were slow to dry, and the carriers were therefore reduced in length so that each held only 10 transplants.

Carriers with 3 mm thick neoprene sponge rubber material caused some damage to the transplant stems, until the slot width had been increased to 4 mm. This modification eliminated damage from all except a few transplants with particularly thick stems, but the widened slots had the disadvantage of allowing some ambient air to be sucked into the drying tunnel. These problems were solved by using carriers fitted with brush strip instead of slotted rubber, to provide an improved air seal and prevent damage to the stems.

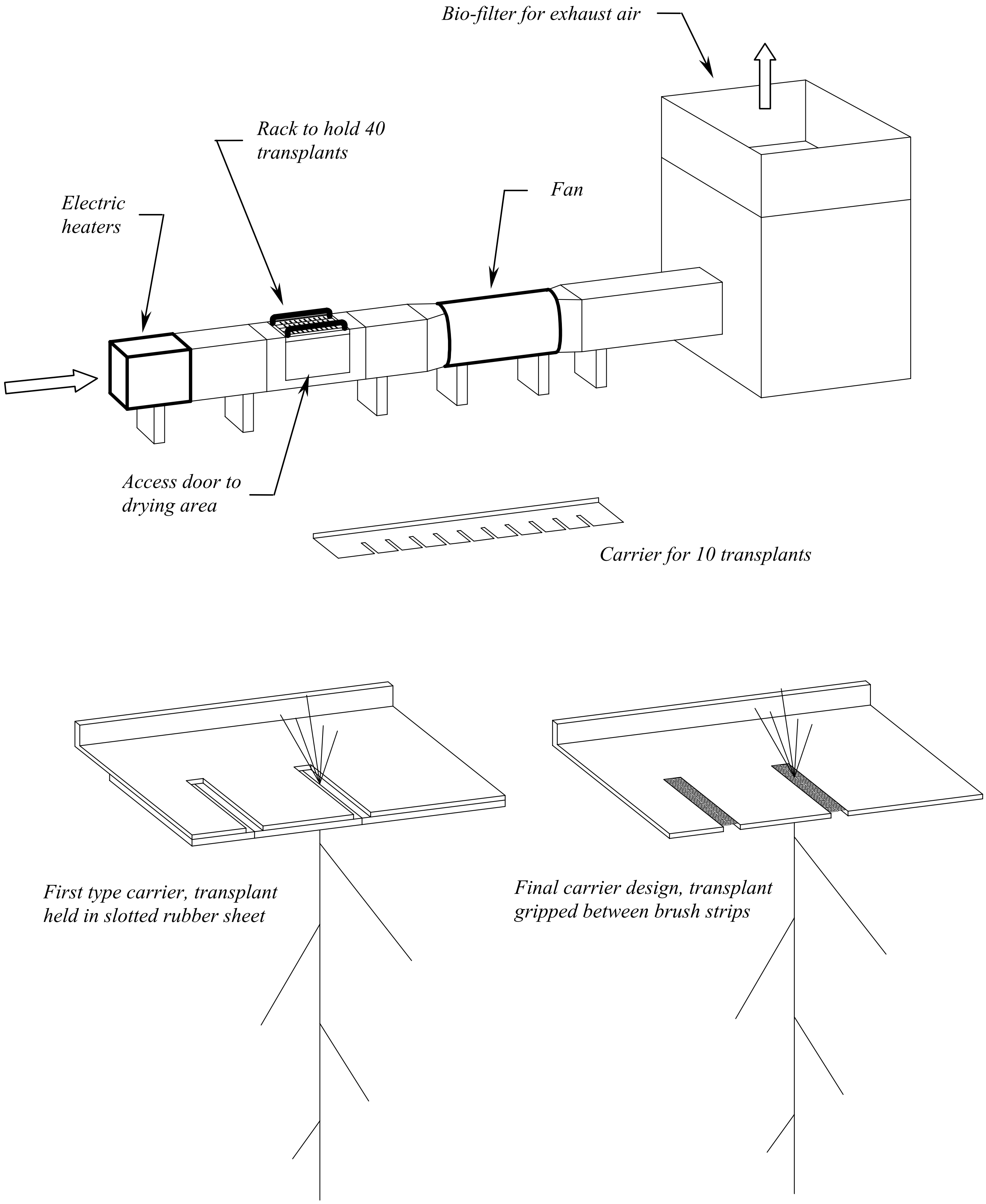

Fig 2 Drying tunnel for transplants

4 Carry-over of water and tracers

Possible methods for detecting insecticide droplets within the air stream were investigated. Drager detector tubes are not manufactured for the chemicals involved. Discussions were held with manufacturers of light scatter aerosol monitoring equipment, but no suitable device was located – such instruments are not generally capable of distinguishing between liquid droplets and solid dust particles. It was therefore decided that droplets would be captured on paper strips, so that the splash areas could be used for comparative assessments.

