TRENDS IN FORESTRY MECHANIZATION AND CONCEPTS FOR CONTAINERIZED SEEDING IN NEW ZEALAND

by

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ABSTRACT

Review of the literature on the future of wood resulted in the conclusion that long term future demand will be for large quantities of cheap fibre. There is likely to be a reduction in emphasis on the form and dimension of individual trees.

Mechanization and automation are defined and the relative importance of tree establishment within the total forest industry noted. Some general principles of forest mechanization are proposed and discussed.

The New Zealand potentials for wood fibre production and forest mechanization are analysed. Reforestation history of radiata pine (Pinus radiata, D.Don.) in New Zealand is briefly described, and the basis for, and problems with, bare-root planting are discussed.

An alternative tree establishment system, involving the precision setting of a bullet-like container enclosing a seed, is proposed. The case for this theoretical system is argued on the basis of its potential biological equality with bare-root planting, which the author considers to be sufficiently promising to be worthy of field investigation, and its suitability to total mechanization. Some possible costs of the system are calculated and potential benefits are postulated. It is concluded that the concept is worthy of careful field study in New Zealand.
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1. INTRODUCTION

"....we are in the midst of the super-
industrial revolution.
If failure to grasp this fact impairs
one's ability to understand the present, it
also leads otherwise intelligent men into
total stupidity when they talk about the
future. It encourages them to think in simple-
minded straight lines.......
....Such linear projections characterize most
of what is said or written about the future.
And it causes us to worry about precisely the
wrong things.
One needs imagination to confront a
revolution."
(Future Shock, P 186 - Toffler, 1970)

This thesis is concerned with a very small part of Toffler's
(1970) changing world. Being concerned with forestry, it must
look to the future. Concern with mechanization places us in a
field of such bewildering evolution that perhaps even the most
vivid imagination would be too conservative.

In mundane terms, an attempt is to be made to forecast a
possible future mechanized system of reforestation (or
afforestation) in New Zealand radiata pine (Pinus radiata, D.Don.)
plantation forestry. These are the limits, but they themselves
are part of a much larger framework with which we must be concerned
- world forestry and its major product, cellulose, the future of
which is of major significance to the tiny topic which will be
examined in this thesis.
World Wood Trends

There are two major questions in any discussion of the future of industrial cellulose. The first is the ability of world resources to supply projected future demands, and this is closely linked to the question of the nature and extent of substitution for cellulose by alternative materials. The once popular idea of an imminent world shortage of wood has now generally been replaced by the hypothesis that resources are adequate to meet foreseeable demands, but that cellulose will have to be obtained in very different ways compared to today (Streyffert, 1966; Anon., 1966). The new techniques required would include tapping of presently untouched reserves, intensification of silviculture, utilization of the tropical hardwood resource, breeding new strains, etc.

It is at this point that the threat of substitutes must be mentioned. The most pessimistic attitude (from the point of view of cellulose) in this respect that the author has seen, is that of Dawkins (1969). He saw little prospect of intensive silviculture and mechanization maintaining sufficiently low wood procurement costs to fight off the challenge of substitutes. The still large reserves of fossil fuels and the ubiquitous nature of the AlFeSiCa minerals - and the relatively concentrated forms in which these occur compared with the scattered nature of cellulose - could mean the gradual replacement of cellulose by plastics and AlFeSiCa derivatives as wood costs increase.
Dawkins dismissed the argument that we will require all our resources, by the contention that the substitutes are so abundant as to be capable of filling our wants until technology is such that the substitutes themselves will be renewable through recycling. Thus the ultimate advantage of cellulose - its renewability - might be of little help in the struggle against alternatives.

These arguments are, of course, concerned with the future and we are learning increasingly to be wary of the traditional forecasting methods involving extrapolation of past trends. Some of the most unexpected opinions have proved to be right and vice versa. Dawkins' opinion, then, must be considered.

There are, however, some comments regarding the kinds of energy that would be needed to allow some of his ideas to actually occur that require discussion. The dream of future supplies of unlimited cheap power have been dampened somewhat by Lovering (1969). He noted the large capital costs required by, say, nuclear energy production for transmission, waste disposal and operation. He noted also that cheaper energy would little reduce the total cost of mining and processing rock, since the major components of this are capital and labour.

Dreams of extracting metals from ordinary rocks rather than ore were also dampened by Lovering when he noted the huge amounts of waste produced in the extraction of metal from ordinary granite.
The ratio of waste to metal would be in the order of 2,000:1.

The question of future power production is very complex and cannot be fully discussed here. There is, however, little doubt that new sources of energy will be a wonderful asset, but their greatest value is likely to be in their capacity to provide desperately needed power when the fossil fuels are exhausted. One forecaster places the remaining life of the world's fossil fuels at 2-3 centuries for coal and 70-80 years for petroleum and natural gas (Hubbert, 1969).

Recycling of cellulose fibres is already an established fact and its technology is well ahead of that of its competitors. The current recycling rate in the United States pulp and paper industry is some 18-20%. Countries such as Japan and West Germany have reached rates as high as 35-40% (Gordon, 1971). Rising wood prices forecasted for the United States by Josephson (1971), will only serve to improve the economics of recycling.

A full account of all the various projections of the future of cellulose is outside the scope of this thesis. The subject is confused with argument and counter-argument that bracket the whole range of the opinion spectrum from acute pessimism to bouncing optimism. I have no alternative but to draw from this kaleidoscope a few subjectively selected points to allow the setting of a context in which to build this thesis.

It is generally agreed that the greatest single component of the cost of finished cellulose products is the cost of wood.
procurement (Williams and Haas, 1971). In Norway, as but one example, 80% of the cost of sawn lumber is involved in the stump-to-mill process (Pers.comm.). Wood procurement, and forest operations generally, have long been labour intensive and labour costs have been spiralling alarmingly. Williams (1971) noted that labour costs in eastern Canada have risen by 92% since 1960.

The mechanization already introduced into eastern Canada (primarily wheeled skidders) has slowed the wood cost increase to 13% over the last 10 year period, but timber companies still pay 40% of their costs in labour and 65% of this is involved in the stump-to-roadside phase of logging (op.cit.).

Labour costs in eastern Canada are so high that manual planting of cutovers has reached as high as $70 per acre (excluding stock) and, with no mechanization in sight, companies are looking to assisted natural regeneration as the only way of economically restocking their cutover land (Page, 1971).

With no prospect of a slowdown in the labour cost rise, forestry, at least in the currently major wood producing countries, is experiencing a cost/price squeeze similar to that in the agricultural industry. The latter led to the intensive agricultural mechanization described by Barber (1971). Such intensive mechanization is urgently needed by the forest industry to reduce, or at least maintain, wood costs at a level which will allow, in turn, the maintenance of the competitive position enjoyed by cellulose.
In addition to labour cost, labour availability and quality are factors in the argument for increased forest mechanization. Forest work, for all its glamour to some, is generally remote, dirty, hard, uncomfortable and, at times, dangerous. Despite the high pay, logging camps experience very high turnovers necessitating frequent retraining and reducing man-day production. The cost of maintaining subsidised camps or, increasingly, commuter transport, adds substantially to the overheads. High labour costs are, in part, a result of the need to combat the more favourable working conditions of the urban environment.

Machines, particularly the latest developments with increased automation, air-conditioned and/or heated cabs etc., isolate the man from the dangers and rigours of the environment - and consequently free him from its work-sapping limitations such as mud, cold etc.. The psychological attractions of machines - considered important in the farming industry (Barber, 1971) - and their demands for greater skill and less brawn, attract a better class of worker, interested and willing to be trained. The very much reduced work force allows faster, more efficient commuter operations which ensure that the off-duty, more urban-oriented demands of the skilled machine operator can be met.

Demands for wood are rising and although the raw material supply for the manufacture of what might be called reconstituted wood is likely to be adequate, other supplies may not. Josephson
(1971), speaking for the United States, noted

"...Under present levels of management and no serious overcutting, foreseeable supplies of lumber and plywood will soon fall short of potential demands, with a consequent increase in timber prices and greater use of competitive materials."

Toffler (1970) has noted the problems of forecasting the future in a world of rapidly accelerating technical innovation and increasing transience. It would appear, therefore, to be dangerous to attempt to forecast in what form the world of a rotation hence (even the relatively short radiata pine rotation) will require cellulose (assuming it wants it at all!!). It seems safer to assume that the problems of cellulose utilization will be solved in the laboratory and translated into industrial processes. Form and dimension of the trees grown would then be of less importance in their utilization than they are today.

It is concluded then, that the future demand will be for large quantities of low cost fibre with but limited importance attached to tree form and dimension. Intensive mechanization is necessary to obtain the low cost and is favoured by the reduced form and dimension demands. This development is vital to the health, and even the future existence, of the forest industry.

Definitions

It is appropriate here to define the words mechanization and automation as they will be used throughout this thesis. Mechanization
is defined as the replacement of human and/or animal muscle power with that of a motor-driven machine. The operator retains direct control of the activity by his manipulation of the machine controls, but his physical strength essentially is not utilised as a power input.

During the development of any particular operation, there will be degrees of mechanization. Thus, in tree felling, the power input required of man decreased as axes, crosscut saws, chain saws and finally tractor-mounted hydraulic shears were developed. (The axe is technically a simple machine, although not covered by the above definition of mechanization.)

A process, or part of a process, becomes automated when its various component activities can be carried out by the machine without the direct and immediate control of the operator. The automatic cycle is set in motion by the operator who then becomes only a watchdog, capable of intervening and stopping the cycle should this become necessary or desirable. As an example, the processing stage of the Koehring-Waterous shortwood processor is automated. The operator loads a tree into the processing tower which proceeds to delimb and buck the bole into predetermined lengths automatically. The operator is freed to manipulate the cutting and loading of a second tree.
Relative importance of tree establishment.

An overview of the forest industry clearly indicates that the establishment phase, and tree planting in particular, constitute a small percentage of the total cost of growing and delivering wood to the utilization plant. Detailed logging costs have not been published in New Zealand but an average figure of $NZ600 per acre was generally accepted at a recent symposium (Chavasse, 1969). The author fully appreciates that a potential reduction in planting cost of up to 90%, even after the addition of compound interest, may be of little importance when compared to the total wood cost to the mill.

Despite the relatively low amounts required, however, money for tree establishment, particularly reforestation, traditionally has been severely limited in New Zealand except for a brief period in history - 1925-35 - known as the "planting boom". Also, the work has often been thought of as a means of providing work for temporarily unemployed workmen - a hangover from the days of the Great Depression - despite the fact that very small proportions of recent annual programmes have been completed as make-work projects.

If funds are to continue to be limited and if, as the author believes, labour is to be increasingly difficult to obtain, development of cheap, highly mechanized systems is imperative. No apologies need be made, then, for the following concentration on tree establishment. The relative position of this phase within the forestry picture is recognized, but the allocation of priorities for possibly limited development funds is not the author's concern.
at this time.
2. GENERAL PRINCIPLES OF FOREST MECHANIZATION.

Compared with some other industries, mechanization in forestry is relatively primitive. Automation in the industry is almost non-existent. It is possible, however, to enunciate some general principles of forest mechanization, drawing on experience from other industries and from the limited development in forestry to date. These points are discussed below.

The Systems Approach.

McColl (1969) has defined the systems approach as one of "a recurring cycle of goal orientated steps to lower order objectives". He stressed the importance of the correct choice of goal in technological progress and his words again perhaps best state the consequences of a wrong choice. "To choose the wrong end is to try to solve the wrong problem; to choose the wrong means is only to try to live with an unoptimised system." In a highly critical account of the progress of logging mechanization in eastern Canada, he noted that the industry's continued preoccupation with means has led to repeated disenchantment with mechanization developments and a failure (he claims) to reduce wood costs to the required level.

An example of this argument is to be seen in the recently developed shortwood harvesters such as the Koehring. This is a highly
sophisticated machine, which even incorporates a considerable degree of automation. It is still producing short wood, however, a system that was designed for man and horse, to supply the mills whose wood rooms have remained basically unchanged since the days of labour intensive logging. It comes as no surprise then to learn that even after two years of operation, direct costs of wood produced to roadside by this machine are no lower than the previous tree-length skidding and hand-bucking (Page, 1971).

The means, that of mechanizing the shortwood system, has been achieved, but the end, the shortwood system itself, remains unchanged. This despite a wealth of literature that notes the advantages of the treelength and full-tree systems (McColl and Pepler, 1950; MacArthur, 1969; Kirkpatrick, 1964; Mitchell, 1966), and forecasts of a continuing decline in the shortwood system's use. (Hughes, 1970). The development of this machine provides an example of sub-optimisation about which McColl says: "In general, optimisation of each sub-system will not lead to a system optimum." The large investment in the machines may, in fact, bear out McColl's words that "...improvement of a dominant sub-system may actually worsen the overall system."

There are other examples of sub-optimisation to be found in forestry, most of which result from attempts to mechanize a particular operation rather than first defining the ultimate goal. Thus windroweing of logging debris in the southern pine region has created
a situation where full advantage cannot be taken of planting machines; a hand crew must be retained to plant the windrow area itself. In some areas this has resulted in slightly higher costs for machine and supplementary hand planting combinations compared to fully manual systems (Page, 1971). Labour shortages force the maintenance of the planting machines.

The current battle between bare-root and container-grown stock is too often reduced to a comparison of two methods of planting when, in fact, it is two systems of reforestation which are to be compared. A look at the systems reveals the superior suitability of containers to mechanization and a new dimension is given to the comparison.

The dangers of sub-optimisation are to be found between, as well as within, the various phases of forestry. Perhaps the most neglected of these interrelationships is that of logging and reforestation. If logging is regarded as the first stage in the regeneration or conversion of the standing forest to a new stand, then it becomes a sub-system and the dangers of sub-optimisation are real. There are many cases of these dangers being ignored. Page and Spiers (1969) in a discussion of the interrelationships between logging and re-establishment under New Zealand conditions, noted how logging could often be manipulated, by altering timing, hauling method etc., to obtain better and cheaper reforestation. They concluded by saying, "Intelligent control of logging operations is a
most desirable tool of forest management. The forest manager must have an appreciation of the cost problems that are the immediate concern of the logger and yet retain the critical position necessary to make viable his position as land manager."

Smithers (1964) stated the obvious when he noted that savings in logging costs resulting from mechanization must be sufficient to offset any additional silvicultural costs that might occur.

Regarding logging as a sub-system within the total fibre growing system is, encouragingly, an increasing concern of forest managers. In the black spruce forests of parts of Ontario, the additional cost of modifying logging to an alternate strip system - approximately $16/acre - in order to obtain what is considered satisfactory natural restocking, is judged preferable to the $50-70/acre required to implement what was claimed as somewhat unreliable artificial restocking methods currently available. (Page, 1971). Quantitative definitions of satisfactory stocking were not available. At least one forest company in the southeast of the United States now plans its logging and reforestation activities as one exercise (op.cit.).

A brief examination of other industries, which have developed a higher degree of mechanization and automation than forestry, illustrates the application of the systems approach. The production line in the car factory is perhaps the best known, but the approach can be seen also in the more closely allied agricultural industry. The desired end in wheat harvesting is clean threshed grain. No
threshing machines are being designed today; instead there is a basic design of combine harvester which is produced by all manufacturers and which is suitable for all variations in the individual wheat crops such as straw length, yield per acre etc. The machine design is such that it produces conditions favourable for the next operational phase, straw baling, by "windrowing" the straw, facilitating pick-up by the baler.

Although the systems approach, as defined by McColl, has become a science in its own right - hence systems engineer - the term as used here includes the wider meaning of the necessity for an overview during the design of any operation or machine. If it is assumed that the forest land under consideration is intended for fibre growing on a sustained yield basis, then the effects of the machine or operation on the site itself are to be included. The term ecosystem is relevant and the importance of considering the effects of mechanization upon it are discussed later.

**Regional and Site Effects.**

There are a number of factors in any forest region which affect the potential for and economic success of mechanization. These are:-

- size and number of ownerships;
- size of contiguous area;
- site: uniformity and productivity;
- market diversity;
- social background of region, including cost and availability of labour;
- terrain;
- climate;
- availability of technical expertise, either through domestic industry or importation, at the design, manufacture, supervisor, operator and maintenance levels.

Particular operations are in themselves sensitive to more detailed factors. For example, productivity of the current single tree harvesting machines is dependent upon individual tree size and, to a lesser extent, volume per acre (Aird, Cottell, Winer and Bredberg, 1970; Hannula 1970). The above points, however, are general factors which would be pertinent to all forest machines, although relative values would vary with different systems and functions.

