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PROFITABLE GLASSHOUSE CROPPING PLANS

A Linear Programming Analysis for varying resource combinations

by

C. LLOYD and R. J. PERKINS

BULLETIN No. 108/H 1

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FOREWORD

This monograph by C. Lloyd and R. J. Perkins is an ambitious exercise in the application of linear programming to the problems of maximising profits in glasshouse production. They make no claim to answering all the questions, both economic and technical, which a grower may ask. Even so, the work embodies a vast amount of painstaking work in formulating the problems faced by growers, in collecting the data needed, and in processing the data so as to provide realistic answers to important questions which confront growers.

The authors have concentrated on three important conventional crops, viz tomatoes, lettuce and chrysanthemums but since these can be grown and marketed at varying periods of the year, the possible set of combinations and rotations becomes extremely large and can only be dealt with by electronic computer. Glasshouse owners have different resources such as labour and heating capacity at their command. It is not possible, even with the aid of electronic computers to take all the possible variations in resources between one grower and another into account but the analysis has been made over a range of fourteen combinations of labour and of heated and unheated glasshouse space. This should cover a large part of the range of resources found in practice and provide models which approximate closely to the set-up of a large number of individual growers.

The monograph has been aimed primarily at the horticultural advisory officer but it should not be beyond the understanding of the intelligent and interested grower who wishes to systematically analyse his business with a view to increasing his profits. It should also be of use in the teaching of students of horticulture and agriculture in the application of operational research tools to the industry.

The authors are prepared to help in resolving difficulties of exposition either by correspondence or by attending meetings where a worth-while number of interested people are concerned. In order to avoid separate printing, the monograph contains certain appendices which deal with the development of future work and ideas in this field. These are largely of a professional nature and may not be of immediate interest to the majority of readers.

W. J. THOMAS.
Professor and Provincial Agricultural Economist.

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CHAPTER I

MANAGEMENT TECHNIQUES AND GLASSHOUSE ORGANISATION

Although the area under glasshouses in England and Wales has declined by only 300 acres, or 8 per cent, over the last decade—and part of this can probably be explained by increased demand for building land around our major towns and cities—the glasshouse industry has nonetheless undergone significant adjustments. In particular, the area devoted to tomatoes, the most important single product of the industry, has fallen by 700 acres; but the consequent loss of output has been more than offset by increased imports from overseas. Indeed, it can be argued that competition will intensify still further as countries in the Mediterranean region and possibly even farther afield—with more obvious climatic advantages and lower labour costs—attempt to increase their exports of horticultural produce in the course of economic development. These factors, combined with possible action aimed at reducing barriers against international trade, imply that further changes in the pattern and techniques of British glasshouse production will become necessary if growers are to compete effectively in the future.

Whilst survival under rigorously competitive conditions may be aided by the adoption of advanced production techniques and ' know-how ' the full potential of technical innovations and improved husbandry can only be realised if growers pay equal attention to the economics of management, and particularly to the selection of the most profitable cropping and marketing programmes.

These aspects of glasshouse management appear to have been relatively neglected in the past, and in this report we attempt to show how a modern technique of crop selection, linear programming, which has found wide use in the analysis of economic problems in other industries, may be used as an aid to policy formulation and profit maximisation within the horticultural firm.

Like other operational research tools, linear programming is a mathematical technique, in essence enabling one to identify the combination of crops or activities which results in the most profitable deployment of the resources available to the grower. Thus, the technique is akin to conventional budgeting methods in that both methods compare alternative enterprises in terms of their profitability and resource use; but linear programming has the important advantage, among others, that the whole holding and a wide range of feasible alternative crops can be considered at the same time. To cover such a range of alternatives using other techniques is virtually impossible.