Trials were carried out with transplants that had been dipped in a fluorescent dye (Saturn Yellow). The Saturn Yellow powder was mixed at a concentration of 0.25% by weight, with liquid consisting of 99% water and 1% wetting agent. Five strips of black paper, which was found to show the fluorescent dye better than any other colour, were mounted in the tunnel at distances of between 0.5 m and 2.0 m downwind from a single transplant held in the centre of the duct. The paper strips, 510 mm wide and 30 mm high, were fixed to angled slats set in the manner of a Venetian blind (Fig 3), with the first strip 50 mm from the top of the tunnel and subsequent strips at 70 mm spacing. Tests were carried out at air speeds of 4 - 9 m/s and the area of the fluorescent dye splash marks on each strip was measured.

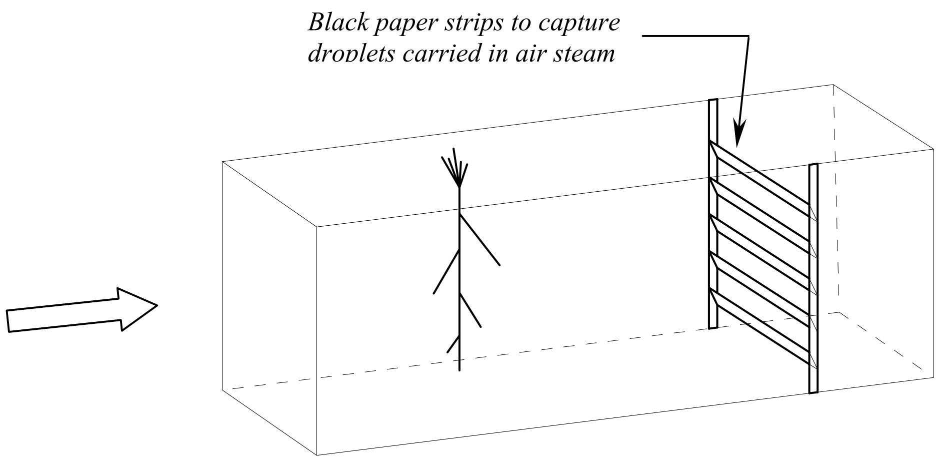

Fig 3 Apparatus for droplet carry-over assessment

A summary of these tests is given in Table 2. As expected, higher air speeds result in more carry-over of liquid. The effect was particularly noticeable for air speeds greater than 5 m/s. Full results are given in Appendix 2.

Table 2 Fluorescent dye carry-over

	Total splash area of dye spots on black paper (mm^2)			
Distance downwind / Air speed	0.5 m	1.0 m	1.5 m	2.0 m
4 m/s	3.5			
5 m/s	8.2	6.5	3.1	
6 m/s	218.1	11.4	20.6	
7 m/s	656.6	52.2	3.3	9.4
8 m/s		130.0	189.5	27.9
9 m/s		424.1	147.3	89.3

5 Selection of maximum air speed

Following a review of these results and discussions between SAC and FC staff, it was agreed that air speed when drying the 18 000 transplants needed for planting trials would probably have to be restricted to a maximum of 5 m/s, but that a small number of tests should also be conducted using air speeds of 6 - 7 m/s.

6 Assessment of minimum drying times

6.1 Experimental technique

Trials were conducted to study the effect of air speed and temperature on the rate at which transplants could be dried after dipping. The experiments involved temperatures of 30 - 41 °C, air speeds of 5 - 7 m/s and drying times of 4 - 15 minutes. All transplants were washed in water prior to any drying trials.

Some of the transplants were dipped in water. Others were dipped in the Saturn Yellow solution, so that progress of evaporation could be observed through the window in the drying tunnel under UV illumination.

Effectiveness of drying was assessed by wiping each transplant through a paper tissue, a technique that had been developed by FC Technical Development Branch. Any dampness on the transplant was clearly visible as a patch on the tissue.

6.2 Effect of large droplets

It became apparent that a thin film of moisture could quickly be evaporated, but large droplets remained as liquid. When a Sitka transplant is withdrawn from the dip tank, some of the liquid collects into large droplets that hang from the tips of the needles. Droplets hanging from the transplant would be no more effective against pest attack than a thin film, wasteful of chemical and difficult to evaporate.