The higher capital and other fixed costs of machines make them dependent on the larger, capital-rich organizations for their purchase. The efficient organization of work methods and maintenance facilities also generally relies on possession of a fleet of machines, a further point in the favour of large organizations.

Increasing sophistication - and hence expense - of machines
results in high fixed costs. There is therefore a strong incentive
to maximize machine utilization (Silversides, 1966), and reduce
unproductive moving times to a minimum. Large contiguous areas,
therefore, are generally necessary for the use of the more complex
machinery. These areas are further restricted by the necessity for
their boundaries to include only those conditions under which the
machine can work. Mechanical systems tend to be less flexible than
their labour intensive counterparts in their products and the
conditions required for effective operation. Mechanization almost
invariably necessitates greater standardization.

Mechanization increases man-day production and therefore is
encouraged as labour becomes scarce and/or expensive. Notwithstanding
the frequent need for operator and maintenance staff training
(mentioned later), the introduction of machines can reduce reliance
on human skills - eg. tree planting machines - and thus labour
quality problems can be a spur to mechanization.

Terrain, both through topography and ground conditions,
exerts a strong influence on mechanization potential. Despite a
very large industrial and military research effort, steep broken
slopes still provide a formidable barrier to machine utilization.
There is an urgent need for a breakthrough in prime moving techniques
to allow the application of mechanical systems to the steeper
country (Rennie, 1971). This is especially true of New Zealand where
some 50% of the future exotic forest land is currently classed as
non-tractorable (Chavasse, 1969).

Terrain conditions and hazards such as mud, snow, vegetation, insects, snakes etc., which have previously limited the progress of men and animals, are a decreasing problem to modern machines. For example, the introduction of the Drott feller/buncher and wide-tired grapple skidders, has allowed the logging of some swamp lands in the southeast of the United States which had previously proved too inhospitable for manual methods (Page, 1971). The necessity to close down the old labour intensive logging methods during extreme cold and the spring break-up in eastern Canada, was one of the spurs to logging mechanization in that region (op.cit.).

Increasingly sophisticated machines demand, in turn, a more advanced level of technical expertise at the design, manufacture, supervisor, operator and maintenance levels (Aird, Cottell, Winer and Bredberg, 1970; Silversides, 1966; Barber, 1971; Morgan, 1971). The availability of all these factors, either within the domestic industry or by importation, is of extreme importance to the successful introduction of mechanical systems to any given area.

The term mechanization covers a wide range of intensities and mechanical sophistication and to generalize on the conditions required for the introduction of any system is dangerous. But a summary is desirable and the foregoing would suggest that any form of mechanization is favoured by large owners (or the economic support of same) of large contiguous areas of relatively even-aged and
uniform forest, grown to produce a limited number of raw material forms. Topography is currently a limiting factor, but other, environmental and social conditions which result in scarce or expensive labour, favour mechanization. It is well to note here, though, that there are dangers in over-mechanization if available technical expertise is insufficient or social problems, such as unemployment, may result.

New Zealand's particularly favourable position, with some reservations, in relation to these factors, will be discussed later.

Influence of work methods and organization.

Intensive mechanization necessitates profound changes in an organization. Personnel needs change, as does the type of man that is attracted to the industry. Barber (1971) noted the psychological effect of agricultural machinery in slowing the drift of labour towards the more sophisticated work conditions of the cities. The modern worker is looking more and more for status and job satisfaction (Morgan, 1971); operation of a complex machine can supply these wants and provide a kudos that the manager would be foolish to ignore. If automation fulfills its correct role in forest machine design, this trend will be continued and the monotonous manual operations, which can result from partial mechanization (e.g. feeding trees to a planting machine), will at least be minimized.

If the forest worker of the mechanical age is motivated
differently at his job, he is also likely to have very different wants during his off-duty time. Bush camp life is unlikely to be acceptable and commuting operations are likely to become even more essential than now. Reduced man-power requirements, for a given level of production, however, will mean smaller units of men to be moved allowing the use of small, fast means of transport. Aerial commuting, at least on a 10 days on 4 days off basis, is already a reality in isolated parts of British Columbia.

Although machines are increasingly isolating the operator from the dangers and discomforts of the bush environment, they are in turn producing their own forms of safety hazards which demand new methods in safety training. Perhaps the most insidious of these are the still incompletely understood health hazards resulting from such factors as vibration, noise and fumes. Swedish surveys have shown that 49% of forest workers suffer to some degree from white finger disease, caused by chain-saw vibration. (Sorenson 1969). New forms of safety training, new safety standards, and much more research is required on these machine-age safety hazards. As machines and systems become more sophisticated, so do the worker hazards become less obvious. Ergonomic studies are now employed by many manufacturers in the design of new machines and hopefully many of the potential problems can be alleviated at this stage.

If safety training becomes more complex with increasingly sophisticated mechanization, so too does the process of job training
of operators. In many parts of North America, preoccupation with the machinery itself has led to a neglect of the need for operator training to maximize machine life and production (Morgan 1970). Differences between crews and individual operators have been found to be more significant in affecting the production of a machine than any of the environmental factors (Aird, Cottell, Winer and Bredberg, 1970; Winer, 1965). Taking the economic approach, Gagne (1971) noted how operator training can increase machine availability and showed the presence of an optimum level of investment in this aspect.

Morgan (1971) noted that in the Tennessee Valley, sawtimber loggers alone lost $2.6 million in wages due to down time. The majority of this he attributed to inefficient use of men and machines and failure to apply the work systems demanded by the more sophisticated methods of logging.

Training and the application of new methods are required at the supervisory and management levels as well as at the operator level (Silversides, 1966). Aird et al. (1970) found that intelligent supervision of Beloit Harvester operations - involving such factors as reserving difficult areas for daytime operation only and matching machine differences to terrain differences - had a considerable effect on production. They concluded:

"The best operations were distinguished by effective management support. This included the provision of good repair and maintenance facilities and procedures,
the provision of well-trained foremen with the
necessary support facilities of vehicles and
radio communication, and the provision of
skilled and well motivated operators... The
different field studies have clearly confirmed
the important role that effective management
plays in the conduct of a logging operation."

The author gained the same impressions from observing a
number of different site preparation operations in the southeast of
the United States (Page, 1971) and there is no doubt that the
principles apply to all highly mechanized operations.

Multi-shift working is becoming more and more prevalent in
forestry operations, a trend which is forced by the high fixed
costs of machinery and the need to carry out large programmes with
the lowest possible capital investment in machinery. Night work
brings with it its own crop of safety hazards and organizational
difficulties, but increasing experience and development of powerful
and portable lighting units are steadily increasing this practice.

The working of machines in teams is a further procedure which
greatly increases the efficiency of mechanical systems. Concentration
of machinery reduces the logistic problems of maintenance provision
and operator transport. It is a particularly useful technique in
many land preparation operations where there is a danger of tractors
becoming bogged or 'bellied'. Other machines in the vicinity can
render assistance and prevent expensive hold-ups in production.

In a recent article, Gagne (1971) has pointed out that there
is an optimum level of investment in all the factors mentioned above.
Above certain levels of investment, diminishing returns per unit
investment provide a warning of the dangers of over, as well as under,
expenditure. He noted that the tailoring of equipment to the particular conditions to be encountered is a further way of increasing job efficiency but that this factor too, is subject to the law of diminishing returns.

Mechanization may often allow the introduction of new systems. Barber (1971) noted a number of examples of this in the agricultural industry including hay baling and silage harvesting. Transportation of pulp wood from forest to mill in chip form (Silversides, 1959; Logan, 1965) and weed control by mechanical means at the site preparation stage (Chavasse, 1969), are two examples in forestry.

There is also little doubt that the introduction of mechanical systems will lead to a change in approach to many silvicultural techniques. Silversides (1966) pointed out the probability of a move to the extensive application of mechanized silvicultural techniques at the expense of specific site care, and Adamovich (1968) has sounded the death knell of silvicultural selection if thinning is to be mechanized.

Wambach (1969) noted that two schools of thought exist, at least in North America, regarding the inter-relationships of mechanization and silviculture. One school favours the adoption of mechanical methods when, but only when, they will assist in attaining silvicultural objectives. The second takes the view that silviculture can and should be adapted to meet the demands of economically necessitated mechanization.
Preoccupation with this controversy, however, should not obscure the fact that the demands of mechanization are often in harmony with those of silviculture. The demands of silviculture are often flexible over a wide range and choosing the situation from this range which most favours the machine or system prejudices nothing. For example, Wambach (1969) and James, Tustin and Sutton (1970) have shown the silvicultural flexibility of initial stand spacing and configuration, within wide limits. There often is no reason why a combination of spacing and configuration most suited to mechanization (wide, rectangular spacing) should not be adopted.

Some extra costs may be involved in such adaptations of silviculture. Examples are the need to control weed and understorey under plantations of widely spaced trees and the extra cost of protecting monocultures. Although optimisation of the discounted cost/benefit ratio would generally be the aim, inclusion of all the costs and benefits is essential. The short term economic benefits and some of the costs of the introduction of mechanical systems, and any necessary silvicultural modifications, are generally known. Knowledge of all the factors involved, however, is generally incomplete and the cost/benefit ratio approach must, therefore, be used with caution.

The influence of work methods and organization on the efficiency of mechanical operations has been badly neglected. This is despite the fact that many workers have found the various factors involved to be paramount in the level of productive output achieved.
This neglect is probably due to the difficulties of quantifying the various aspects and the consequent reliance on subjective opinion. Questions of management efficiency are obviously delicate subjects and an objective onslaught on long entrenched ideas and philosophies faces more than the usual number of obstacles. Likewise, necessary changes in worker motivation face considerable resistance from the traditional suspicions of organized labour.

Although an increasing number of factors which influence the efficiency of any particular system or operation are being quantified, there still remain a number of intangible costs and benefits to any mechanical system. It is likely that these will continue to defy anything other than a subjective or qualitative assessment. For example, neatness within a plantation is a definite asset to mechanization of forest operations but its exact dollar value is elusive.

The aesthetics of mechanical operations are not only non-quantifiable, they can be regarded as either a benefit or a cost depending on the outlook of the beholder. Nevertheless they are factors which must be considered - possibly to an increasing degree - in the evaluation of any system. Schreiner (1970) claimed the ordered, farm-crop-like appearance of sycamore silage operations as one of the system's advantages.

Technology is developing at an accelerating rate and there is little doubt that progress in our ability to maximize its benefits
is beginning to lag. But Toffler (1970) has warned of far more serious consequences of our burgeoning technology - the confusion and numbness of future shock as technological revolutions succeed one another ever more frequently, even within one lifetime. For some, a defence is found in a complete commitment to technological progress for its own sake. Thus the means becomes the end itself and the concept of an optimum is meaningless.

This thesis is no place for such a philosophical discussion but it is well to remember that already we are confused and divided over the impact and future of our technology and that we cannot measure all the benefits and costs. The dangers are as real in forestry as they are in any field of human activity and concern for mankind must demand a watchdog on all technological development.

Development and Manufacture.

The Royal Commission on Farm Machinery in Canada (Barber, 1971) reported a number of disturbing factors concerning farm machinery manufacture. Formed at least partly because of farmer suspicion of the high prices they were charged (e.g. price per horse power is the same for large and small tractors), the Commission investigated machinery prices compared with manufacturers' costs. It found that the 85% rise in farm machinery price since 1949 (compared to a 3% rise in the price of wheat) was at least partly a result of manufacturers being unable to absorb rising raw material and labour costs. Sophisticated machines also require more expensive
skilled labour and complex processes in their manufacture. As machines become larger and more complex, fewer are required and the manufacturer begins to lose some of the economies of scale.

Not all of the current high prices could be explained by such legitimate economic reasons as above, however. Much of the large difference between machine prices and manufacture costs was caused by the very high costs of distribution and dealer inventories. The Commission also concluded that there was still room for significant economies of scale in manufacturing. An estimated 7-8\% could be saved by consolidation of the industry into fewer firms. With some 30-40 firms currently manufacturing centre frame articulated vehicles, a similar study of the forest industry could well be warranted.

The Barber report notes that the manufacturing industry has almost a monopoly of the technical expertise in agricultural machinery design. No independent government or university research and testing stations exist which could also give impartial advice to farmers. Such a situation is particularly serious in farming where the customer is generally a private individual. Differences between agriculture and forestry are significant here. In forestry (with the possible exception of farm forestry) the growers are generally fewer, have large holdings and are not often individuals. The resources of the timber grower, especially co-operatives of growers, are great and the question of who should lead in machinery development - the user or the manufacturer - is important.
McColl has discussed this question at considerable length. He stated that the user has "20-30 times" the incentive of the manufacturer in innovative endeavours. He therefore concluded that we have two choices - between the "imitative-competitive" route traditionally controlled by the manufacturer and the "innovative-cooperative route that can, and should, be controlled by the user firms". Although accepting that the manufacturing firms have an important contribution to make at the machine production stage, he felt that their natural interests are frequently opposed to those of the user at the conceptual and developmental stages. The manufacturers are not co-ordinated, and non-industry centred.

He convincingly illustrated his point with the example of the rubber tired skidder. Now manufactured by some 30-40 firms, it is interesting to compare these machines, which have had until recently a service life of around 5,000 hours, with the original Bonnard Logger MK. IV.. This prototype, plus the five preproduction models that were made, saw life on two operations. They were operated in excess of 10,000 hours without adequate spare parts or technical support. They therefore had a life characteristic more than double that of the imitations produced in the last decade. The Bonnard's subsystems such as power shift transmission, positive differential locks, integrated hydraulic systems etc., have only recently become available. Yet the Bonnard Logger, a result of industry sponsored research, was produced in 1955. It was McColl's
opinion, though he quotes no calculations, that at least $100 million has been lost by the industry in allowing this to happen.

In a recent tour of North America (Page, 1971) the author found that the majority of forest machinery design, at least outside logging, was being carried out at the user level. Originating often from the forestry staff, the new ideas would be translated into a prototype by small local engineering companies or by company employed personnel. The larger organizations felt that this was a far more satisfactory situation than relying on the large manufacturing firms' somewhat limited interest in forest machinery. Weyerhaueser's Equipment Development Task Force at Plymouth, N.C., was the most highly organized example of this approach that was seen.

Similar approaches were being adopted in logging machinery design also. St. Regis Paper Company's logging engineering division is developing a number of low cost, hydraulically operated attachments to fit a variety of tractors which will be within the price range of the small private logger so prevalent in the southeast U.S.

International Paper Company's Busch Combine and TH-100 thinning machine, now being produced by an equipment manufacturer, are classic examples of the user led approach to new machinery developments.

With reference to logging machinery, many of the user firms have combined into co-operatives - viz. American Pulpwood Association, Canadian Pulp and Paper Association Swedish Logging Research Institute. Such a co-operative effort is very much needed in the
field of afforestation equipment. The manufacturer generally is going to show little interest in the high risk area of forest machinery design and it is up to the co-operative efforts of the users to produce the prototypes and prove their worth.

The great multiplicity of manufacturing firms will also mean that any research that they might do is in danger of considerable duplication which can only result in an eventual higher selling price.

**Effects on Environment and Long-term Site Productivity.**

It was noted above that mechanization almost always necessitates greater standardization. It demands uniform crops on which to work which, in many situations, may mean a monoculture. It is well known that the most stable ecosystem is the most diverse. It follows then, that mechanization may lead us to less stable ecosystems.

Although not developed in response to the demands of mechanization, the failure of some spruce monocultures in Saxony and Switzerland during the nineteenth century (Troup, 1955) is one of the most often quoted examples of the dangers of forest monocultures. (Although the picture is confused by cases of poor siting of some of the spruce plantations.) Deterioration of second rotation radiata pine by an average of one site class in South Australia, is a more recent example. Lewis and Harding (1963) noted that this could reduce the yield of second rotation crops by 25%
compared with the original plantations. Although fertilizer application is currently restoring the lost productivity, the problem is by no means completely understood.

Such experiences are, of course, common in agriculture and are counteracted there by the injection of yet more technology in the form of fertilizer, pesticides, plant breeding etc., and rotation or alternation of crops. Mackintosh-Ellis, the first Director-General of Forests in New Zealand, when proposing the establishment of pure radiata pine plantations during the 1920's, anticipated similar problems but considered potential growth rates to be such that the forest industry would be able to afford the necessary expenditure to cure any problems that arose. Experience to date with two pest epidemics would bear him out.

Despite such successes in agriculture and forestry, however, our efforts are generally curative rather than prophylactic, and furthermore we can, of course, cure only those problems we are currently capable of detecting. The ever stronger protests of concerned groups that we may be creating future problems of unprecedented seriousness cannot be ignored. Rachel Carson, with the publication of her Silent Spring in 1962 began a controversy over the use of chemicals in agriculture and forestry which still rages today (Graham, 1970).