Any mathematical simulation of real life is of necessity a simplification of the complex set of factors which confront the practical manager and which determine ultimate performance; and the solution to such a model is no more accurate or relevant than the information which is used to analyse the problem. But this is not a denial of the usefulness of linear programming, for even in applications to agriculture—in which many elements are outside the immediate control of the farmer—the technique has been used successfully for forward planning purposes.

Glasshouse production is perhaps better suited to analysis by sophisticated management techniques than are other types of agriculture, for, with the possible exception of the amount of light received by crops, the glasshouse operator has a high degree of control over the physical environment in which his crops are produced. The performance of crops under glass is therefore more predictable from season to season and, given a reasonable level of technical competence, crop yields exhibit less variability than in other spheres of agriculture.

Similarly, the requirements of a crop for labour and other factors of production are more predictable, not only in total but also in seasonal distribution, and these can be measured by keeping appropriate records over a period of time.

All forms of forward planning necessitate the prediction of future costs and prices, and this may be particularly hazardous for horticultural crops which tend to suffer considerable short term price fluctuations. Solutions to this problem within the context of linear programming range from acceptance of figures based on past prices and adjusted for major trends to highly sophisticated statistical treatments which allow for differing attitudes towards risk-taking. At this juncture, though, it is sufficient to note that cropping patterns may require periodic modification in the face of changing market prices if profits are to be maximised through time.

The first of the stages inherent in programming is, then, to identify all of the relevant factors which are likely to affect the final cropping plan. Included in this category are the requirements of each feasible crop for resources or factors of production, and the identification and specification of those resources which could conceivably limit or constrain the scale of operations. Similarly, information is needed about the profitability of each of the crops to be considered in the planning model. Secondly, this body of physical input/output and financial data has to be embodied in an economic model, taking the form of a set of equations which describes the working of the holding under consideration. And, thirdly, the model itself requires solution, whilst the solution in turn invites analysis and possible action.

We do not attempt here a recitation of the mathematical foundations of linear programming since the subject has received exhaustive treatment elsewhere, and because these theoretical aspects of problem-solving are not likely to be of immediate concern to commercial growers or their advisers[1]. Whilst there are available many published applications of the technique to a wide variety of industrial situations it has been little used in the horticultural field. One accessible example of an application to glasshouse cropping, by Dorling[2], concerns a very simple case in which only four resource restrictions and eight " enterprises " are considered. But in that particular case-study, crops are grouped into predetermined rotations, a method which possibly prevents the attainment of a profit maximising solution. In what follows we have treated individual crops as separate enterprises and have given the computer a " free hand " to compile rotations which maximise profits for any given set of resource restrictions. At the same time we have aimed at achieving a greater degree of realism by incorporating in our models many more of the constraints to which cropping is subjected in practice.

Rather than restrict the analysis to a specific glasshouse holding[3], which would possibly not be very representative in the context of general advisory work, we have preferred to construct a basic model for a hypothetical holding of one acre. Then, by varying the combinations of resources assumed to be available, it has been possible to simulate conditions on a wide range of differing holdings. It is hoped that this approach yields information which, whilst not providing a complete solution to the problems of any particular holding, does nevertheless throw light on the broader problems of management within a range of situations to which the input/output data used in the study refer.

The chapter which follows describes the type of holding to which the analysis is applied, the resources which were thought to be most important in determining the cropping plans, and the various resource combinations which were considered. Finally, details are given of the input/output data on which the computations and subsequent analysis are based.

Chapter III outlines the profit maximising cropping plans developed for fourteen different sets of resource combinations and the basic results are presented in both tabular and diagrammatic form.

Managers are frequently faced by problems such as, " Is it financially worthwhile installing more heating apparatus? ", " Will it be profitable to hire more labour? ", or perhaps " Does my existing manpower earn its keep? ". These, and allied questions, form the basis of Chapter IV where we comment on the economic implications of the basic results. In particular, an examination is made of the productivity of labour and capital (as represented by the ratio of heated to unheated glass), with the aim of highlighting the effects on profits of adjustments to the " resource mix " at the disposal of the grower. Some assessment is also made of the extent to which the profit maximising plans may need to be modified if crop prices differ from those initially assumed.