Considerable effort was expended in a search for methods to remove the large droplets. Holding a transplant by the roots and imparting a "whip" action is very effective, but would be difficult to incorporate into a machine. Tests showed that a pulsed high speed air jet, directed at transplants moving on a conveyor system, would induce a degree of shaking and remove some of the droplets; a disadvantage of this approach is that the droplets could fall onto the floor of the drying tunnel, evaporate and build up a deposit of chemical, unless all the shaking took place above the dip tank.

To allow experiments to proceed, a standard method for removal of excess droplets was adopted : the transplants were shaken by hand for 10 seconds, allowed to drip for 120 seconds, shaken again for 10 seconds, and then placed in the drying tunnel.

6.3 Results from drying experiments

Following the decision made earlier (see Section 4 above), an air speed of 5 m/s was used for most of the drying trials. Transplants dried at 30 ºC remained noticeably moist after 5 minutes, and some dampness was still detectable even after 15 minutes in the drying tunnel. With a temperature of 35 ºC the transplants remained wet after 5 minutes in the drying tunnel. Temperatures of 40 - 41 ºC were used over periods of 4 - 10 minutes. Many of the transplants were completely dry after this treatment, but every experiment left occasional damp spots on one or more plants. In additional experiments, air speeds of 6 - 7 m/s instead of 5 m/s made little difference to the rate of drying. There were no apparent differences in the drying rates for transplants dipped in water and those dipped in dye. Results of these experiments are summarised in Appendix 3.

6.4 Effect of drying regime on transplant physiology

Seven batches, each of ten transplants, were dried at 30 °C, 35 °C or 40 °C for periods of 5 - 15 minutes. Staff of FC Northern Research Station (NRS) compared these against an undried control batch, and reported that no physiological damage had been detected. Details of the treatments are given in Appendix 4.

Since no damage was reported, it may be advisable to carry out a small number of trials to find out whether higher temperatures and shorter drying times could be used without adversely affecting the transplants.

7 Selection of drying temperature and time

After discussion between SAC and FC staff, it was agreed that the transplants required for field trials should be dried using an air speed of 5 m/s, an air temperature of 40 ºC and a drying time of 5 minutes. Even though a few damp spots might remain after such treatment, FC staff considered that this would be acceptable for the present set of field trials, provided that the majority of transplants were dry.

8 Drying of material for planting trials

It was initially envisaged that 18 000 transplants would have to be dried in readiness for planting trials. The quantity was later reduced to approximately 5 400 transplants, which were dipped in insecticide at NRS, brought to SAC premises and placed in the drying tunnel.

All of these transplants were completely dry after 5 minutes exposure to the air temperature of 40 ºC and air speed of 5 m/s.

The equipment functioned with few problems. Operators were able to locate transplants in the carriers at a rate of about one per second. It was clear that simple modifications to the drying tunnel, particularly in respect of transplant handling arrangements, could provide a satisfactory method for drying moderate quantities in experimental work. It would not be difficult to devise apparatus to keep operators away from chemical in the dipping tank. However, the transplant carriers would be liable to contamination by insecticide and, as these carriers would have to be used repeatedly, operators would need protective clothing.

More radical design changes would be needed to provide a method for treating large quantities of transplants and isolating operators from the chemical.

9 Additional drying experiments

9.1 Cause of drying rate variation

A series of experiments, not previously scheduled, was conducted to find out why transplants dipped in insecticide at NRS were completely dried within five minutes, while those dipped in water/dye at SAC premises dried much more slowly. It was reasoned that the faster drying rate of transplants dipped at NRS might result from :

- loss of drips of liquid due to delay between dipping and drying;
- a reduced quantity of liquid due to some difference in the method of dipping;
- wetting / sticking agents in the NRS dip;
- differences in physical characteristics of the plants.

Transplants dipped in water and then shaken for extended periods still retained some droplets. From this it was inferred that delay between dipping and drying would have little effect.

Variations in technique while dipping transplants in water did not appear to affect the quantity of droplets retained.

A batch of transplants was dipped in insecticide at NRS, taken to SAC, and placed in the drying tunnel with an air speed of 5 m/s and temperature of 40 ºC as in previous trials. None of the batch had any visible droplets before drying, each being covered only by an apparently uniform liquid film. All these transplants were dry after 5 minutes treatment. Most of the surface area was in fact dry after only 3.5 minutes, but these shorter drying times left a few damp patches, and it was clear that the dampness was in every case associated with a deposit of soil particles. Results are shown in Appendix 5.