The flood of such literature which currently assails us, however, may blind us to the fact that even the technical innovators themselves are calling for a greater understanding of the implications
of the new techniques. Rennie (1971), in a review of world progress in mechanization of forest site preparation, made the following relevant points.

"But most of the stated needs for lowering costs and optimising the technique are really calling for a greater understanding of the underlying biological changes that are being wrought by these techniques. The better predictability of fire, the more effective use of herbicides, the conversion technology in Australia, the optimisation of scarification and ploughing and the ideal network of drains in peatland afforestation are all really requesting that the relationship between the technique and the biological characteristics of the system be better known, so that the technology can be modified to bring about the desired biological change."

He made the plea that our approach to the problems should be such that it "...matches the sophistication of some of the technology that now exists." He proposed that the "...silvicultural situation - its problem or opportunity - be the focal point of organization, rather than the technique." Here is another plea that we should get the end sharply into focus and beware of preoccupation with the means.

Barber (1971) has commented that, in Canadian agriculture, at least, fundamental biological research is lagging behind machine development.

Forestry faces an additional problem, compared with agriculture, with respect to public reaction to mechanization. The recent upsurge in public concern for our rural lands has come long after mechanized farming was introduced and such methods have been, in many respects, accepted. In the United Kingdom, for example, although bewailing the
reduction of such familiar rural features as hedgerows, the public generally sees intensive, orderly agriculture as a good thing and, moreover, is content to merely look at it.

But the modern recreationist wants to do more than look at forests. He sees them as his rightful playground and his preconceived ideas of forest beauty are unlikely to be in agreement with the demands of intensive mechanization. Large cutovers, regularly spaced, evenaged single species stands, the roar of machinery 24 hours a day and 7 days a week, and restricted roads are not likely to satisfy his demands.

Public education will no doubt go a long way towards settling some of the conflicts. The hunter will find more game in the intensively managed forest and the roads, when he can use them, will improve his access. The myth of the desert-like pine plantation, devoid of all bird life, has been exploded at least in New Zealand (Jackson, 1971).

It would be naive, however, to believe that the public will come to accept all the requirements of forest mechanization or that it will be possible to "educate" them to a new set of values. As with so many similar situations the answer will be a compromise. Where the short term economic demands of mechanization are at variance with the requirements of other forest uses - and this includes more than just recreation - this conflict becomes a further cost of the mechanical system and as such must be weighed against the benefits.
Direct machine effects such as soil compaction, accelerated erosion and top soil removal can have severe effects on long term site productivity, stream water quality etc.. The author has been shown how indiscriminate bulldozing of cutovers in parts of Virginia had reduced site index which was there dependent upon the depth of the top soil over the clay-loam subsoil (Page, 1971).

Top soil removal and compaction of landing sites on the pumice country in New Zealand necessitates expensive rehabilitation operations, or demands the withdrawal of these areas from the productive forest estate. From 8 to 18% of the logged area can be alienated in this way (Page and Spiers, 1969). If current logging techniques are ever compared with a future alternative system, that does not create the large areas of compacted landings, the cost of this land alienation must be measured against the current methods.

The word 'system' is a dangerous one - meaning different things to different people. But it does not change too much the sense in which the word has been used in this thesis up to now, when we note that every forest is an ecosystem. The demands of cheap mechanized cellulose production force us more and more to modify our forest ecosystems to less diverse and consequently less stable forms. Defence against this instability takes the form of increased management inputs. But the dangers of suboptimisation are as real in the forest ecosystem as in any other system and much more research and forethought is required to ensure that these are avoided as we
introduce mechanization and its accompanying silvicultural and management modifications to the forest.
3. SOME NEW ZEALAND POTENTIALS.

In this section an attempt will be made to focus the points of the previous discussion on to the particular situation in New Zealand. For convenience the section will be divided into two; a) the potential for fibre production within the world context, and b) the particular advantages and problems of mechanization of New Zealand's exotic plantation forestry.

This topic could be the subject of a thesis in its own right and a summary only has been attempted here. Much information has been drawn from the forestry sector of The National Development Conference (1969) and the reader is referred to this report, and to the detailed working party sub-reports, for comprehensive examination of New Zealand's forestry future.

a) Potential for fibre production.

Speaking in New Zealand, Westoby (1970) noted, ".. the price of wood is tending to become more decisive and wood quality less decisive (in world markets). This naturally opens up great possibilities for those countries suitably endowed to produce wood cheaply and quickly." There is little doubt that New Zealand is one of these countries.

Situated between latitudes 35° S and 47° S, and having an equable climate, the country is admirably suited to the growing of the exotic species which have been introduced. The rainfall of 25-80 inches per year over the greater part of the country
is adequate for these species. In only a small part of the country (parts of Canterbury and Otago) does rainfall drop to the 15-25 inch level. The outstanding feature of New Zealand's precipitation to tree growth, however, is its even distribution throughout the year.

Other features of the climate in the commercial timber zone are as follows. Temperatures range from 90°F in the summer to 15°F in the winter. Unseasonal frosts are likely to occur and cause damage to tree growth, but exceptionally severe killing frosts are rare. Relative humidities are generally high at 70-80% and sunshine is of the order of 1700-2200 hours per year. Growing seasons, comparatively free from drought or prolonged cold, are long compared with those of countries with higher climatic extremes.

New Zealand has a wide variety of soils and the 1969 Forestry Development Conference found no reason to believe that these were not at least as favourable to forest growth as those found in countries with the same climatic range. The pumice soils, formed from past rhyolitic showers over the central North Island, are particularly suitable. With a few exceptions, which represent only a small proportion of the land on which further afforestation is contemplated, soils are nutritionally adequate and allow free rooting to great depths.

The combination of the favourable soil and climatic conditions mentioned above and the properties of the two major exotic species
planted in New Zealand - radiata pine and Douglas-fir (*Pseudotsuga menziesii*, Mirbo.Franco.) - result in extremely high yields by world standards. Table 1 shows estimates of realisable yields at age 30 in different parts of New Zealand.

Table 1. Estimates of realisable yields at age 30, in different parts of New Zealand.

(Data taken from "Merchantable Yield Tables for Exotic Conifers", WP 2.2.1, Forestry Development Conference, New Zealand, 1969.)

<table>
<thead>
<tr>
<th>Species</th>
<th>District</th>
<th>Cu.ft. per acre per year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiata pine</td>
<td>Auckland</td>
<td>215-240</td>
</tr>
<tr>
<td></td>
<td>Central North Island</td>
<td>330-370</td>
</tr>
<tr>
<td></td>
<td>East Coast and Nelson</td>
<td>230-240</td>
</tr>
<tr>
<td></td>
<td>Canterbury foothills</td>
<td>150-170</td>
</tr>
<tr>
<td></td>
<td>Canterbury plains</td>
<td>270-300</td>
</tr>
<tr>
<td></td>
<td>Tapanui, Southland</td>
<td>270</td>
</tr>
<tr>
<td>Douglas-fir</td>
<td>Central North Island (at 30 years)</td>
<td>340-390</td>
</tr>
<tr>
<td></td>
<td>Central North Island (at 60 years)</td>
<td>270</td>
</tr>
</tbody>
</table>

These figures are extremely generalized, intended for use in computations covering very wide areas, and furthermore are considered conservative. The first rotation of New Zealand's exotic species have received minimum management and little data exist to forecast the potential yields from an intensification of management. The subcommittee on growth potential and wood suitability which reported to the Forestry Development Conference noted that in particular ".. higher yields could be expected if thinnings were more frequent,
although the latter do not at present appear to be economically attractive."

The same sub-committee compared these growth rates with other parts of the world and concluded: "On world standards, New Zealand's exotic forests are unsurpassed in softwood production per acre." On present information, growth rates of radiata pine in Chile - which has a belt of country in latitude 35-39oS with a Mediterranean climate more closely akin to radiata pine's native habitat in California than New Zealand's - can be considered equal to those in New Zealand (Yudelevich, 1966).

Little is yet known of the potential growth rates of Douglas-fir in New Zealand but it would appear that they surpass the best in the United Kingdom. Height growth of plantation-grown Douglas-fir on the best sites in New Zealand is on a par with the best sites in the U.S.A. (the latter is probably natural regeneration rather than plantation grown), but volume growth is considerably greater, perhaps by as much as 100%. The difference between New Zealand and Canadian growth is even more marked.

The question of whether New Zealand can match this production potential with the necessary low costs is more complex. The silvicultural systems by which the two major species are grown - large contiguous blocks of even-aged single species stands - offer a number of economic advantages. New Zealand is also little troubled with such elsewhere damaging agencies as fire, wind and
Extensive areas of monoculture can, however, be vulnerable to insect and fungal attack, protection against which could raise management costs. Damage to date, however, has been slight and even the most serious fungal threat yet, *Dothistroma pini* (Hulb.) appears amenable to control at low cost per acre.

The potential dangers of insect and disease attacks on New Zealand's exotic forest species have long been recognized. Appropriately the forests are kept under constant surveillance by a team of forest biology observers, who work in close association with an experienced pathology research team, and the country as a whole is protected by an efficient and well-organized import-quarantine system. Neither of the above organizations is reason for complacency but their creation serves to illustrate the country's recognition of and readiness to cope with the potential problems.

Falling growth rates in second and subsequent rotations is a phenomenon long associated with wild monocultures. With a few very limited exceptions, this problem does not appear to be troubling radiata pine in New Zealand. On the pumice soils indications are that the reverse is true and second rotation crops are showing signs of improved growth, although the relative effects of improved spacing and possible improved site are not known. Evidence to date suggests that cycling of nutrients in radiata pine plantations, at least on pumice soils, will retard serious depletion of nutrients at
least until the end of the second rotation (Will, 1968). Soil nutrient reserves of potassium and calcium seem adequate for a number of tree crops but supplies of nitrogen and phosphorous will largely depend upon their release from soil organic matter which form stable complexes with allophane in the soil (Will, 1968).

There has been a tendency to dismiss completely the potential danger of production fall-offs in New Zealand radiata pine forestry as a result of the excellent performance of the pumice soils as compared to the sands of South Australia (Lewis and Harding, 1963) and the nitrogen poor soils of the Nelson district (Stone and Will, 1963). Will's summary of current knowledge (1968), however, demonstrated sufficient potential problems to justify continued research into the question of pine plantation nutrition.

Forestry Working Party No. 2; Production Forestry, of the 1969 National Development Conference took all these factors into account and concluded: "We have the climate, the soils and the species to grow high quality long-fibred cellulose quickly, and, if we go about it the right way, to grow it extremely cheaply by world standards."

Having grown this cheap, high quality softwood fibre, New Zealand is faced with the final problem of selling it. The arguments at the beginning of this thesis suggested that, assuming costs are kept down, the world is likely to continue to demand wood fibre, despite the competition of substitute materials. Westoby (1970)
also took this view but warned that New Zealand's product - long-fibred softwood pulp - is no longer the premium material that it used to be. Quoting a number of international trends, including the Japanese pulp industry's change from an 85% softwood raw material intake in 1955 to only 15% softwood and 58% hardwood intake in 1967, he predicted that softwood will continue to find a market only while it is cheap enough. The advantages of this situation to New Zealand, but also the warnings against complacency, are obvious.

New Zealand's geographic position with a latitude in the forties and a longitude in the hundred and seventies may be excellent for growing radiata pine, but it does not offer the best access to the world's principal forest product markets. Shipping rates and the frequency and regularity of shipping have always been, and will continue to be, a problem to New Zealand's export trade (Manufacturing Committee's report to the National Development Conference, 1969).

Westoby's answer to the problem, shared in large measure by the Forestry Sector of the National Development Conference, is for New Zealand to move ahead into the production of high value lines, manufactured from her supplies of cheap, versatile raw material.

In addition, the political framework for developing a complimentarity between the forest economics of New Zealand and her closest potential market expansion field, Australia, has already been established (New Zealand-Australia Free Trade Agreement, NAFTA).
The report of the Working Party No.1, Marketing, to the Forestry Development Conference, showed that these problems are well recognised by the industry within New Zealand, and in particular, firm recommendations were laid down concerning the need for serious study of New Zealand's future shipping needs and the ways in which these will be fulfilled.

A review of New Zealand's potential for fibre production would not be complete without some reference to the land resource available for forest production. This matter was investigated by the Land Resources Subcommittee during the 1969 Forestry Development Conference.

The National Forestry Planning Model (Familton, 1969) calls for an annual new planting rate of 57,000 acres between 1970 and 1975. Although national planting rates are to be reviewed every 5 years from 1968 on, the model also noted that a de novo planting rate of 52,000 acres per year until 1985 is necessary to satisfy growing domestic demands and maintain continuity of exports after 1995. It was a concern of the Land Resources Subcommittee, therefore, that land was available for this programme. Some 1.6 million acres was required.

Two factors complicated the work of the Subcommittee. Firstly, they found that "...considering the question of land availability and suitability for forests,...no adequate, reasonably complete description of land in New Zealand exists." (See footnote p.44)
Secondly, the committee was not satisfied that adequate criteria exist to choose among various alternative land uses.

They were therefore forced to use a 1959 breakdown of the New Zealand land base which is badly in need of revision. This breakdown is shown in Table 2.

Table 2. New Zealand land base.

<table>
<thead>
<tr>
<th>Land Category</th>
<th>Million acres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Merchantable indigenous forest (1.3) and productive exotic forest (1.0):-</td>
<td></td>
</tr>
<tr>
<td>Category A...........</td>
<td>2.3</td>
</tr>
<tr>
<td>Intensive agriculture - Improved pastures (19.5) and Arable, orchards etc.</td>
<td></td>
</tr>
<tr>
<td>Category B...........</td>
<td>20.8</td>
</tr>
<tr>
<td>Land suitable for future development in one form or another - Fern, scrub and second growth (5.7), Unimproved Pasture (13.0) and Understocked merchantable forest (1.5):-</td>
<td></td>
</tr>
<tr>
<td>Category C...........</td>
<td>20.2</td>
</tr>
<tr>
<td>Land not suitable for development - Unmerchantable forest (11.5), Urban, water, minor islands (2.2), Other (9.4):-</td>
<td></td>
</tr>
<tr>
<td>Category D...........</td>
<td>23.1</td>
</tr>
<tr>
<td>Total</td>
<td>66.4</td>
</tr>
</tbody>
</table>

(Footnote to p.43) The Land Use Capability Survey Handbook, produced for the Soil Conservation and Rivers Control Council by the Water and Soil Division, Ministry of Works, Wellington, was published in 1969. It helps little in alleviating the problems noted above, however. Intended as a guide to classifying any particular tract of land, it makes no attempt to inventory New Zealand's land resource. Even as a guide to land use classification its value is somewhat doubtful as it takes the traditional and very much outmoded approach of rating land by its agricultural capability (forestry once again being relegated to those lands on which all forms of farming are considered out of the question) rather than presenting a system of land evaluation for each of all the possible uses.
In order to produce the low cost wood (assuming present day methods of management) land must have certain characteristics in reasonable combinations.

(a) A large area (probably in the region of 100,000 acres) must be available for afforestation in one locality, so that the large volume of wood required for integrated utilization can be assembled in one place without excessive transport costs. As has already been noted, large contiguous areas are also required to allow the economic implementation of large scale mechanized systems. Sutton (1964) doubted that forests under 10,000 acres could be economically justified.

(b) The soil and climate should be capable of rapid growth of a desirable species, preferably radiata pine or Douglas-fir. The costs of preparing land for afforestation and of maintaining the plantations should be low.

(c) The land characteristics which govern the cost of harvesting the wood must be favourable. Under current methods, those characteristics are associated with terrain permitting low cost road construction and tractor logging. Exact descriptions of such land have not yet been formulated.

(d) Consideration must also be given to the cost of providing the services such as power, water and transport needed by utilization plants.

Attention is focussed on the 20.2 million acres of Category C (see Table 2) for expansion of New Zealand's exotic forest estate.
It is felt that more than enough land, with the necessary characteristics, is available within the 5.7 million acres of land currently carrying fern, scrub and second growth forest.

The National Development Conference noted that forest product exports from New Zealand were limited only by the supply of wood. Usmar and Yska (1971) have more recently noted that the export possibilities are now being more thoroughly examined in their own light and conclude that the result will likely be even greater argument for increased forest establishment.

Even given the necessary combinations of land characteristics mentioned above, there is little doubt in the author's mind that the 1.6 million acres of Category C required to maintain the annual planting targets set in 1969, is only a small proportion of the total additional land available for exotic forest establishment.