Finally, in Chapter V we give an airing to some of the problems, technical and otherwise, which warrant further consideration in future work of this nature. Throughout the monograph the analysis and conclusions are addressed primarily to horticultural advisers and interested growers, and this has to some extent determined our approach and presentation. Undoubtedly, though, more investigations in the same field will be undertaken and, with this in mind, a number of appendices on methodological problems are included with the report which may hold some interest for research workers in the future.

[1] The mathematics of linear programming are elaborated in most standard textbooks on operational research methods as well as in more specialised sources. The actual computation of models, which is relatively simple but extremely tedious, is performed by electronic computers, and most computer manufacturers provide computing services at relatively low cost.

[2] M. J. Dorling, Planning glasshouse crop production, *Journal of Agric. Econ.*, Vol. XIV, No. 2, 1960.

[3] One recent study of a specific holding by linear programming is I. G. Simpson, A. W. Hales and A. Fletcher, Linear programming and uncertain prices in horticulture, *Journal of Agric. Econ.*, Vol. XV, No. 4, 1963.

CHAPTER II

FORMULATION OF THE PROGRAMMING MODELS

1. The Basic Model and its Variants

Although the glasshouse cropping programmes developed in this study by linear programming methods are derived from theoretical models and do not refer to any specific holding, it is nevertheless necessary to construct these models within a basic set of assumptions which may be representative of real situations.

The holding itself is assumed to be sited in Lancashire, and the input/output data described later are broadly relevant to that area. The economy of the holding is taken to be based entirely on glasshouse crops and the total glasshouse area has been set at one acre of cropping houses throughout the study. In addition, one tenth of an acre of permanently benched propagating houses is assumed to be available; and there is sufficient low glass in the form of dutch-light frames for hardening off and raising plants for all feasible cropping programmes. Finally, outside land is assumed to be available for crops which do not spend the whole of their cropping cycle under glass, such as chrysanthemums grown outdoors in pots and flowered under glass. The cropping houses themselves are taken to be of two distinct types: firstly, heated houses fitted with an up-to-date and efficient heating system, and, secondly, unheated multi-bay dutch-light structures.

Given this basic framework it is recognised that the most profitable (or optimum) combination of crops which can be grown depends on two major factors, namely the *ratio* of the heated to unheated cropping area, and the amount of manpower assumed to be available. Separate and distinct solutions have therefore been computed on the assumption that, whilst the total cropping area is one acre, the *ratio* of heated to unheated cropping acreage is 0·25:0·75 (i.e. one quarter of an acre of heated glass together with threequarters of an acre of unheated structures), 0·5:0·5, 0·75:0·25, and 1·0:0; and, for each of these four situations the labour force has been allowed to vary by units of one full-time man from three men per acre to six men per acre of cropping houses. In theory, then, there are sixteen independent models, each corresponding to a different combination of available resources and each giving rise to potentially different cropping plans. It was found during computation that two of these models (those with six men and a ratio of heated to unheated glass of 0·25:0·75 and 0·5:0·5) are redundant from the economic viewpoint because the increase in gross profits which results from employing the sixth man is less than the increase in labour costs and these resource situations are consequently neglected in the following analysis. In aggregate, then there are fourteen models all of which are derived from one set of input/output information.

2. The Feasible Crops

For a variety of reasons it would not be possible to consider the full range of crops which could conceivably be included in the cropping programmes of the glasshouse holdings described above and we have therefore omitted " speciality " crops which do not find major places in the cropping programmes of Lancashire growers. This, perhaps, is sufficient justification for ignoring these; but in addition we were conscious of the fact that linear programming in its basic form assumes that prices are " given " by the market and do not change appreciably in response to market supplies. However, the implementation of cropping plans involving an expanded acreage of some minor crops could lead to substantial reductions in their market prices, which in turn may invalidate a solution which is in theory thought to be profit maximising.