The thin liquid film and lack of large droplets indicate that the insecticide formulations used at NRS must have included very effective adjuvents. By contrast, transplants dipped in water or Saturn Yellow dye solution, or in water with the wetting agent used during the January 2000 feasibility study, had all been affected by droplets on the ends of needles or at branches in the stems.

From this trial it was inferred that rapid drying can only be achieved if :

- effective adjuvents are used;
- there are no soil deposits on aerial parts of the transplants.

9.2 Effectiveness of pre-washing

A further trial was conducted in an attempt quantify how far pre-washing (to remove soil deposits) would affect the time needed for drying.

Transplants were cleaned by pressure washer, dipped in insecticide at NRS and then dried for different periods. Results were inconclusive. A few damp spots remained in the transplants even after 5 minutes drying (see Appendix 6).

These transplants had to be lifted from a restock site that had been planted in April 1999, because no other material was available at that time. They were considerably larger than the material used in previous tests and had thicker stems, rougher bark and much more foliage; these physical characteristics may have rendered them more difficult to dry than normal transplants.

10 Design considerations for a high-throughput system

The experiments described in this report have established that an air speed of 5 m/s, air temperature of 40 ºC and drying time of 5 minutes would generally be appropriate for Sitka transplants.

SAC staff have considered various possible designs for a high-throughput system. The approach adopted will depend on the outcome of discussions between SAC and FC regarding factors such as :

- throughput rate required;
- space available for the equipment;
- cost of providing heat energy on site;
- likelihood that transplants will be contaminated by soil;
- requirements for grading during the insecticide treatment process;
- exhaust air quality standards.

Some of these issues are outlined below.

10.1 Target throughput rate

FC requires a system that will allow transplants to be treated and dried in large quantities. With existing hand-dipping arrangements, a team of five operators can treat approximately 50 000 transplants per day.

Experience gained during the course of this study indicates that an operator can reasonably be expected to load individual transplants into holders at a rate of about one per second. That would theoretically equate to 27 000 transplants in a 7.5 hour day, but some delays are certain to occur, and a realistic daily target might be 20 000 for each operator. If staff were available, shift work could be adopted to make better use of machine capacity.

10.2 Drying tunnel configuration

During the present study the transplants were inserted into slots 65 mm apart, which is probably near the optimum for loading into a stationary carrier. Any narrower spacing could interfere with the air flow and increase the number of contact points between adjacent transplants, thus tending to reduce the drying rate.

It might be difficult to load the transplants onto a moving conveyor system unless the spacing were increased to (say) 100 mm.

If transplants were loaded at a rate of one per second, conveyed in a single line at 100 mm spacing and dried for 5 minutes, the drying tunnel would have to be 30 m long. On that basis, transplants conveyed 10 abreast might appear to need only a 3 m long tunnel, though in practice the longitudinal spacing would probably have to be greater for the abreast system.

A design that involves moving transplants vertically (eg into a dip tank) might require even greater spacing, to minimise "snagging" of branches or needles between adjacent plants.

An abreast-type drying tunnel could be widened to allow use by two or more operators. Two operators could in principle attach transplants to a single-line conveyor, but doubling the conveyor speed to allow this would also require the drying tunnel length to be doubled; it might be more satisfactory to install two conveyor traces side by side within a single tunnel.

A single line conveyor implies a tunnel of small cross section, and minimises the fan size and the heat energy requirement. An abreast-type tunnel will involve greater energy consumption, though it would be possible to recover some of the waste exhaust heat in either layout.

10.3 Dip v. drench

Equipment design would be simplified if the insecticide could be applied as a high volume spray drench rather than by dipping. Drenching would avoid vertical movement, and mean that :

- the conveyor could be simpler;
- adjacent transplants would not move relative to one another in a vertical plane, and could therefore be more closely spaced without risk of snagging.

Dipping and drenching would probably require separate approvals for use of the insecticides.

10.4 Requirement for pre-washing

Transplants having soil adhering to the stems or needles are difficult to dry. Pre-washing will be almost essential if soil contamination is a common occurrence. However, there was no difficulty in drying the 5 400 transplants prepared for FC planting trials. Pre-washing will inevitably make the design more complex and expensive. It is necessary, therefore, to decide at an early stage whether the equipment specification will or will not incorporate pre-washing.