Although the forest industry still contributes relatively little to New Zealand's G.N.P. (op. cit.) and the agricultural industry remains the mainstay of the economy, there is a trend towards public acceptance of forestry as having a significant role to play in the future economy of the country. Although deficient in some respects, a number of pioneering studies have been carried out which have shaken the traditional view that forestry should always be relegated to the land considered sub-marginal to farming (e.g. Ward et al., 1966). Continuing work of this nature, supplemented and controlled by the deliberations of the recently established
Land Use Advisory Committee, is bound to result in a more rational approach to the possibility of forestry as an alternative land use and a probable increase in the amount of presently undeveloped land which will be made available to afforestation.

Considerable areas of abandoned and economically sub-marginal farm land are also likely to be found well suited to timber production.

Such trends can only be accelerated by the current problems in the world wool market and the entry of New Zealand's major trading partner, the United Kingdom, into the European Economic Community. The latter, in particular, will force a considerable degree of reorganization and rationalization on the agricultural industry.

The lamentable lack of a land capability inventory in New Zealand, presently precludes any attempts to estimate accurately the potential land base for forestry. Even assuming the topographic demands of the present day machinery and techniques, the area, over and above that required by the targets of the National Forestry Planning Model, will certainly be measured in millions of acres. In addition there is a considerable potential production which will come from afforestation projects in which timber production is not the major objective (e.g. the so-called protection-production forests mentioned in the report of forestry working party No. 4, Multiple Use Forestry, 1969, and schemes such as that described by Macarthur (1971).
Notwithstanding the terrain limitations cited above, the Forest Research Institute's symposium on land clearing (Chavasse, 1969) was confident that more than 50% of the land to be afforested in the future in New Zealand would possess slope limitations that would preclude the use of tractors. This author expects that techniques will be developed in the future which will allow site preparation, planting, tending and harvesting operations to be carried out on this class of country (which has not yet been adequately defined) without raising wood costs to prohibitive levels. Examples of some possible techniques are described by Mann (1967).

Although it is pure speculation, the temptation to estimate some possible future production potentials of New Zealand exotic forestry has been too great to resist. The following calculations have utilized a blanket mean annual production potential of 300 cubic feet per acre. This rate of growth has been achieved on many of the medium to good sites of the first rotation of radiata pine, despite an almost complete lack of silvicultural treatment since planting. Management inputs such as spacing control, production thinning (if this becomes economic), genetic improvement, closer utilization and fertilization on the limited areas where specific nutrient deficiencies have reduced growth rate in the past, will very likely improve the growth rate of the second and subsequent rotations considerably.

The areas of lower growth rates, such as the Canterbury Plains (see Table 1) will constitute a relatively small proportion
of the future planting area and should have little effect on the national average growth rate.

The figure of 300 cu.ft./acre is, therefore, considered by no means optimistic and increases from intensification of management should largely compensate for any lowering of site quality that might occur as the forest land base is increased.

Table 3. Potential gross annual yields from N.Z. exotic forestry, assuming various land bases.

<table>
<thead>
<tr>
<th>Land base - millions acres.</th>
<th>Millions cubic feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0 (Present productive exotic forest)</td>
<td>300</td>
</tr>
<tr>
<td>3.2 (N.D.C. target requirements)</td>
<td>960</td>
</tr>
<tr>
<td>5.0</td>
<td>1500</td>
</tr>
<tr>
<td>10.0</td>
<td>3000</td>
</tr>
</tbody>
</table>

(Note:- current annual cut from whole of B.C. is 2,000 million cubic feet - B.C. Forest Service, Annual Report for 1970.)

Usmar and Yska (1971) have noted that population and development pressures have not yet overwhelmed the environmental attributes of New Zealand. Bad mistakes have been made in the past in land clearing practices (eg. Chavasse, 1969) and the introduction of exotic herbivors (notwithstanding some beneficial effects of the latter - viz. the tourist and domestic recreational values of hunting deer), and these should be adequate warning that New Zealand must learn from the lessons of other countries. Such considerations will inject some caution into the development planning of the country's exciting, if presently imprecisely known, forest potential.
The approach to planning of possible industries to utilize indigenous hardwoods, briefly outlined by Usmar and Yska (1971), is encouraging in this respect. The potential of the beech (Nothofagus spp.) resource on the west coast of the South Island was assessed after conservation, recreation and amenity factors had been considered. The reduced land base is thought capable of supporting a 500 tons/day Kraft mill.

These kinds of priorities must never be lost. Even if New Zealand is a little technologically backward today, there is no doubt that she has an environmental quality that is the envy of many more advanced countries. The forest products industry in general is not world renowned for its compatibility with the environment and any judgement of its future potential in New Zealand must ensure that its economic advantages are not bought at the price that has sometimes been paid elsewhere.

In summary, it would appear that with careful consideration of a number of problems primarily concerned with her geographic position and environment, New Zealand's forest industry has a potential, limited by, although relatively very large in comparison to, her absolute size, to supply some of the forest products the world is likely to require and at a price the world will be prepared to pay.
2. Potential for Forest Mechanization.

It is convenient to deal with this topic under two sub-divisions:

1. those factors related to the particular type of forestry in New Zealand; how, where and by whom exotic forestry is practiced.
2. those factors which are a result of the wider implications of New Zealand's peculiar national features.

The most prevalent silvicultural system in New Zealand exotic forestry is even-aged management of monocultures. The potential dangers of such forestry (and New Zealand's awareness of same) have already been discussed. Such systems, however, are the best suited to large scale mechanization of all phases of the forestry enterprise. The simple and uniform ecological conditions, and tree and log sizes found under such conditions, facilitate machine design and allow the wider application of any one particular design. The forests are in fact already standardized and hence more compatible to a marriage with machinery.

New Zealand forestry is characterized by a small (under ten) number of large, forest growing organizations (excluding the farmer foresters), the largest of which is currently the State itself. Such organizations possess the scale of operations that is required to justify intensive mechanization and are capable of the large capital outlay generally required. Large areas and organizations allow the implication of such techniques as multi-machine teams and
multi-shift working. Good maintenance and managerial backup are likely to be more readily available also.

There is every indication that these characteristics of ownership and individual forest size are likely to continue. Thus recommendation 23(b) of the Forestry Sector's report to the 1969 National Development Conference reads:-

"That the location of future planting programmes should be dictated by the following consideration(s):-

(b) The need to create further large forest concentrations in areas which can fulfil the conditions favouring the development of large-scale industries. The economies of scale in forestry operations as well as in forest industries should be recognized."

A small number of major markets is a feature of New Zealand exotic forestry. Although of particular advantage to the mechanization of logging and transportation phases, this feature also contributes to the overall standardization of forestry operations which benefits mechanization of all phases of forestry,

Consideration of New Zealand's terrain and soils presents a less optimistic picture of forest mechanization. A very large proportion of the current exotic forest estate is to be found on flat to rolling country on relatively stable soils. The question of available land for future afforestation has already been discussed; Quantitatively there is sufficient land to at least treble the National Development Conference's target estate for the year 1989. There is much doubt, however, about how much of this land will be able to support intensive mechanization - at least with today's machines - because of limitations imposed by slope and/or erosion potential.
A recent questionnaire (Chavasse, 1969) showed that of the 1,292,000 acres to be planted by the respondents during the next thirty year period, only 52% was negotiable by crawler tractor. With the new attitudes to land allocation between forestry and agriculture which should result from the recommendations of the National Development Conference, more land of gentler slope should become available to afforestation.

There is no doubt, however, that steep hillsides will long be a problem for forest mechanization in New Zealand. Large areas of what have been termed protection-production forests are being established. These schemes involve the use of exotic species to rehabilitate farmland which has been abandoned because of erosion problems. Although soil protection will be the over-riding role of these forests, it is intended that some timber will be taken from them (eg. Olsen, 1970).

Rennie (1971) noted the need, on a world wide scale, for a breakthrough in prime moving techniques to allow the mechanization of forest operations on steep terrain. Nowhere is this more needed than in New Zealand.

As a general rule New Zealand can be considered a labour hungry country. In many industries, then, mechanization which allows increased or maintained output with the minimum increase in labour requirements is favoured. This situation applies to New Zealand forestry but with the caution that forestry has in the past provided relief to small levels of unemployment produced by a relatively high proportion of seasonal work. The "seasonally unemployed" are
considered by some to be the result of poor fiscal and monetary policies on the part of the Government and to be a purely temporary phenomenon. The actual numbers involved are, in any case, very small and unlikely to materially contribute to the labour needs of New Zealand's rapidly expanding forest industry. It is concluded, therefore, that increased mechanization will be an essential part of forestry's future.

Although decreasing the total quantities of labour required, and particularly reducing the demands for the lower qualities of labour, mechanization does create in turn a demand for certain skills in the operation and maintenance of the machines. If she is short of labour per se, then New Zealand is particularly short of skilled labour. Assisted immigration of skilled workers and training of her presently unskilled labour force are two ways in which New Zealand intends to prevent any hold up of increased production through mechanization and any unemployment which may tend to result from a reduced demand for unskilled labour (Report of the Labour Committee to the National Development Conference, 1969).

It must be remembered here that New Zealand is a socialist country with a long history of government provided welfare services (e.g., socialized medicine). Full employment is a national aim which for all practical purposes is almost constantly attained. This attitude is best illustrated by quoting from the Labour Committee Report to the N.D.C.:-
"The committee considers that the Government should accept the responsibility for the effective functioning of an overall manpower policy designed to provide full and productive employment, but which would at the same time be consistent with other economic objectives such as growth, price stability and the maintenance of adequate levels of overseas funds. In making this statement, however, the committee wishes to stress that manpower is a factor of production that must be examined in social as well as economic terms."

The committee also noted the problems of forecasting labour demands and trends but felt that one trend that was definite was a move toward requirement of more skilled and fewer unskilled labourers. It therefore considered that education, vocational training and retraining programmes are an essential part of the Government's labour policy.

In summary, then, mechanization within New Zealand is encouraged by a general labour shortage. Any localized unemployment problems which could arise from "over" mechanization would be intolerable in New Zealand, but it is the intention of the Government's labour policy to anticipate and prevent such situations occurring within limits that are economically feasible.

In an attempt to conserve overseas funds and to protect her own small manufacturing industry - the development of which is considered vital to offset the problems associated with an economy based on primary products - New Zealand has long restricted imports of certain types of machinery under certain conditions. Up to now, two distinct systems have been in operation.

The first of these, import licensing, was designed to "help contain expenditure on imports within the limits of available overseas
exchange, while ensuring that the resources are used as effectively as possible."(Anon., 1970).

The import licensing system is gradually being phased out in favour of a system of protective tariffs and, in 1970-1971, 65-70% of private imports by value were free of licensing.

New Zealand has long had an agricultural machinery industry (in the 1880's New Zealand was exporting plough shares to the United States) which currently possesses 110 plants producing, in 1966-67, machinery valued at $17 million. Such machinery is subject to import licensing. Many of the heavier types of machinery used in forestry would not be made by these companies and, in some cases, they would be free of import licensing. In all cases, however, the onus is on the New Zealand user to show that a domestic manufacturer cannot satisfactorily produce the machine.

The New Zealand Customs Tariff has the objectives:— ".... to provide revenue, and to afford reasonable protection to economic New Zealand industries, while at the same time assuring New Zealand manufacturers of entry for their raw materials at the lowest possible duty rates if the materials are not produced in New Zealand." (Anon., 1970). The tariff is based on the Brussel's nomenclature and rates of duty vary according to the country of origin and the classification of the goods. Table 4 shows some examples of tariffs taken from the Customs Tariff of New Zealand.
Table 4. Some New Zealand Customs Tariffs.
(extracted from The Customs Tariff of New Zealand, N.Z. Customs Dept., R.E. Owen, Govt. Printer, Wellington 1967)

<table>
<thead>
<tr>
<th>Item</th>
<th>British Preferential</th>
<th>Most Favoured Nation</th>
<th>General Tariff</th>
</tr>
</thead>
<tbody>
<tr>
<td>A) Crawler tractors:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>hydraulic control parts;</td>
<td>25% (Can.-35%)</td>
<td>25%</td>
<td>60%</td>
</tr>
<tr>
<td>other parts;</td>
<td>Free</td>
<td>5%</td>
<td>10%</td>
</tr>
<tr>
<td>(Ditto wheeled tractors)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B) Disc ploughs</td>
<td>10% (Can.-35%)</td>
<td>10%</td>
<td>40%</td>
</tr>
<tr>
<td>C) Ploughs general</td>
<td>10% (Can.-35%)</td>
<td>20%</td>
<td>40%</td>
</tr>
<tr>
<td>D) Cultivators</td>
<td>10% (Can.-35%) (Aust.-Free)</td>
<td>10%</td>
<td>40%</td>
</tr>
</tbody>
</table>

These two systems, although designed to protect the nation as a whole, could at times cause considerable inconvenience and additional cost to a prospective importer of machinery. The gradual phasing out of the import licensing schedule will remove some of the inconvenience, but the tariff, combined with the cost of freight, will result in machines in New Zealand being priced considerably higher than in countries possessing large, efficient manufacturing industries.
New Zealand industry is likely to be capable of manufacturing the heavy land clearing and site preparation machinery required in forestry, although probably at a higher price than an overseas equivalent, but it is unlikely to be capable of producing sophisticated logging equipment and heavy prime movers for some considerable time.
4. A FUTURE REFORESTATION SYSTEM FOR NEW ZEALAND RADIATA PINE.

General Background.

Reforestation is a comparatively new concept to New Zealand exotic forestry, although her high growth rates and early start in re-plantation forestry have put her considerably in advance of other exotic forest growing nations.

In the early days of logging of the exotic forest estate, natural regeneration was thought to be so immediate and abundant that little attention was given to reforestation (Ure, 1949). In later years, however, when the efficiency and popularity of natural regeneration began to decline (see below) and it became necessary to invest considerable sums in artificial restocking, an objective look at the importance of reforestation would have been desirable. Enough money was being invested in site preparation of the cutovers before artificial restocking could be undertaken, that a study of the relative rates of return on an investment in afforesting new land compared with the cutover would have been justified. Despite the limited resources available for forest establishment, no such study was carried out. The re-establishment of cutover within existing forest boundaries was considered the first call on funds.

This attitude remains today and is exemplified by the Forestry Sector's inclusion of, "restocking existing mature exotic forest as it is felled" as the first of a list of methods of achieving wood production targets, in their report to the 1969 National Development Conference. From the point of view of the
forest purist this is an excellent attitude; from that of an economist, in a country where capital is currently more limited than land, it would demand closer examination. For the purposes of this thesis, the attitude is merely accepted.

The history of reforestation of radiata pine in New Zealand has been one of decreasing reliability of and reliance on natural regeneration. The subject is covered by two papers (Page, 1970, 1971 b.) and only a very brief synopsis is presented here.

Before large scale logging commenced in the mid-1950's, natural regeneration was considered adequate. Accelerated logging from 1956 on, however, led to a very great increase in the mileage of stand edge and a consequent population explosion of the seed eating birds and mice (all exotic) to which the stand edge was the most favourable habitat.

Radiata pine has a serotinous cone and very rarely are sufficiently high temperatures reached to open these cones during winter-logging. They therefore remain closed on the slash until the first hot day of spring, which also coincides with the time of most severe food shortage for the seed eating birds and mice. Most seed is consumed as soon as it drops from the cones and natural regeneration of these winter-logged areas fails.

During summer-logging ground temperatures are high enough to open the cones on the felled trees during the two to three week delay between felling and yarding. The yarding operations then bury the seed out of reach of the predators.
Broadcast aerial seeding with repellent coated seed was introduced on the winter-logged areas to reinforce the deficient natural stocking and proved successful.

Both natural and artificial seeding, however, failed when logging reached high altitude, flat country where unseasonal frosts brown off the young seedlings in the early autumn. Windrowing of slash and hand planting became necessary on these sites.

The increased attention that New Zealand foresters were being forced to pay to the restocking of radiata pine cutovers resulted in a more critical study of the naturally regenerated areas which had previously been considered adequately stocked. From these surveys it was concluded that, "no(large)area of natural regeneration can be expected to be satisfactorily stocked...." (Page, 1970).

Poor distribution of the individual trees was the major complaint, resulting in a patchwork of badly or non-stocked areas interspersed with areas of over dense stocking, the latter demanding expensive precommercial thinning or spacing. The same complaints, to a lesser but still significant degree, could be levelled against the results of aerial broadcast seeding. Under the very short rotations of radiata pine growing in New Zealand (26-35 years) control of spacing from the earliest years of the stand is of great management significance.

At about the same time as the above work was going on, great strides were being made in the field of tree-breeding. New Zealand's radiata pine population shows a very great degree of variation and
the potential for improvement in form and yield through the use of genetically superior seed is very great (N.Z. Forest Service, 1969). Orchard seed retails at approximately $NZ30/lb (Chavasse, pers.comm.) and such an expensive commodity should not be broadcast from an aircraft as was possible with the much cheaper forest collected seed.

The advantages and increasing availability of planting stock grown from orchard seed, further accelerated the move away from natural regeneration and left aerial seeding in the role of a stop gap until sufficient improved stock and labour were available to allow planting of all areas.

In comparing these operations it should be remembered that use of genetically improved stock allows a stand to be started with a very much lower initial stocking. The target stocking of 1,000 evenly spaced stems per acre on much of the New Zealand pumice country (Page, 1970) was necessitated by the need to have a sufficiently large population of these very variable individuals to allow the selection of 80-150 final crop trees per acre. The poor distribution of seedlings arising from natural or broadcast seed demanded that total stockings in the order of 3-5,000 stems per acre were necessary to ensure adequate effective stocking (1000 evenly spaced stems per acre) after precommercial thinning.

Appendix 1 shows some average costs of reforestation operations on one large State owned plantation forest. They quickly dispel the myth that natural regeneration and aerial seeding are cheap.
The basis for planting.

New Zealand has a long background in the planting of bare-root radiata pine. The much hallowed planting "boom" of the 1920's and 30's, when the bulk of the currently maturing exotic estate was established, relied to a very large extent on this method (although quite large areas were established by spot seeding).

Scott (1960) noted that radiata pine is extremely easy to raise in the nursery, producing robust and healthy seedlings in one season.

The season in which planting of open-rooted stock can be carried out is very long. Under normal operating conditions the full six month winter period is available for outplanting. Under research conditions, and particularly using specially prepared nursery stock, it is possible and, in terms of improved early growth, often advantageous, to plant all the year round (Moberly, 1970).

The combination of a long planting season and the short nursery time required to produce plantable radiata pine stock have spared New Zealand the logistic problems of say eastern Canada where extremely limited planting seasons and the necessity to grow seedlings of such species as white spruce (Picea glauca Voss.) for 2-4 years in the nursery, have led to the comparatively recent interest in container planting (MacKinnon, 1968). The potential advantages of container grown seedlings in terms of planting season extension, easier planning and lower cost have not been of great significance in New Zealand. Containers have only been considered in New Zealand for
very sensitive species such as the Eucalypts (Bunn and van Dorser in Chavasse and Weston, 1969).

Research on radiata pine establishment is now firmly committed to the bare-root concept. Efforts are concentrated on improving the cost and quality of the nursery product through such means as intensive mechanization, precision sowing, mechanical pretreatment of seedlings (wrenching) etc. (Chavasse and Weston, 1969; Chavasse, pers.comm.).

The fortuitous combination of soils and climate, which produces the very high growth rates of radiata pine in New Zealand, unfortunately produces the same effect on the competing weed species. The need for tree seedlings to be free of this competition as soon as possible (in order to minimize weeding costs) is often used as an argument for bare-root planting as opposed to seeding methods of reforestation. The argument presupposes a superior growth rate from the planted tree.

Although there is little doubt as to the superiority of the planted tree in competing with weed growth up to about twelve inches in height, the author has seen many instances of trees arising from natural or artificially applied seed rapidly overhauling planted stock within one season. This is discussed more fully in the next section.

The problem of weed growth is being attacked on two fronts in New Zealand. Chemical control has shown considerable promise in the release of overtopped plantations from such weeds as lupin, gorse etc. The technique, however, is liable to come increasingly under fire for environmental reasons.
Mechanical cultivation of the site has recently received considerable attention in New Zealand. As well as contributing to easier planting conditions and appearing to cause an increase in early growth, well timed cultivation can have considerable effects in suppressing weed growth in the early stages of a plantation's life. If such methods can hold back weed growth for the length of time required for a tree growing from seed to catch up with a planted seedling, assuming this is possible, one of the arguments for planting, as opposed to seeding, will have been invalidated.

Problems with bare-root planting.

The techniques of tree planting have changed little and the principles not at all for 400 years (Walters, 1967). As Walters (1971) has pointed out, Evelyn knew the dangers inherent in the transplanting of bare-root stock and the procedures required to counteract them 300 years ago. (Evelyn was quoting Theophratus so the knowledge has been around even longer.)

This long history of the use of a single principle and a number of related techniques could imply a soundness and satisfaction with a system that cannot be equalled or exceeded. A glance through past issues of Forestry Abstracts, however, shows that a very considerable research effort is still being put into the improvement of bare-root planting. Much of the work is repetitive and outdated, but there is little doubt that there are very real problems with the bare-root system which might suggest a need for a search for a new system.
Some of the problems with bare-root planting, particularly as they relate to radiata pine, are discussed below.

**Planting shock.**

Planting shock is a very loose term and it is used here to head a section concerned with all aspects of a tree's sensitivity to all stages of outplanting.

Any physical removal of the plant from one growing medium to another will destroy to some extent the more sensitive parts of the root system and necessitate a period of recovery during which the damaged parts of the roots are replaced. A period of growth, varying in length with species, planting site and the amount of damage done, is therefore lost while the plant regenerates the lost or damaged tissue. This problem has long been recognized but only recently has intensive work been undertaken to attempt to improve the root growth capacity of bare-root planting stock (e.g. Stone and Norberg, 1971).

During this period of root regeneration the tree's ability to withstand adverse environmental conditions, particularly with regard to water stress, is more or less impaired. This situation leads to varying limitations, particularly regarding season of outplanting, on the establishment of forest trees by bare-root planting. At least under research conditions and using seedlings which have received multiple wrenching in the nursery bed (van Dorser in Chavasse and Weston, 1969) these limitations are slight with radiata pine in New Zealand (Moberly, 1970). It is doubtful, however, whether the care
given to research plantings can be applied economically at an operational level and the extent of the limitations imposed by the tree's root growth capacity under New Zealand conditions is likely to depend more upon preconditioning of the planting stock in the nursery by such techniques as wrenching.

It is interesting to note here that although the practical advantages of wrenching radiata pine in reducing the tree's susceptibility to "planting shock" are well demonstrated, the physiological basis for this result is very incompletely understood (Cameron and Rook in Chavasse and Weston, 1969).

Because of the great sensitivity of the lifted nursery seedling to environmental conditions, problems are to be found in the handling, transport and storage phases of forest establishment with bare-root stock. Again tolerances vary with the species, climate etc. but an exact knowledge of these tolerances in any particular set of conditions is rare. Research work is still being carried out - though with the added advantage of various sophisticated techniques - to illustrate such time proven concepts as the necessity to keep bare root exposure between lifting and outplanting to a minimum (Mullin, 1971).

In many parts of the world various techniques have been developed to attempt to protect the transplants from the dangers of exposure. Puddling the roots with the nursery soil and plant dipping with a number of commercial anti-transpiration mixtures, such as Agricol and Collatex (sodium and ammonium alginates respectively), are examples. Results are once again as varied as the species and
localities tested. Rook (1970) found that Agricol and Collatex were toxic to radiata pine when the puddled seedlings were planted out into hot dry conditions.

It is not intended here to attempt a comprehensive review of all the various treatments, storage and transport methods etc. which have to be employed to protect the bare-root seedling during the critical stage between lifting and outplanting. Suffice it to say that problems exist, to greater and lesser degrees, and that the sensitivity of seedlings to this stage in turn creates logistic and administrative problems, often limits planting seasons and results in reduced survivals if due care and consideration are not taken in the handling of the seedlings.

In New Zealand the enumeration and enforcement of the correct procedures in the handling, packaging and transport stages is considered a major research and administrative goal in the development of the bare-root planting technique for radiata pine. In one conservancy, Auckland, the correct application of long known (and largely commonsense) procedures in these stages of establishment has resulted in a reduction of blanking (supplementary planting) from 30% to nothing, at a saving of some $10/acre (Chavasse, pers.comm.).

The over-riding point, however, is that, with the exception of a few recent techniques designed to precondition the tree in the nursery bed to better withstand the transplanting stage, the requirements of care in handling, transport etc. have long been known. We have, however, shown a singular lack of ability to put all this knowledge into practice. The reasons are various and involve such
factors as the poor quality of labour and/or supervision, reluctance to spend money on the required transport and storage facilities, attempts to meet planting targets, possibly set for political or financial reasons without regard to the requirements of tree handling necessary to ensure survival, and a host of others. Kirkland (1969) has traced the history of Douglas-fir establishment at Kaingaroa Forest in New Zealand and found that the success of these operations - and hence the quality of the stands present today - varied distinctly from period to period. Consultation of the old (beautifully hand-written!) compartment records shows clearly that without exception good results occurred during periods when great care was taken with species siting, establishment techniques and vigorous follow-up protection for the new stands.

We are living in an age where the application of such techniques will be increasingly difficult. The economic and industrial conditions under which we will have to work, even in forestry, may not allow enough care and attention to individual site, shipments of seedlings, periods of particular weather conditions and even to the individual tree itself at the actual planting stage. At the same time the future economics of growing trees will not allow us the expense of supplementary planting to reduce the effects of uneven spacing and growth which results from poor establishment. Up to now we have failed to apply consistently the necessary techniques to ensure success in the bare-root planting method, despite our long knowledge of the requirements. There is no reason to suggest that without much effort, we will improve in this respect in the future.
Adaptability to mechanization.

The necessity for greater mechanization of the cellulosic growing enterprise in the future has already been discussed in this thesis. The demands of mechanization are one of the industrial conditions mentioned above.

Manual planting remains the most prevalent tree establishment technique in New Zealand today. Walters (1969) has identified a similar situation in North America. In both countries attempts have been made to mechanize the operation by the introduction of modified agricultural machinery (basically a modified broccoli planter). Despite nearly half a century of development, however, bare-root tree planting remains at best only partially mechanized. Bare-root seedlings are characterized by dimensions which vary from seedling to seedling. Such a lack of standardization greatly hinders the development of an automated handling system and forces the current machines to rely heavily on manual assistance in the placing of the tree in the furrow and in subsequent follow-up operations to improve the job done by the machine.

Varying succulence of the bare-root seedlings is a further handicap to total machine handling and planting. Today's so-called planting machines, then, are somewhat optimistically named. More correctly, they serve to open the furrow or hole and reclose this after the tree has been manually inserted.

In recent years much work has been carried out in the U.S.S.R. on the mechanization of planting. One of the latest machines
described by Kornienko (1970), although designed to alleviate some of the biological problems of bare-root planting by producing a slit without compacted sides and covering the roots with loose soil, still has, however, a high manual labour content. The single row machine requires a team of four - driver, two planters and an assistant to straighten trees where necessary.

The Russians are also attempting to overcome some of the problems involved in the automatic handling of non-uniform trees. Nevertheless, Usanov (1969) in discussing some of the many problems involved, noted that of the five experimental types of handling system so far developed, none was then ready for commercial application.

The sensitivity of bare-root seedlings to damage between lifting and planting is a further barrier to total mechanization of the planting operation.

The accommodation necessary to protect the critical requirements of seedling physiology at all stages of its transfer from nursery to planting site, suggests a need to develop a new system of forest tree establishment. The new system should be more adaptable to total mechanization without sacrificing the advantages of spacing control, and should yield improved and consistent survival at lower cost.

Root distortion.

There is now some evidence that root distortion at the time of planting can contribute considerably to lower survival and slower initial growth (Ertfeld, 1968; Chavasse and Weston, 1969). Stem form
can also be adversely affected and, in New Zealand, toppling of young stands when exposed to wind has been related to 'J' shaped, or "hockey stick" roots caused by poor planting technique (Chavasse and Balneaves, 1969).

This problem is of increasing importance in New Zealand as more sophisticated management techniques are developed. It has also been found to be more widespread than was formerly thought, including a considerable incidence on the pumice country. At one forest, Rotoehu, it is barely possible to select 250 stems per acre (from 6'x6' planting) for pruning due to the high proportion of toppled or butt swept stems (N.Z. Forest Service, 1970).

Ertfeld (1968) found the incidence of root distortion to be high in both machine and auger planting. The best root and stem forms and height growth were found in Scots pine which had grown from seed on the same sites. Many young radiata pine in New Zealand have been excavated and it has been found that, "On the whole (but not invariably) regeneration (natural) has good taproots and well distributed laterals, while nearly all the planted trees have grossly distorted root systems." (Chavasse, pers.comm.).

The problem is a difficult one to investigate. Poor operational results in the field may often be due to insufficient or poor quality supervision the adverse effects of which are difficult to pinpoint both technically and politically. Research plantings to test the different tools and methods used operationally tend to yield inconclusive results, perhaps because care and attention paid to such plantings is unlikely to be similar to that received by trees
planted in normal operations.

In New Zealand there is an increasing tendency to place manual planting on an incentive basis. There is no doubt that such measures increase planting rates and, to a certain extent, attract a better type of worker to the job. Improvement of planting quality by this method, however, is doubtful. Although planting is generally thought of as an unskilled job, all the tools available today for the planting of bare-root stock demand care in their use if the tree is not to be abused. Such care takes time and its maintenance requires vigorous supervision the moment the operation is placed on an incentive basis involving only quantity. If the supervision is successful, planting an individual tree must take longer and result in a demand for a higher base rate in the incentive scheme, and hence more expensive planting. The author has seen many unsuccessful attempts to escape the fact that well planted trees are expensive trees.

The paragraph above discusses only the actual planting stage. Equal care is required of labour at all stages from the nursery to the field.

Nurseries.

The production of bare-root planting stock demands the establishment of large permanent nurseries. The idea of small temporary nurseries has now been abandoned in New Zealand. The requirements of a good nursery soil for radiata pine are complex and were discussed at length by Chavasse and Weston (1969). Such land is expensive and generally located at distances from the afforestation
site which create difficulties in transportation and seedling acclimatization.

Growth of 1-0 radiata pine is considered to remove more nutrients from the soil than any other plant crop in New Zealand (Will, in Chavasse and Weston, 1969). The quantities of nutrient removed from an acre include the equivalent of 501bs of dolomite, 2001bs of sulphate of ammonia, 751bs of potash and 50lbs of superphosphate. As utilization of nutrients cannot be expected to be much better than 40%, at least twice the above amounts will be required each year by a crop of 1-0 radiata pine (op.cit.).

The necessity for the use of all the other chemicals required in the forest nursery - soil sterilants, fungicides and insecticides - leads to considerable expense. Cost of stock is a significant proportion of the total cost of reforestation. Four years old (2-2) spruce in Ontario can cost as much as 4.6¢ per tree (Page, 1971) although cost of 1-0 radiata pine in New Zealand is generally around 1.5¢ per tree. Perhaps more significant in the argument against bare-root stock is the care required in the handling and planting procedures necessary to ensure successful establishment of bare-root stock.

It may be pertinent to note here that the large scale use of chemicals so necessary in the modern bare-root nursery is potentially liable to the attacks of the increasingly ecologically aware public. The land area required for the growing of bare-root planting stock is small compared with the size of the established plantation. The average seedling density quoted in the symposium edited by Chavasse
and Weston (1969) was approximately 200,000 per acre of gross nursery area. Thus one acre of nursery supplies sufficient 1-0 trees to plant 400 acres at $6' \times 12'$. Any ecological problems associated with chemical use in forest nurseries is likely to be on a small scale. Nevertheless, the author is sufficiently concerned about the possible effects of intensively managed nurseries to cite these potential problems as one argument in favour of efforts to develop a tree establishment system that eliminates nurseries.

Nursery research is continuing to improve our knowledge of the requirements of our forest tree species in the germination and seedling stages, but the nursery system itself remains unchanged. Both Walters (1969) and Kinghorn (1970) have noted how a new approach to the germination and growing of seedlings - in these cases container planting - reduces requirements for a nursery. Smaller compact nurseries can be used which require no more than an adequate water supply. A compact nursery permits the use of relatively expensive facilities such as greenhouses, removing suitable climate from the list of nursery site requirements.

Summary.

The present major system of establishing radiata pine in New Zealand - bare-root planting - has certain disadvantages. Despite recent developments in the pre-conditioning of seedlings, considerable care is required in the lifting, packing, storage, transport and planting processes to prevent excess exposure of, and
physical damage to, the trees. Care is also required at the planting stage to avoid distorted roots and the possibly slower and poorer quality growth and risk of toppling. It is unlikely that these requirements will be compatible with the economic and industrial conditions under which forestry will be practised in the future. In particular, bare-root planting, because of the sensitivity and variation in size and succulence of the individual trees, is the system least accommodating to total mechanization of reforestation.