10.5 Separation of conveying elements

If pre-washing is incorporated, substantial volumes of wash water will have to be disposed of, and it will be important to avoid contamination of the wash water by insecticide. Washing would almost certainly be carried out using high speed water jets, which are certain to impinge on the conveying system as well as on the transplants. Thus the conveyor on which washing is carried out must not be allowed to enter the insecticide dip tank.

It is highly desirable that components touched by the operators (eg when loading transplants onto the conveyor) should not become contaminated by insecticide.

In order to achieve these objectives, it may be necessary to load transplants onto a first stage handling system, where they are washed, and then transfer them to a second conveyor for dipping and drying; operators would not come into contact with this second conveyor.

10.6 Opportunity for grading

Hand loading individual transplants into any treatment system provides an opportunity for the operator to reject sub-standard material.

With transplants loaded onto a single line conveyor, it would be possible to add automatic grading (using machine vision techniques) on the basis of length, stem thickness, foliage colour, etc. Such grading would not be so easily incorporated with an abreast conveying system.

10.7 Exhaust air quality

During drying experiments the air speed was restricted to minimise carry-over of insecticide, and the exhaust air was directed through a bio-filter. These were cheap, reliable, low-tech precautions. More sophisticated air cleaning equipment could be fitted, but costs could be high.

Actual emissions of insecticide to the atmosphere have not been measured, nor was there any analysis of the filter material. Accurate measurements ought to be carried out before a system is put into regular use, and a method would have to be specified for disposal of contaminated filter material.

11 Proposals for equipment development

SAC and FC staff have discussed the experimental results and design considerations described above, and agreed the following.

A reasonable throughput target is 20 000 transplants per operator per shift, so that a two-operator machine can treat 80 000 during two shifts.

The system must provide an option for pre-washing transplants to remove soil deposits.

Operators will reject any sub-standard material when loading transplants into the system. Machine vision and robotic grading are not likely to be required in the near future. The equipment design should be kept as simple as possible, so that maintenance can be carried out by the operators or by local engineering workshops.

The design must be such that operators do not come into contact with machinery contaminated by insecticide.

After dipping, transplants will be dried for 5 minutes with an air speed of 5 m/s and an air temperature of 40 ºC.

Some of the FC premises may not be able to accommodate very large machines, and the design should reflect this. A maximum length of 15 m has been suggested by FC staff.

SAC staff consider that the best way to meet these objectives is to dip and dry several transplants abreast on a slow-moving conveyor, and are confident that a system based on agricultural produce conveyor technology may be realised.

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Appendix 1 Thermometer calibration

NAMAS calibrated thermometer °C	Digitron type J thermocouple thermometer °C
31.0	29
36.9	35
41.8	40/41 *
45.2	43/44 *

* display alternating between two numbers

Appendix 2 Droplet transport

Capture of droplets from a single transplant (Saturn Yellow dye splashes)

Air speed 4 m/s **Downwind distance** 0.5 m			
Position (1 - top, 5 - bottom)	Splash diameter mm	No. of splashes	Area of splashes mm^2
1	0.5	1	0.20
2	0.5	2	0.39
3	0.5	4	0.79
4	0.5	8	1.57
5	0.5	3	0.59
		Total splash area	3.53

Air speed 5 m/s **Downwind distance** 0.5 m			
Position (1 - top, 5 - bottom)	Splash diameter mm	No. of splashes	Area of splashes mm^2
1	0.5	10	1.96
2	0.5	7	1.37
3	0.5	10	1.96
3 cont.	1.0	1	0.79
4	0.5	8	1.57
5	0.5	3	0.59
		Total splash area	8.25

Air speed 5 m/s **Downwind distance** 1.0 m			
Position (1 - top, 5 - bottom)	Splash diameter mm	No. of splashes	Area of splashes mm^2
1		0	0.00
2	0.5	3	0.59
3	0.5	6	1.18
3 cont.	1.5	2	3.53
4	0.5	6	1.18
5		0	0.00
		Total splash area	6.48

Air speed 5 m/s **Downwind distance** 1.5 m			
Position (1 - top, 5 - bottom)	Splash diameter mm	No. of splashes	Area of splashes mm^2
1		0	0.00
2		0	0.00
3	0.5	3	0.59
4	1.0	2	1.57
5	0.5	1	0.20
5 cont.	1.0	1	0.79
		Total splash area	3.14