An alternative to bare-root planting.

General description and specifications.

Although somewhat similar ideas are in fact being tested today (eg, Anón. b, 1969; J.Walters, pers. comm.) no system that possesses all the features enumerated below exists. No attempt will be made here to describe exactly the components and processes involved in such a system. It will remain a concept, the practical feasibility of which will be argued.

Specifications for such a system are as follows:-

- A system of reforestation (or afforestation) is envisaged that would involve the placement, at a precise spacing, of a containerized seed. (See Fig. 1) The naturally high germination potential of radiata pine, coupled with seed sorting and/or pretreatment, will ensure almost 100% germination and fast initial growth.

- The latter will be assisted by the provision within the container of all the requirements of the seedling until the stage in its development is reached when its requirements
can be met by the planting site. Thus the container should furnish a suitable germination and growing medium, nutrient and water supply and protection from insect, fungal and animal pests and climatic extremes, at least to the point where the seedling is no more dependent upon, or susceptible to, these agencies than a conventional bare-root seedling.

- Having performed the above functions, the container will be such that it will in no way restrict the further development of the tree.

- The total cost of manufacturing and loading the container, its transportation and planting, plus the cost of any special provisions necessary for the successful establishment of the seedling, shall be considerably less than the present system of planting nursery grown, bare-root stock. In particular, the system will be suited to total mechanization. All stages of handling will be dealing with an object of uniform shape and size without the sensitivity to mechanical handling and exposure exhibited by bare-root seedlings. Figures 2 and 3 show a potential mechanized planting device suited to the proposed system.

The feasibility of the system is now discussed under a number of headings.

Germination.

The natural viability of radiata pine seed is high. In 1960 Scott noted that New Zealand nurseries were obtaining around 9,000 plants per pound of seed (average 15,000 seeds per pound), this gives a plant percent of approximately 60. The situation has improved considerably since then (Chavasse and Weston, 1969). Many of the losses can be attributed to seed predators (birds and mice) and there seems to be some doubt as to the continuing efficiency of some of the traditional chemical seed coatings used in the nursery such as 'Arasan' and red lead (op.cit.).

Radiata pine seed does not exhibit any natural dormancy and hence many of the pretreatments which are necessary to obtain
Figure I. Possible design of container for container seeding (actual size).

- Reticulated extension tube - possible means of protecting seed and germinant from predators and excess insolation.
- Planting lug
- Germination and rooting medium - e.g. peat and vermiculite mixture plus fertilizer
- Water reservoirs - e.g. finely perforated plastic spheres
Figure 2. Possible machine for setting of containers. Sketch of principle only; not a working drawing.

Scale $\frac{1}{5}$ natural size.

direction of travel — — — — — — — —

texture casing

direction of rotation

rotating wheel, speed synchronised with land speed of tractor

central magazine of containers

hinged arm

clamp

container about to be set in ground

ground surface
Figure 5. Series diagram to show action of possible seed container setting machine.

Scale - approximately $\frac{1}{10}$ natural size. 
(x) indicates the same point on each diagram a. to e. 
Horizontal scale at ground surface is distorted, thus position of (x) may not be accurate.

- direction of revolution of planting wheel. 
- direction of travel of prime mover.
satisfactory germination percentages with some other forest species are not required. There is some evidence that pretreatments such as cold water soaking or treatment with "Ethrel" can increase germinative energy (N.Z. Forest Service, 1970; Chavasse and Weston, 1969).

Working with seed from Australia's oldest seed orchard, Brown (1971) found that the orchard seed had higher germinative energy than three forest collected samples. Ten days after the beginning of the test, 81% of the orchard seed sample had germinated while the mean for the three other samples was 52%. After 28 days, 87% of the orchard seed had germinated compared with 72% for the forest collected seed. At this time also 6% of the orchard seed was found to be sound and ungerminated thus indicating a 93% viability or potential germination.

Seed predation rather than poor germination has been the major problem in the nursery raising of radiata pine to date. Very little work has therefore been done on pretreatment. The literature on seed pretreatment of other species is extensive including various chemical treatments, sonic treatment (Lisenkov, 1964), γ-radiation (El-Lakany and Sziklai, 1968) and others. Further work on radiata pine could reveal pretreatments that would increase still further the already very high germination percentages and germinative energy.

Considerable work has been carried out with radiata pine in the effects of seed sorting on germination. The removal of empty
seed by sorting is the obvious first step and many methods of doing this have been described for other species. These include ethanol flotation (Barnett 1970), X-ray techniques (Eden, 1965), hot-plate testing (Llodrá, 1964) and mechanical sorters. The last have been tried with only limited success in New Zealand and wind tunnel methods are currently under investigation (N.Z. Forest Service, 1970, a).

Nursery trials have already shown that, "when seeds are sown at precise spacing and depth, the large seed gave an average increase or growth at nine months of three inches more than small seed" (op. cit.).

The importance to planting stock quality of precise seed density in the nursery bed has been shown in New Zealand (Chavasse and Weston, 1969) and work is in progress to improve germination expectancy of radiata pine, primarily by seed sorting, to the point where precision sowers can be used to lay seed at the optimum spacing initially and allow the production of uniform seedlings which can be lifted mechanically without the necessity of culling. Confidence in the potential of this research indicates that the germination requirements of the proposed container seeding system can be met. Improvements of seedling vigour through pretreatment and sorting are also of great potential value to the proposed system.

Early growth.

Improvement of early growth through seed sorting has already been mentioned.
Much work on the fertilizer requirements of radiata pine seedlings has been done (Will in Chavasse and Weston, 1969). Some additional work should be capable of quickly determining the ideal mixture to promote maximum growth of a containerized seed. Many rooting media are now available (e.g. vermiculite/peat mixture) and the ideal medium for germination and early growth of radiata pine would need to be found.

Recent work is showing that the early growth of many tree species can be altered significantly by manipulation of such environmental factors as temperature, light and carbon dioxide concentration (e.g. Tinus, 1971). The degree to which such modifications can be made in a field planted container are obviously limited. In the past, container systems have been limited to supplying a physically optimum rooting medium and the required nutrients. An adequate water supply is of great importance to the survival and rate of early growth of seedlings and the provision of a water reservoir within the container would have many advantages as well as possibly allowing an extension of the season in which the containers could be set. The idea is already receiving study at University of British Columbia's Research Forest (Walters, pers. comm.).

Small, finely perforated plastic spheres, filled by compression in a water bath, and strategically placed within the rooting medium would allow fairly long term storage of the water with a minimum of evaporative loss.
Supply of water at the germination stage may provide some additional problems but careful arrangement of the rooting medium materials and precise planting of the seed within the container, coupled with pretreatment and sorting to ensure rapid germination, should allow the required conditions to be maintained for sufficient time.

Having provided the conditions necessary for germination and early growth, plus protection from various agencies, it is important that the container does not restrict growth of the seedling in later stages. Constriction of root growth, in particular, has long been a criticism levelled at such container seedling systems as the Walters bullet (Kinghorn, 1970; White and Schneider, 1971). The Walters system attempts to overcome this problem by breaking the container at the time of planting by means of knives on the planting gun (Walters, 1969). Although effective when the gun is used, the system does not allow destruction of the container if planting is done in some other way such as from the air (Walters, 1971).

A rigid and strong container is considered necessary for the following reasons:-

(a) It can be pushed or shot into the soil, removing the necessity to open a planting hole or slit and therefore simplifying the planting process.

(b) It will provide better mechanical protection at least from small predators.

(c) It provides a vehicle for the seed and growing medium that is suited to mechanical handling.
Potential container materials are now becoming available chiefly from the plastics industry. The injection moulding technique, possible with many plastics, allows the mass production of complex container designs at low cost. Some recent investigations of the biodegradability of a material called caprolactone polyester suggest that it could be ideal for a container system such as described here (Dr. J. Potts, Union Carbide Co., lecture given at U.B.C. on 17th November, 1971). The material would give the initial strength and rigidity properties required of the container but would subsequently break down allowing free egress of the tree's roots. The time taken to biodegrade is controllable by varying the exact formulation of the plastic.

Protection.

A container seeding system must provide protection to the seed and germinant at least to the point where it is no more vulnerable than a recently outplanted nursery grown seedling. During the early stages the seed and seedling will be subject to some of the dangers to which it would be exposed in the nursery. Any nursery problems which are a result of concentration of a large number of seedlings in a small place, however, are unlikely to affect the containerized seed in the field.

The success of protection measures for nursery sown seed against such pests as insects, birds and mice (generally by means of seed coatings) is not outstanding (Chavasse and Weston, 1969). Mechanical protection within a closed container, itself protected
from larger animals and birds by taste or smell, (see fig.1) should provide more efficient protection and also avoid the use of such noxious and troublesome materials as red lead, 'Arasan' and the various insecticides.

Soil pests generally can be avoided by the use of a sterilized rooting medium, but it is still likely that problems may arise from some fungal diseases such as damping-off. Treatment of the rooting medium with a fungicide to prevent re-invasion is possible but presents potential problems. The effectiveness of the fungicide would wear off gradually and a point could be reached where any less susceptible fungi could re-invade the container. The relationships between soil fungi and plants are complex, but there have been cases of normally harmless fungi becoming pathogenic when present in isolation (van der Kamp, pers. comm.). There is a chance, therefore, that the seedling could be attacked by a reinvading fungus which, under normal conditions, would be harmless.

A second possible method of protecting a containerized seed and seedling from fungal attack is to artificially inoculate the rooting medium with a population of fungal species (some of which may form mycorrhizal associations with the seedling) which would effectively prevent the invasion of any pathogen.

It is well known in New Zealand that fungus diseases such as damping-off do occur among young germinants in the field arising from natural or artificially applied seed. It is almost certain then, that protection would have to be given to any container seeding system.
Protection from climatic extremes is also likely to be required. In the nursery this is provided by such measures as irrigation, movable shade screens, cold water sprays, smudge pots etc.. The provision of water reservoirs within the container to ensure adequate supplies has already been mentioned. Weed control through the use of chemicals, or preferably by cultivation wherever this is possible, also help in conserving soil moisture. By the time the seedling is drawing supplies from outside the container, however, it should be sufficiently established to be capable of withstanding at least short duration droughts, measured in days rather than weeks. Longer periods of drought during the growing season are not common in New Zealand and once over the germination stage, the seedling would be relatively safe from dessication.

Sun scorch is a problem to field germinants of radiata pine at present in New Zealand. Container design should be such that partial shade is supplied to the seedling during the earliest stages. A reticulated extension tube (see fig.1) on the top of a bullet is already being tested for this purpose at the University of British Columbia's Research Forest (Walters, pers.comm.). Such a device also doubles as protection against birds and small animals.

It should be noted here that the cost of a plastic container does not bear a linear relationship with the complexity of its design. The injection moulding technique will allow the cheap and
rapid production of the most complicated shape, once the original mould has been made.

Frost has limited the use of seeding techniques for the reforestation of radiata pine in the past (Page, 1970). Limitations can be expected on the use of containerized seeding for the same reasons, but these can be very considerably reduced.

Container seeding, with its greater degree of protection from animal predators, sun scorch and dessication, and provision of optimum growing conditions generally in the early stages of a seedling's life, may allow the seedlings to reach a greater size by the end of the first growing season compared with natural or broadcast seed. This hypothesis still requires to be tested in the field, but if proven, the larger, better established seedlings with their greater degree of woody stem development, should be capable of better withstanding any damaging, early autumn frosts.

There are indications that site preparation, particularly removal of logging debris and cultivation of the mineral soil, reduces the effect of frosts (Page, 1970). Reasons for this are somewhat obscure but are most likely a combination of two factors. First, the cultivation allows better rooting and frees the seedling from vegetative competition, thus contributing to a healthier, better established seedling. Second, there is some evidence that cultivation can actually reduce frost intensity by its effect on the radiation balance of the site (op. cit.). Intensive site preparation, including soil cultivation, is being recognized increasingly in New Zealand as a worthwhile technique with bare-root planting.
(Chavasse, 1969). Its probable necessity for reforestation with containerized seed is therefore unlikely to be an argument against the system.

The danger of frost damage is likely to preclude containerized seeding only on a limited range of sites in New Zealand. It may, however, restrict more seriously the season in which the containers can be set. Setting too late in the season may leave insufficient time for the seedling to become established sufficiently to be able to resist frost damage. The great potential of the system, however, for total mechanization and automation, will allow very large programmes to be completed in a relatively short time, reducing the significance of the seasonal limitations on setting.

Frost lift has been a constant problem of container plantings in North America. There is every reason to expect similar problems in New Zealand. Use of a short life container and the more rapid growth of radiata pine compared with most North American species - resulting in a greater root spread in the first season - may prevent the problem occurring.

Competition from weed growth is often quoted as an argument against seeding methods of establishing radiata pine in New Zealand. The argument presupposes a faster growth rate on the part of planted trees throughout the whole period of the plantation's life than weed growth is a threat (up to 3 years). This argument is based, in New Zealand, on some field evidence that larger bare-
root stock grows faster after planting. (In the argument between seeding and planting the seed is considered to be the ultimate 'small tree'.) The larger trees are, however, more expensive to transport and plant and survivals generally drop once height exceeds 15 inches (Chavasse and Weston, 1969).

Smith and Walters (1965), working with Douglas-fir in coastal British Columbia, found that the larger seedlings at the time of planting survived well and maintained their height advantage. The effect has been maintained for at least five more years (Walters, 1970). The original height differences in the seedlings were caused primarily by differences in amount and kind of fertilizer.

The question of seedling quality is a confused one. Attempts were made to set specifications for planting stock at a recent New Zealand symposium (Chavasse and Weston, 1969) but with little success. Most judgements were based on arbitrary measures such as 'good' colour, hardness, sturdiness etc.. Some recent work carried out by the New Zealand Forest Research Institute suggested that height increment after planting was more related to nursery bed density than to a seedling grade based on height:stem diameter ratios (N.Z. Forest Service, 1970). There is still much research to be done on this question.

It should be remembered that a container seeding system would not subject a seedling tree to a drastic change in growing medium and the consequent necessity to utilize time, energy and
nutrient resources in the initiation of new roots. Nor would there be the potential danger of stand instability and poor form that is thought to be associated with poor planting techniques (N.Z. Forest Service, 1970).

Ertfeld (1968) found that the root distortion of Scots pine at the time of planting affected both stem form and growth rate. Some recent New Zealand evidence has already been discussed (p.72).

A seeding system which allows root development in situ and thus reduces the chances of distortion as well as removing the need to develop new roots after outplanting, may allow growth rates in the seeded tree which will counter, to some unknown degree, the height advantage enjoyed by the bare-root seedling at the time of planting.

There is no doubt as to the superiority of the planted tree in competing with weed growth up to about twelve inches in height. If vegetative competition was strong from the germination stage on, any seeding system would suffer. A seeding system, therefore, would demand weed control in the first season.

Recent work in New Zealand has shown that many of the common forest weeds, such as lupin (Lupinus arboreus L.), bracken fern (Pteridium aquilinum L.), and gorse (Ulex europaeus L.) can be controlled, in the first season at least, by soil cultivation, carefully timed to ensure the destruction of roots and rhizomes (Chavasse, 1969). Grass remains a problem but trials are under way with germination inhibiting chemicals which show promise of a
capability to hold grass regrowth for one or two seasons (N.Z. Forest Service, unpublished internal report).

Intensified site preparation, in general, and soil cultivation in particular, are being increasingly recognized as sound investment in New Zealand forestry in combination with the current bare-root planting techniques. In frost-prone areas it is considered essential (Page, 1971), and its potential in reducing weed competition, facilitating the planting process and improving the degree and speed of attainment of a well-established vigorous plant, is increasingly being recognized. It is unlikely, therefore, that the site preparation demands of a container seeding system will constitute any additional expense over that already justified with bare-root planting.

Weed control by mechanical covering is a technique which has shown considerable success in other parts of the world (e.g. Reitz, 1970) but which has received little formal testing in New Zealand. A temporary plastic soil covering around each container, sprayed on by the same machine that performs the planting, is but one possibility.

Handling and planting.

It has been argued that the postulated container seeding system could satisfy the biological requirements of tree establishment at least as well, and perhaps better, than a system based on bare-root planting. It has also been argued, earlier in this thesis, that future production of wood fibre, cheap enough to
successfully compete with alternative materials, will depend on the introduction of total mechanization into the cellulose growing enterprise. Perhaps the greatest advantage of the system, then, is its potential for total mechanization.

Walters (1968) described a machine that loads soil and seed into plastic bullets. In a later paper, the same author (1969 b) noted the problems that are involved in the precision sowing of single seed into containers. Irregularity of shape and dimension of the Douglas-fir seed are the main reasons for these difficulties. Radiata pine seed is considerably less variable than Douglas-fir and many of the other North American species and there is little serious doubt as to the potential of total mechanization of container loading and seeding in the case of this species.

The uniform shape and size, resistance to mechanical handling and lack of sensitivity to environmental exposure of the seed container compared to bare-root stock, will make the handling, transportation and setting stages simple and easy to mechanize. At the setting stage in particular the container concept has great advantages. With a sufficiently rigid container and prepared ground, the container could easily be pushed (or shot) into the ground and there would be no necessity to make a planting slit or hole and repack the soil around the planted tree. The elimination of these processes would greatly reduce the horse power requirement of the prime mover, much of which is currently absorbed in dragging a planting shoe, or equivalent, continuously, or intermittently,
through the soil.

The uniformity of the containers would allow fully automated metering and feeding of the planter, a part of the operation which is proving very difficult to mechanize with bare-root planting (see above).

Mechanical tree planting or container setting at a rigidly controlled spacing may not allow the required level of microsite selection. The capacity to reject an unsuitable planting site and relocate a tree or container elsewhere is considered an essential feature of an automatic planter in some parts of the world. The microsite variations found in coastal British Columbia or parts of Scandinavia for example, demand this selection.

Although microsite differences can still be significant in New Zealand, the problems are very much less than in the areas mentioned above. Boulder or rock outcrops and stones are rare or non-existent on the majority of soils where exotic forestry is practiced in New Zealand. Soil cultivation before planting is practiced increasingly and planting areas assume more and more the appearance of ploughed fields.

Stumps on cutover land remain a problem, although if aligned in rows, a clear lane will be available between them. Cutover clearing in the southeast United States with angled shear blades which cut off stumps at ground level, followed by bedding or mounding, removed the barrier of stumps and other debris to mechanical planting (Page, 1971 a).
As New Zealand exotic forest management becomes more intensive and as tree utilization becomes closer and operations more mechanized, geometric spacing increases in importance at the expense of microsite selection. Microsite variations, if significant, will, where possible, be evened out by site preparation techniques. If the variations cannot be removed, and they affect tree growth sufficiently, mechanized forest management will simply not be practiced on those areas to the same degree as elsewhere.

Mechanized planting of containers would be adaptable to all forms of prime movers, be they wheels, tracks, legs or aircraft. It is pertinent to note here that precision sowing in rows from aircraft is already a reality, albeit on an experimental basis (Mann and Taylor, 1969). Metering and ejection equipment for clay-encased seed has been designed and built and plans call for three rows at a time to be sown. One machine will be set at the aircraft centre line and one under each of the wings.

The feasibility of aerial planting of container grown seedlings is being investigated at the University of British Columbia Research Forest and elsewhere in B.C.. Results to date were described by Walters (1971 b) and although percentage of trees successfully planted and survival rates are still unsatisfactory, very high potential cost savings are seen in the system. Estimates have been made of 160,000 seedlings being sown on 400 acres in one day by one aircraft at an estimated cost of $2.80 per acre (Anon., 1971).

The use of aircraft as prime movers in forest operations
other than transport, reconnaissance and spraying is as yet fraught with many problems. Not the least of these is guidance of aircraft to target areas, which is under study in North America (Mann and Taylor, 1969) and has received very limited study in New Zealand (eg. Page, 1969 a,b). Despite these problems, however, the potential of aircraft in speed and cost reduction are very great and development work is likely to continue, particularly in New Zealand where a large and efficient agricultural aviation industry has long been in existence. Appendix 2 is an attempt to show the potential of aircraft and also to illustrate the magnitude of some of the engineering problems that would be involved in aerial precision setting of containerized seed.

The suitability of a system for total mechanization is an advantage which can only increase in value as the cost of labour continues to rise and its availability and quality tend to fall. The need for care in the bare-root system to ensure close to 100% success has already been mentioned. That there is little faith in the required level of care being applied, is perhaps illustrated by the planting targets set by the 1969 National Forestry Planning Model. The satisfaction of growing domestic demands and the maintenance of continuity of exports requires a net increase in exotic forest estate of 45,000 acres per year until 1985. An annual new land planting rate of 52,000 acres is considered necessary to achieve this. Such figures indicate an expected 16% failure rate.
Cost

To quote costs of a reforestation system which is still but a concept is, of course, impossible. Under New Zealand conditions, however, where the bare-root planting technique can produce results generally considered acceptable in terms of survival, a new system needs to show potential advantages other than an ability to equal the biological success of the existing system. This section then, attempts to estimate objectively some of the potential costs of the container seeding concept and to compare these with costs of the existing bare-root technique (although the latter are, themselves, incompletely known).

The major processes in each system are split, in Table 5, into a number of common cost factors. Each of these is then discussed in some detail. Deficiencies in data have prevented detailed analysis on all but the planting operation itself.

Table 5, Common cost factors of container seeding and bare-root planting.

<table>
<thead>
<tr>
<th>Cost Factor No.</th>
<th>Cost components by system.</th>
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<tbody>
<tr>
<td></td>
<td>Container seeding</td>
</tr>
<tr>
<td>1.</td>
<td>Seed costs.</td>
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<tr>
<td>2.</td>
<td>Cost of container filling and seeding.</td>
</tr>
<tr>
<td>6.</td>
<td>Setting (complete mechanization).</td>
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</tbody>
</table>
1. Seed costs. Seed costs per established tree are likely to be similar for each system. Both systems will use orchard seed as it becomes available. Recent work in New Zealand has demonstrated the relationship between seed size and seedling vigour and the importance of precise initial spacing of germinants within the nursery bed, to obtain optimum and even seedling growth (Chavasse and Weston, 1969). Totally mechanized lifting, bundling and outplanting will demand an almost complete absence of culls and the bare-root seedling system will require the same extremely high germination percent as the container seeding.

It is likely, in fact, that the highly mechanized bare-root nursery will demand even higher standards of evenness of germination and early growth, due to the need for precise timing of the various operations.

2. Container and nursery costs. To the author's knowledge, no satisfactory account of nursery costs exists in New Zealand. Particularly, the high capital costs of nursery land, buildings etc. has not been taken into account in calculations of seedling costs. The most recent figures available are from the nursery at Kaingaroa Forest in the North Island which grows 10 million trees per year. One year old radiata pine seedlings from here were costed at $NZ12 per thousand or 1.2¢ per tree (N.Z. Forest Service, 1970 b).

Details of the cost of buying and loading containers is scanty and no costs are available for New Zealand. The best information available in British Columbia indicates the production costs
of bullets, Ontario tubes and bare-root Douglas-fir (2-0) to be:-

<table>
<thead>
<tr>
<th></th>
<th>Cost per Seedling</th>
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<tbody>
<tr>
<td>Bullets</td>
<td>-2.00¢</td>
</tr>
<tr>
<td>Ontario tubes</td>
<td>-1.00¢</td>
</tr>
<tr>
<td>Bare-root</td>
<td>-1.35¢</td>
</tr>
</tbody>
</table>

The container system costs here presumably include the actual growing of the seedling as well as the cost of container plus loading.

It would appear then, that the competitive position of container seeding will depend much upon the cost of the individual containers. It should be possible to pay up to 1.0¢ per container to maintain the cost of loaded containers at approximately the same level as bare-root planting stock.

There is no doubt that once the relevant machinery had been designed and manufactured, the loading and seeding of the containers would be a very much faster, more compact and less labour intensive operation than the growing of bare-root seedlings. The operation would be completely independent of weather.

It is often assumed that protection of young seedlings from damaging agencies can be more cheaply and efficiently provided in the confined environs of the nursery. This is probably true as far as protection from the larger browsing animals is concerned (i.e. the nursery can be fenced). If, however, the protective functions of the container postulated earlier, can be realized, this may cease to be the case. The crowded conditions of the nursery bed are themselves an encouragement to the rapid spread of certain diseases and pests and force the application of protective measures -
albeit at a cheap rate per seedling - which may not be necessary to the container seeding system.

The continued application of intensive plant rearing techniques to the same area of ground may lead to problems such as soil exhaustion and the build up of soil chemical contents to phytotoxic levels. At best, such situations will demand the application of further, curative treatments and hence additional expense. For example, attempts to find treatments that would guarantee 100% protection of nursery seedlings from the needle blight *Dothistroma pini*, resulted in a treatment which involved the application of 2lb active copper per acre (as a cuprous oxide suspension in water) every two weeks. No toxicity problems were found after one season's treatment but the effects of such massive doses of copper over several years is unknown (N.Z. Forest Service, 1969).

3. & 3. Storage. Storage is less likely to be necessary with the container seeding system. Very fast production rates at the loading stage (eg. the loading machine described by Walters, 1969 a, is capable of filling 864 bullets per minute) will allow a close tie in of the operation with field demands. Should storage become necessary, the greater independence of the containerized seed from environmental conditions will make this process very much simpler, and hence cheaper, than with the more sensitive bare-root stock. Long term storage should be possible in a cold room and less volume would be required per unit number of containers than with
the bare-root stock. This factor then is likely to be considerably cheaper with container seeding.

4. Transport. The sensitivity of bare-root stock to exposure and handling necessitates special provisions during transportation. Special packaging and loading procedures are required to prevent excess drying and crushing and temperatures must be carefully controlled inside the transporter. Refrigerated vans are now thought necessary in many parts of the southeastern United States (Page, 1971) and have been mooted in New Zealand.

No such problems exist with containerized seed. The loaded containers would be relatively insensitive to fluctuations in environmental conditions and their more robust nature would allow the use of fully automated loading and unloading techniques. Lower volume and weight per unit number, plus the absence of any restrictions on packing density (often necessary to prevent overheating of bare-root stock), would allow more containers to be carried per unit volume of transporter, than with bare-root seedlings.

Transportation then, should be very much cheaper and simpler with the container seeding system.

5. Site Preparation. Site preparation requirements of the two systems have already been discussed. There is unlikely to be much cost differential between the two systems in this respect if current trends towards more intensive site preparation for bare-root planting continue.
6. Setting or Planting. It is in the actual planting operation that the greatest cost savings are likely to be realized with the container seeding system. Manual planting of container seedlings in North America is claimed to be possible at double (Kingham, 1970) or even triple (Walters, 1969) the rate obtainable using bare-root stock.

It is in the suitability of the system to highly mechanized planting, however, that the greatest cost saving potential lies. The fact that the container can be merely pushed into the ground obviates the need for a planting furrow and therefore reduces the horse-power requirement of the prime mover. The smaller prime movers required will be cheaper to operate. The planting method possible with containers, and its adaptability to a mechanical feed system, should allow very much faster travel speeds than is possible with tractor drawn bare-root planting machines. Speed will be limited by terrain and tractor power and design, rather than the feed rate of the planting device.

An attempt has been made below to calculate a likely cost of mechanized planting of containerized seed. The following assumptions have been made:

(a) Planting is at 6' intervals with 12' between rows.

(b) Two setting machines, twelve feet apart, are mounted on or towed behind the prime mover. Operation of these, and movement of the containers from storage to the setting head, are entirely automatic and are powered by the hydraulic system of the prime
mover. Possible designs have been illustrated in fig.2. $NZ10 per hour has been allowed as the hire rate for the container setters.

(c) The prime mover is assumed to be a class V wheeled tractor (over 50hp., F.A.O. classification). Many modern examples of such tractors are capable of a maximum speed around 20 mph. (eg. Timberjack 550 - 22.8 mph; Franklin 170/XL - 15.4 mph; manufacturer's specifications.).

It is assumed that the power required to both drive the container setting machines and overcome their resistance to the tractor's movement will be less than half that available from the power source. Speeds of 10 mph over flat prepared ground are, therefore, thought entirely feasible. Slope limitations to such travel speeds are beyond both the scope of this thesis and the author's ability to investigate. The following calculations, therefore, may, at this stage, only be applied to flat or gently rolling country. Increasing slope would presumably require the use of more powerful tractors or an alternative prime moving technique.

$NZ20 per hour is allowed as the hire rate for the prime mover.

(d) Only one driver/operator is required. Current (1970) tractor driver wage rates in the New Zealand Forest Service are $NZ1.10 per hour. In the following calculation $NZ2.00 per hour has been used to allow $NZ0.90 per hour for labour overheads.

The cost calculation then is:-
i) Planting rate: -

two row setting allows an 8 yard swath
to be covered at each pass. With 1760 yards per mile and
4840 square yards per acre, the area covered will be:-

\[
\frac{10 \times 1760 \times 8}{4840} \quad \text{acres per hour}
\]

\[
= \frac{29}{29} \quad " \quad " \quad (\text{approx.})
\]

At 6'x12' spacing 605 containers are set per acre. Planting
rate can be alternatively expressed as:-

\[
605 \times 29 \quad \text{containers per hour}
\]

\[
= 17,545 \quad " \quad " \quad "
\]

ii) Cost: -

Class V tractor plus two planting-
machines at a combined hourly
hire rate of $NZ30

- $NZ 30.00

One driver/operator at total
cost (incl. overheads) of $NZ2
per hour

- $NZ 2.00

Total planting cost per hour

- $NZ 32.00

iii) Cost per acre: -

\[
\frac{32}{29} \quad - \quad $NZ 1.10 \quad \text{per acre}
\]

iv) Cost per tree: -

\[
\frac{32}{17,545} \quad - \quad $NZ 0.0018 \quad \text{per tree}
\]

These costs can be compared with some data that are available
in New Zealand on the cost of bare-root planting.
At Kaingaroa State Forest the average cost of planting on cleared cutover (see Page 1971 c, for details of clearing) at 1,000 stems per acre, was $NZ11.03 per acre (N.Z. Forest Service, 1970 b). This work was carried out on an incentive basis (hourly rate plus bonus payments depending on production) and the costs include direct labour only; overheads, transport, supervision, etc. are not included. If this figure is increased by 80% to cover overheads and reduced by 30% to compensate for the closer spacing used, a more realistic figure, approximately $14 per acre, is obtained for comparison with the hypothetical cost above. Mechanized container planting, therefore, has a potential of reducing manual planting costs by a factor of round about twelve.

No costs of machine planting of bare-root stock have been published in New Zealand. Manktelow (1967) described bare-root planting with crank-axle Lowther planters in the Tarawera Forest of the Tasman Pulp and Paper Company. The optimum system found in this work was an Allis-Chalmers HD-11 tractor (110 hp.) pulling two Lowther machines set seven feet apart on the tow bar. Actual planting costs were not mentioned in the article (with widely varying hire rates and accounting systems they would have meant little anyway) but a planting rate of 10,000 trees per 8 hour day per machine was quoted. An approximate cost per tree, and then per acre at a spacing of 6'x12', has been calculated from these data.
i) Daily cost: -

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>HD-11 tractor at $NZ20 per hour</td>
<td>160</td>
</tr>
<tr>
<td>Two Lowther planting machines at $NZ3 each per hour</td>
<td>48</td>
</tr>
<tr>
<td>Labour - three men at $2 each per hour (including overheads)</td>
<td>48</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>256</strong></td>
</tr>
</tbody>
</table>

ii) Cost per tree: -

\[
\text{Number of trees planted} = 20,000 \\
\text{Cost per tree} = \frac{256}{20,000} = 1.3\text{c per tree.}
\]

iii) Cost per acre at 605 spa. (6'x12'): -

\[
605 \times 1.3\text{c} = $NZ7.90 \text{ per acre (approx.)}
\]

It would appear then, that the container seeding concept has the potential to reduce machine planting costs by a factor of approximately seven.

The figures quoted here should be viewed with considerable caution. They have been used merely as an exercise to illustrate the potential cost savings, at the planting stage, of container seeding. Estimates have been made that deliberately err on the high side for the new postulated system and on the low side for current methods. Despite this, the container seeding system shows a potential for reducing planting costs by around 90%.

7. Weeding. The weeding requirements of the two systems have already been discussed. If the assumptions made in that discussion were correct, there should be no difference in weeding costs between the two systems.
If trees arising from container seeding were unable to equal the growth of planted bare-root seedlings, plantations established by container seeding would require a longer rotation period. If a whole year were lost by seeding, the cost of stumpage foregone could be as much as 300 cubic feet times 4¢ per cubic foot or $NZ12.00 per acre. However, the cost of extending a radiata pine rotation by one year was considered in 1969 to be only $NZ4.00 per acre (F.R.I., Silvicultural Economics Unit, pers. comm.).

Superior growth of radiata pine bare-root planting stock, compared with container seeding such as has been described in this thesis, has not been demonstrated in New Zealand. Field experience with reforestation of this species has indicated to the author that the possibility of better establishment of a protected, containerized seed and possible improved growth of the resulting tree, even to the point of equalling that of planted bare-root trees, is at least worthy of field testing.