Air speed	**6 m/s**		
Downwind distance	**0.5 m**		
Position (1 - top, 5 - bottom)	Splash diameter mm	No. of splashes	Area of splashes mm^2
1	0.5	2	0.39
2	0.5	9	1.77
2 cont.	1.0	2	1.57
3	0.5	3	0.59
3 cont.	1.5	2	3.53
3 cont.	2.0	1	3.14
3 cont.	3.0	1	7.07
4	0.5	20	3.93
4 cont.	1.0	1	0.79
4 cont.	3.5	1	9.62
5	0.5	14	2.75
5 cont.	1.0	6	4.71
5 cont.	4.0	1	12.57
5 cont.	7.0	3	115.45
5 cont.	8.0	1	50.27
		Total splash area	218.14

Air speed	**6 m/s**		
Downwind distance	**1.0 m**		
Position (1 - top, 5 - bottom)	Splash diameter mm	No. of splashes	Area of splashes mm^2
1		0	0.00
2	0.5	3	0.59
3	0.5	3	0.59
4	0.5	4	0.79
4 cont.	1.0	1	0.79
4 cont.	1.5	1	1.77
4 cont.	2.0	1	3.14
5	0.5	3	0.59
5 cont.	2.0	1	3.14
		Total splash area	11.39

Air speed	**6 m/s**		
Downwind distance	**1.5 m**		
Position (1 - top, 5 - bottom)	Splash diameter mm	No. of splashes	Area of splashes mm^2
1	0.5	5	0.98
2	0.5	4	0.79
3	0.5	9	1.77
4	0.5	7	1.37
4 cont.	1.0	3	2.36
5	1.5	2	3.53
5 cont.	2.5	2	9.82
		Total splash area	20.62

Air speed **7 m/s** **Downwind distance** **0.5 m**			
Position (1 - top, 5 - bottom)	Splash diameter mm	No. of splashes	Area of splashes mm^2
1	0.5	7	1.37
2	0.5	28	5.50
2 cont.	1.0	4	3.14
2 cont.	1.5	1	1.77
2 cont.	2.0	1	3.14
3	0.5	17	3.34
3 cont.	1.0	5	3.93
3 cont.	1.5	4	7.07
3 cont.	2.0	3	9.42
3 cont.	2.5	1	4.91
3 cont.	3.0	1	7.07
3 cont.	3.5	1	9.62
4	0.5	14	2.75
4 cont.	1.5	1	1.77
4 cont.	2.5	1	4.91
4 cont.	5.0	1	19.63
4 cont.	7.0	1	38.48
4 cont.	9.0	2	127.23
4 cont.	10.0	1	78.54
5	0.5	20	3.93
5 cont.	2.5	1	4.91
5 cont.	5.0	3	58.90
5 cont.	6.0	5	141.37
5 cont.	8.0	1	50.27
5 cont.	9.0	1	63.62
		Total splash area	656.59

Air speed **7 m/s** **Downwind distance** **1.0 m**			
Position (1 - top, 5 - bottom)	Splash diameter mm	No. of splashes	Area of splashes mm^2
1	0.5	9	1.77
2	0.5	13	2.55
2 cont.	1.0	2	1.57
3	0.5	1	0.20
3 cont.	1.0	2	1.57
3 cont.	1.5	1	1.77
4	0.5	7	1.37
4 cont.	1.5	3	5.30
4 cont.	2.0	3	9.42
5	0.5	6	1.18
5 cont.	2.0	1	3.14
5 cont.	2.5	2	9.82
5 cont.	4.0	1	12.57
		Total splash area	52.23

Air speed	**7 m/s**		
Downwind distance	**1.5 m**		
Position (1 - top, 5 - bottom)	Splash diameter mm	No. of splashes	Area of splashes mm^2
1	0.5	2	0.39
2	0.5	5	0.98
3	0.5	4	0.79
4	0.5	5	0.98
5	0.5	1	0.20
		Total splash area	3.34

Air speed	**7 m/s**		
Downwind distance	**2.0 m**		
Position (1 - top, 5 - bottom)	Splash diameter mm	No. of splashes	Area of splashes mm^2
1	0.5	4	0.79
2	0.5	12	2.36
3	0.5	8	1.57
4	0.5	6	1.18
4 cont.	1.5	1	1.77
5	1.5	1	1.77
		Total splash area	9.42

Air speed	**8 m/s**		
Downwind distance	**1.0 m**		
Position (1 - top, 5 - bottom)	Splash diameter mm	No. of splashes	Area of splashes mm^2
1		0	0.00
2	0.5	20	3.93
2 cont.	1.0	1	0.79
3	0.5	11	2.16
3 cont.	1.0	18	14.14
3 cont.	1.5	7	12.37
4	1.5	5	8.84
4 cont.	2.0	2	6.28
4 cont.	2.5	3	14.73
4 cont.	3.0	2	14.14
5	2.0	2	6.28
5 cont.	3.0	3	21.21
5 cont.	4.0	2	25.13
		Total splash area	129.98