Although as much as three feet of growth from seed has been observed in one year, bare-root nursery stock is generally only 15 inches tall when planted. Effects of planting on "check" and subsequent height growth must be studied in comparison with direct sowing of containerized seed. Because of the varying proportions of selection of seed and sites, uncontrolled comparisons of growth of planted and naturally sown seedlings can be misleading.

Similarly, controlled studies are needed to determine whether or not possibly greater mortality of container sown seeds,
compared to bare-root trees, would increase the cost of the former system. Again, the author feels the potential of container seeding to equal, or even exceed survivals currently being achieved with bare-root planting, is worthy of consideration.
5. CONCLUSIONS.

The introduction to this thesis discussed probable world demands for cellulose in the future. Although estimates of quantitative demand vary a great deal, there is general agreement that one definite trend is towards a greater use of reconstituted wood.

With technology developing at an ever accelerating rate, the threat of substitute materials becomes greater. The price differential between cellulose and its competitors, in many areas, is narrowing rapidly. Cellulose, as a raw material, has the disadvantage of being widely dispersed, with consequentially high, and rapidly increasing, costs of growing and harvesting. For cellulose to remain competitive, these spiralling costs must be controlled.

Intensive management of a decreasing land base and, particularly, intensive mechanization, will be required to obtain the necessary large quantities of wood fibre at a sufficiently low cost.

Mechanization in the forest growing industry is currently primitive compared to many other enterprises. Nevertheless, it is possible to enunciate some general principles of forest mechanization.

The systems approach to forest mechanization has been somewhat overlooked in the past and examples of sub-optimisation have arisen. Such mistakes are made when we attempt to mechanize, or develop generally, individual operations in isolation. Hence
replanting is only one operation in a total system of reforestation which can be thought of as starting with the logging phase. There is a danger of concentrating on the trees instead of the wood.

Mechanization brings with it the necessity for new work and management methods. Failure to change the latter will, at best, prevent the maximum benefits being gained from the mechanization process. Multi-shift and team-working, provision of adequate maintenance and repair facilities and careful operational planning are examples. The machines will bring with them a need for different types of personnel at the operative, maintenance, supervisory and administrative levels. Failure to obtain or train these people will again compromise the potential of the mechanization process.

The introduction of machines without the required personnel being available or without the required site and stand conditions, minimum sized working areas etc., could be very expensive. Increasing mechanization generally means increasing capital investment and the efficient use of that capital is essential.

The potential social problems of over-mechanization must be recognized and avoided. Mechanization should never be introduced for its own sake alone. It is only recently that we have begun to notice the social effects of what Toffler (1970) calls our super-industrial revolution.

Similarly a watch must be kept on the environmental effects of our attempts to mechanize. A number of authors have noted that our ability to design and manufacture machines is already ahead of
our understanding of the underlying biological processes which ultimately control the land's ability to produce,

Within this framework, New Zealand's potential as a producer of cheap wood fibre, and the suitability of New Zealand exotic forestry to mechanization, were examined.

A favourable combination of climate, soil and species produces, in New Zealand's exotic forests some of the fastest conifer growth rates in the world. Although this exotic estate is currently small by world standards, the potential land resource is large, if presently little known. An estimate here places New Zealand's total annual fibre production potential (assuming a very great increase in establishment effort) at 50% more than the current annual cut of the whole of British Columbia.

New Zealand's latitude and longitude do not place her favourably with respect to world trade. Expanding markets in Australia and Japan, however, and the continued, increased attention to the provision of efficient port and shipping facilities should minimize the effects of this relative isolation.

In many respects New Zealand's exotic forest environment provides excellent conditions for intensive mechanization. The majority of the exotic estate is concentrated into very large contiguous blocks, consisting primarily of even-aged monocultures. Plans for future expansion call for a continuation of this trend. Management of these large blocks is vested with a small number of large organizations, the largest of which is the State itself.
Markets, and consequently the range of raw material forms required, are few and large.

On the minus side, there are considerable terrain problems. A large, though as yet incompletely known, percentage of the available land resource is in land currently considered too steep for tractors. Unlike many other parts of the world, much of this steep land has the highest site index for radiata pine. (Reasons for this are unknown but it is probably associated with the climate and the water retention properties of pumice.) The need for a breakthrough in steep country prime moving techniques is urgent in New Zealand.

New Zealand is generally considered a labour hungry country - an encouragement to mechanization. The sector in which this deficit is greatest, however, is the skilled and trained management personnel. The present government recognizes this problem and essential parts of the current labour policy are education, vocational training and retraining programmes. New Zealand is a socialist country and unemployment, even on a local level, produced by over-mechanization would be intolerable.

New Zealand has today an environmental quality that is the envy of many more advanced countries. Mechanization (and the forest industry generally) is not always compatible with some environmental values and there is little doubt that an increasingly aware public will ensure that economic development is not bought at the price
that has sometimes been paid elsewhere.

In summary, it would appear that, with careful consideration of a number of problems primarily concerned with her geographic position and environment, New Zealand's forest industry has a potential only limited by, although relatively very large in comparison to, her absolute size, to supply some of the forest products the world is likely to require and at a price the world will be prepared to pay.

The fast growth and hardiness of radiata pine seedlings coupled with a mild climate and a good supply of manual labour earlier in this century, led to the establishment of bare-root planting as the major afforestation system in New Zealand exotic forestry. As reforestation methods began to evolve and the advantages of artificial establishment of trees at regular spacing became clear, it was logical that the bare-root system should again be adopted for the establishment of the second rotation.

There are, however, some inherent disadvantages in the system. The majority of these are concerned with the fact that the tree must be completely removed from one rooting medium and transplanted to another. Active, growing roots are destroyed in the process and must be regenerated at the new growing site. During the transplanting process the tree is vulnerable to exposure and physical damage and must be protected by special packaging techniques and careful handling.

Planted trees have been found to have a very much higher incidence of root deformation (with its accompanying effects on
stem growth and quality and stand stability) than trees which have grown, in situ, from seed.

The lack of uniformity in size and shape of the transplants and their sensitivity to mechanical handling and exposure creates problems in attempts to mechanize the forest establishment process.

Taking advantage of the very high natural viability of radiata pine seed (which can be further increased by seed sorting and pretreatment) a theoretical alternative system for radiata pine establishment has been proposed.

The system envisages a cheap mass produced container into which is loaded a genetically superior (i.e. seed orchard grown) seed plus all the requirements for fast germination and early growth. These would include a suitable growing medium, water supply and nutrients. The container would provide protection from birds and small rodents and excess insolation. The seed and seedling would be further protected by added insecticides and an artificially inoculated fungus population which will prevent the invasion of pathogenic species. The container, although rigid and firm when set out, would be biodegradable to allow unrestricted root egress. Suitable biodegradable plastics are just now becoming available.

Assuming the biological feasibility of the system, many points of which are already demonstrable, it presents a number of distinct advantages over the bare-root system. All phases of the establishment operation from loading to outplanting are much more
adaptable to total mechanization. The containers would be of a uniform shape and size and insensitive to mechanical handling and exposure compared with the bare-root stock.

A large, capital intensive nursery, with all the potential problems of continuous growing of single species in concentrated beds, would be unnecessary.

Observations of natural and planted seedlings suggest that by eliminating the transplanting stage a better formed and faster growing tree can be obtained. The improved root system would also lead to a more stable stand.

The advantages of intensive site preparation, even before bare-root planting, are being increasingly recognized in New Zealand. It is unlikely that a container seeding system would have any greater demands in this respect than bare-root planting.

The suitability of the system to total mechanization is likely to be the most significant of the advantages. The problems of mechanizing nursery and bare-root planting are great and are still a long way from being solved, even after centuries of the method's use. It has been indicated that mechanization of the planting phase of container seeding could reduce costs by a factor of around ten compared with bare-root planting. Other phases, such as transport and storage, are also likely to be possible at lower cost.

It must be stressed that, at this stage, the system is nothing more than a concept. Certain of its attributes have been
demonstrated elsewhere (eg. the suitability of container systems
generally to mechanization) and some of its demands will be
required by other systems anyway (eg. highly mechanized nursery
growing of bare-root transplants is likely to demand extremely
fast, even and complete germination of the seed). The potential
advantages and cost savings, however, more than justify further
analysis of the system and a start on the experimental testing
of the techniques involved.

Laboratory trials would not have provided much helpful
information for development and testing of the concepts outlined
herein. They evolved primarily from four years of New Zealand
field experience in establishment of radiata pine and exposure
to North American ideas about mechanization and containerization.

The concepts proposed herein are considered to be worthy
of operational and research trials in the field in New Zealand.
The author hopes to be closely associated with planning and
execution of such investigations on his return to New Zealand
in 1972.
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APPENDIX 1

Some sample re-establishment costs from New Zealand State Forests. (Source: N.Z. Forest Service, 1970 (b)).

(a) Aerial sowing.

2 lbs Pinus radiata seed per acre (approx. 28,000 seeds) distributed through "Swathmaster" fertilizer spreader mounted on an Aero Commander 'Snow' aircraft (600 hp). The cost of this operation is dependent upon the cost of the seed which constitutes some 80% of the total operational cost. Only bulk (slash collected) seed has been used for this operation to date.

Seed - 2 lbs/acre at $NZ3.00/lb - $6.00
Flying (A/C hire at $NZ90.00/hour.) - $0.50
Ground control and overheads - $0.50
$NZ7.00/acre.

(b) Supplementary planting.

This is defined as any cut-over planting operation where cognizance is taken of existing seedlings arising from natural or aerially supplied seed. All natural regeneration and aerially sown areas require this treatment (Page, 1971 b).

The per acre cost of this operation, of course, depends upon the amount of supplementation required.

Average cost/acre (1969) - $NZ10.04
Average cost/100 trees (" ) - $NZ 1.45
(c) Blanket planting of cut-overs:

Windrowed:

Average cost/acre (1969) - $NZ11.03
Range in " / " (" " ) - $NZ 8.75 - 13.50

Unprepared:

Average cost/acre (" ) - $NZ25.61
Range in " / " (" ) - $NZ18.58 - 37.75

(d) Windrowing logging slash.

The unmanaged nature of many of the radiata pine stands now being logged results in large quantities of logging slash. Much of this material is dead wood from the many dead stems resulting from natural mortality in the overmature plantations. Future intensive management and closer utilization will likely prevent a similar residue when the second rotation crops are felled. In the meantime, however, the large accumulations of logging slash are a physical barrier to replanting and there is also some evidence that frost regimes are intensified on certain sites by the debris (Page, 1970). Windrowing of the slash with rootrakes removes the barrier and the concurrent soil cultivation is thought to be beneficial also, particularly on the frostier sites.

Cost of windrowing depends on many factors such as operator skill, terrain, tractor type, amount of slash, etc. An average figure for Kaingaroa would be in the region of $25/acre (Page, 1971 c).

(e) Burning slash.

Slash burning is relatively new in New Zealand exotic forestry
and no reliable cost estimates are available. There seems little doubt, however, that costs will be many times lower than mechanical windrowing. $NZ0.50 to 1.00 per acre would not be an unreasonable estimate.

(f) Spacing.

Early spacing control is of great importance in the management of New Zealand's fast growing softwoods. Both natural regeneration and aerial sowing result in localized overstocking (even though other parts of the cutover may be understocked to the point of requiring supplementary planting). Juvenile spacing is almost always required therefore. No successful mechanical system has been developed for this operation and the operation - known as slasher thinning in New Zealand - is carried out manually at a stand height of approximately five feet and at an average cost of $NZ10.00/acre.

The following table indicates some approximate estimates of the total reforestation costs of various types of cutover. The costs are based on 1969 data. Tree stocks costs are taken as $NZ12.00/1,000 for 1-0 and $NZ16.00/1,000 for the 1½-0 trees required on the colder sites.
**Table 6. Some representative reforestation costs in New Zealand.**

<table>
<thead>
<tr>
<th>Operation</th>
<th>Per acre cost for each cutover type. (\text{$N.Z.})</th>
<th>Natural regen.</th>
<th>Aerial Sowing</th>
<th>Windrowed &quot;hard&quot; sites</th>
<th>Unprep. cutover</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air sowing</td>
<td></td>
<td></td>
<td>7.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Suppl. planting (Assume 500spa planted.)</td>
<td></td>
<td>7.25</td>
<td>7.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planting (6x6)</td>
<td></td>
<td></td>
<td></td>
<td>11.03</td>
<td>25.61</td>
</tr>
<tr>
<td>Tree stocks</td>
<td></td>
<td>6.00</td>
<td>6.00</td>
<td>18.66</td>
<td>18.66</td>
</tr>
<tr>
<td>Windrowing</td>
<td></td>
<td></td>
<td></td>
<td>25.00</td>
<td></td>
</tr>
<tr>
<td>Juvenile spacing</td>
<td></td>
<td>10.00</td>
<td>10.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>23.25</td>
<td>30.25</td>
<td>54.69</td>
<td>44.27</td>
</tr>
</tbody>
</table>
APPENDIX 2

An estimate of the potential cost reductions of aerial precision setting of containerized seed and an indication of some of the technical problems involved.

The figures used below (except for such known statistics as aircraft payloads, hire rates etc.) are entirely hypothetical. Despite this, the exercise was thought worth while if only to illustrate that very large savings in per acre costs and time may be possible if aerial methods of planting containerized seed could be developed. The technical problems are also very large but the magnitude of the potential cost, and particularly time, savings is sufficient justification, in this author's opinion, for further analysis of aerial systems.

(i) Container size and weight.

The container is assumed to be 2 cms. in diameter and 10 cms. in length. Applying the volume formula:

\[ \text{Vol.} = \pi r^2 l \]

the volume of the container will be:

\[ 3.142 \times 1 \times 10 = 31.42\text{cms}^3. \]

Assuming the filled container has a specific gravity of 0.8, the containers weight will be:

\[ 0.8 \times 31.42 = 25\text{gms. (approx.)} \]

(ii) Aircraft capacity.

The aircraft used in this exercise is an Aero Commander 'Snow' with a payload of 2200lbs (1,000 kilos). It is assumed that
50% of this payload is absorbed by the container ejection machinery and an aircraft guidance system. The effective payload is then some 500 kilos which represents 20,000 loaded containers.

At a spacing of 6'x12' the aircraft would carry sufficient containers in each load to plant:

\[
\frac{20,000}{605} = 30 \text{ acres (approx.)}
\]

(iii) Planting rate.

Assuming a) a flying speed of 100 mph and b) that the aircraft is equipped with three ejection devices - one under the fuselage and one under each of the wings - the rate of area coverage will be:

\[
\frac{100 \times 1760 \times 12}{4840} = \frac{4800}{11} = 436 \text{ acres/hour.}
\]

or approximately 450 acres per hour of effective flying time.

Required effective flying time per aircraft load is then:

\[
\frac{30 \times 60}{450} = 4 \text{ minutes.}
\]

(iv) Planting cost.

It is assumed that 60% of the aircraft's time in the air is spent ferrying and turning at the end of each run. The amount of paid time required for each aircraft load will then be 10 minutes. (In New Zealand forest operations, when aircraft are hired by the hour the clock is running from the time the wheels begin to roll on the take-off run to the time the aircraft reaches a complete stop after landing. Loading time is charged at a separate rate, if at all.)
The hire rate for an Aero Commander 'Snow' is around $NZ120/hour (White in Chavasse, 1969). The flying cost, on a per acre basis will therefore be:

\[
\frac{10 \times 120}{60 \times 30} = $NZ0.66/acre.
\]

Considering the arbitrary nature of the data used here, and the technical problems that would be involved in such a system, the cost differential between aerial and ground planting systems (the latter calculated in the main body of the thesis at $NZ1.10/acre) is not particularly great. In terms of speed of planting, however, the aerial system, if possible, is greatly superior. The rate of 180 acres per flying hour is some six times the rate per working hour of the ground based system. Increasing the potential speed of the ground prime mover would, of course, narrow the gap, although increased speed is likely to bring with it problems of planting machine design.

The aircraft based system presents many technical problems. No machinery exists yet that could accurately eject the containers at the very high speeds required (although military hardware exists today that is capable of firing rates greatly in excess of what would be required by the above system). For precision sowing aircraft guidance of far greater accuracy than is currently used in the forest industry would be needed. The technology exists today in the form of inertial guidance systems and radio beacon navigators, but very high capital and installation costs have, up to now, been prohibitive.
The figures presented here, however, are sufficient justification for at least further and more detailed theoretical analysis of the system.