Air speed **8 m/s** **Downwind distance** **1.5 m**			
Position (1 - top, 5 - bottom)	Splash diameter mm	No. of splashes	Area of splashes mm^2
1	0.5	6	1.18
2	0.5	42	8.25
2 cont.	1.0	7	5.50
2 cont.	2.0	1	3.14
2 cont.	4.0	1	12.57
3	0.5	10	1.96
3 cont.	1.0	10	7.85
3 cont.	1.5	10	17.67
4	0.5	3	0.59
4 cont.	1.0	5	3.93
4 cont.	1.5	7	12.37
4 cont.	2.0	6	18.85
4 cont.	2.5	1	4.91
5	0.5	3	0.59
5 cont.	2.0	8	25.13
5 cont.	2.5	6	29.45
5 cont.	4.5	1	15.90
5 cont.	5.0	1	19.63
		Total splash area	189.48

Air speed **8 m/s** **Downwind distance** **2.0 m**			
Position (1 - top, 5 - bottom)	Splash diameter mm	No. of splashes	Area of splashes mm^2
1	0.5	15	2.95
2	0.5	21	4.12
2 cont.	1.0	2	1.57
3	0.5	16	3.14
3 cont.	1.0	3	2.36
4	1.0	3	2.36
4 cont.	1.5	5	8.84
5	1.0	1	0.79
5 cont.	1.5	1	1.77
		Total splash area	27.88

Air speed	**9 m/s**		
Downwind distance	**1.0 m**		
Position (1 - top, 5 - bottom)	Splash diameter mm	No. of splashes	Area of splashes mm^2
1	0.5	34	6.68
2	0.5	30	5.89
2 cont.	1.0	3	2.36
2 cont.	1.5	1	1.77
3	0.5	19	3.73
3 cont.	1.5	4	7.07
4	0.5	51	10.01
4 cont.	2.5	2	9.82
4 cont.	3.0	1	7.07
4 cont.	4.0	1	12.57
4 cont.	5.0	2	39.27
5	0.5	70	13.74
5 cont.	3.5	1	9.62
5 cont.	7.0	3	115.45
5 cont.	8.0	2	100.53
5 cont.	10.0	1	78.54
		Total splash area	424.12

Air speed	**9 m/s**		
Downwind distance	**1.5 m**		
Position (1 - top, 5 - bottom)	Splash diameter mm	No. of splashes	Area of splashes mm^2
1	0.5	25	4.91
1 cont.	1.0	4	3.14
2	0.5	95	18.65
2 cont.	1.0	10	7.85
2 cont.	1.5	1	1.77
3	0.5	30	5.89
3 cont.	1.0	21	16.49
3 cont.	1.5	4	7.07
4	0.5	8	1.57
4 cont.	1.0	2	1.57
4 cont.	1.5	2	3.53
4 cont.	2.0	5	15.71
4 cont.	2.5	3	14.73
5	0.5	10	1.96
5 cont.	1.5	1	1.77
5 cont.	2.0	2	6.28
5 cont.	2.5	3	14.73
5 cont.	3.0	1	7.07
5 cont.	4.0	1	12.57
		Total splash area	147.26

Air speed **9 m/s** **Downwind distance** **2.0 m**			
Position (1 - top, 5 - bottom)	Splash diameter mm	No. of splashes	Area of splashes mm^2
1	0.5	8	1.57
2	0.5	21	4.12
3	0.5	6	1.18
3 cont.	1.0	11	8.64
3 cont.	1.5	3	5.30
4	0.5	2	0.39
4 cont.	1.5	8	14.14
4 cont.	2.0	5	15.71
5	1.5	2	3.53
5 cont.	2.0	1	3.14
5 cont.	2.5	5	24.54
5 cont.	3.0	1	7.07
		Total splash area	89.34

Air speed **5 m/s** **Downwind distance** **8.0 m**		**(40 transplants)**	
Position (1 - top, 5 - bottom)	Splash diameter mm	No. of splashes	Area of splashes mm^2
1		0	0.00
2		0	0.00
3	0.5	1	0.20
4	0.5	2	0.39
5	0.5	4	0.79
		Total splash area	1.37

Appendix 3 Drying rate measurements

Effect of air speed and temperature on drying rate

Date	Drying temp °C	Air speed m/s	Drying time min	No. of transplants	Dipping medium	Shake time s	Drip time s	Shake time s	Condition of transplants after test
25/4/00	35	5	5	15	water	n/a	n/a	n/a	Still wet
	35	5	5	15	water	10	n/a	n/a	Still wet
	41	7	7	15	water	n/a	n/a	n/a	Still slightly wet
	41	7	7	15	water	10	120	10	10 dry + 5 slightly damp
	41	6	7	15	water	10	120	10	7 ex 15 dry
	41	5	7	15	water	10	120	10	6 ex 15 dry, odd spots on others
	41	5	5	2	water	10	120	10	Posn. 1 & 10 only, still water on tips
	41	5	5	2	dye	10	120	10	Posn. 1 & 10 only, both dry
	41	5	4	2	dye	10	120	10	Posn. 1 & 10 only, 1 wet spot on each
	41	6	4	2	dye	10	120	10	Posn. 1 & 10 only, 1 spot on each
	41	7	4	2	dye	10	120	10	Posn. 1 & 10 only, 1 spot on one
	41	7	5	10	dye	10	30	10	Some damp transplants, posn. not important
26/4/00	40	7	10	10	dye	10	120	10	1 drop only on transplant 4
27/4/00	40	7	10	10	dye	10	120	10	Mostly dry at 5 min, odd spot still wet after 10 min
	40	6	10	10	dye	10	120	10	Mostly dry at 5 min, spot on transplant 9 after 10 min
	40	6	10	10	dye	10	120	10	Mostly dry at 5 min, spot at 10 min on different transplants
	40	5	10	10	dye	10	120	10	Mostly dry at 5 min, odd spot at 10 min
	40	5	10	10	dye	10	120	10	Repeat of previous test, same result
	30	5	10	10	dye	10	120	10	Still damp
	30	5	9	10	dye	10	120	10	Still damp
	30	5	12.5	10	dye	10	120	10	Odd spot still wet
	30	5	14	10	dye	10	120	10	Nearly dry
	30	5	15	10	water	10	120	10	Nearly dry
1/5/00	40	5	4	10	water	10	120	10	Quite a few still wet
	40	5	5	10	water	10	120	10	Still some damp patches
	30	5	7	10	water	10	120	10	A few drops remain

Appendix 4 Treatments for physiological damage tests

Date	Treatment no.	Drying temp °C	Air speed m/s	Drying time min	No. of transplants	Dipping medium	Shake time s	Drip time s	Shake time s
2/5/00	1	30	5	7	10	water	10	120	10
	2	30	5	15	10	water	10	120	10
	3	35	5	6	10	water	10	120	10
	4	35	5	12	10	water	10	120	10
	5	0	0	0	10	untreated	n/a	n/a	n/a
	6	40	5	5	10	water	10	120	10
	7	40	5	7	10	water	10	120	10
	8	40	5	10	10	water	10	120	10

Appendix 5 Drying of insecticide-dipped transplants

Date	Drying time min	No. of transplants	Dipping medium	Dryness of transplants
22/6/00	0	10	insecticide	All 10 transplants visibly wet
	2	10	insecticide	All 10 transplants damp & dirty, no spots of liquid visible
	2.5	10	insecticide	All 10 transplants damp & dirty, no spots of liquid visible
	3	10	insecticide	All 10 transplants damp, a couple of wet spots on each transplant
*	3.5	10	insecticide	5 out of 10 stems dry, some dirty spots damp
	4	10	insecticide	4 out of 10 stems dry, some dirty spots damp, 1 transplant dry
	4.5	10	insecticide	Odd spot of damp dirt on 8 transplants
	5	10	insecticide	All transplants dry

Appendix 6 Drying of pre-washed transplants

Date	Drying time min	No. of transplants	Shake time s	Dipping medium	Dryness of transplants
27/6/00	2.5	5	0	insecticide	Stems still wet in places on all 5 transplants
	3	5	0	insecticide	All 5 transplants odd spot of liquid at thick needle bunches, stems completely dry
	3	5	0	insecticide	Stems still wet in places on all 5 transplants, (transplants larger than normal)
	3.5	5	0	insecticide	4 out of 5 transplants dry, wet transplant had extremely thick foliage
	4	5	0	insecticide	4 out of 5 transplants dry, one wet at dirty spot
	3	5	10	insecticide	All 5 transplants damp
	4	5	10	insecticide	All 5 transplants damp
	5	5	10	insecticide	3 out of 5 transplants dry, two wet at rough parts of bark