Our attention has therefore been confined to the three crops which are most important in Lancashire in terms of acreage; namely tomatoes, chrysanthemums and lettuce. Within this simple classification there exists a large number of production techniques as well as alternative policies with respect to the timing of planting and marketing; and in total the computer has been asked to choose profit maximising cropping plans from a range of 138 feasible activities, each activity representing a different way of using the available resources of the holding in the production of the three basic crops.

(a) Tomatoes

Three different planting dates have been permitted, corresponding to early heated, mid-season heated, and late cold-grown crops. Both the early and mid-season crops are allowed to run into October; or, alternatively, they can be pulled out to make way for either (i) autumn lettuce, (ii) pot-grown or lifted chrysanthemums, or (iii) chrysanthemums grown from late-struck cuttings.

For the cold-grown crop, actually produced in the houses fitted with heating apparatus, similar pulling-out dates are permitted with the exception of the one which would allow the tomatoes to be succeeded by late-struck chrysanthemums. And, for the same crop grown in unheated structures only two pulling-out dates are permitted, allowing the crop to run on into mid-October or to be pulled out in order to make way for lifted chrysanthemums.

Thus, eleven variations of the tomato crop are considered feasible in the heated houses and two are permitted in the unheated structures.

(b) Chrysanthemums

Two basic production techniques have been considered permissible for crops grown from cuttings propagated at the " normal " time. The first involves holding the crop outdoors in 9-inch pots during the summer months, the second, planting the crop outdoors for that period: each method requires transfer of the crop into the glasshouses in late September for protection during the flowering period. For crops produced by both the " pot-grown " and the " lifted " techniques, which are flowered under heated glass, a distinction is made between crops consisting primarily of mid-season varieties and those consisting mainly of late varieties. So far, then, four different enterprises can be introduced into the heated house, but only the mid-season lifted crop is assumed to be suitable for unheated houses since late varieties can rarely be grown satisfactorily under cold glass and there seems to be no justification for considering the more expensive " pot-grown " technique for cold houses when its value under heated glass is sometimes questioned in practice.

Similarly, three production methods are permitted for chrysanthemums grown from late-struck cuttings. The first involves planting rooted cuttings direct into heated growing houses in mid-August, and taking one flower per plant; the second involves bedding-out, outdoors, plants propagated at the end of May, lifting them into heated houses in mid-August, with five blooms being taken from each plant. For the third method, rooted cuttings are planted directly into the cropping houses in May for flowering in October taking five stems per plant, the crop being grown without heat. For each of the three techniques it is assumed that the grower can either purchase the cuttings from outside or produce them on the holding; therefore, six more mothods of raising chrysanthemums are permissible in the heated houses and a further two activities are feasible for the unheated acreage.

Thus, in aggregate there are ten variants of chrysanthemum enterprises, differing by date and by method of propagation, considered as suitable for the heated houses, and three for the unheated area.

(c) Lettuces

The main differences between the lettuce crops which have been introduced into the model are due to variations in planting and cutting dates. In total, seven heated crops have been considered with cutting dates ranging from December through to April, and two additional cold-grown crops are permitted with harvesting in April and early May. All nine of these crops are considered feasible for the heated houses, but only the two cold-grown crops are relevant for the unheated houses.

(d) Some Omissions

The thirty crop enterprises for the heated houses and the seven activities considered suitable for the unheated structures in developing the mathematical model certainly do not exhaust all the techniques available for growing the three basic crops under glass.

For example, a case could be made for the inclusion of an early chrysanthemum crop, to be cut in July and followed by a second crop planted in August; but we were compelled to omit the early crop from our model because of the lack of representative input/output data. Likewise, we have neglected to include the " all the year round " technique of chrysanthemum production, for with crops put down at weekly intervals we would have quickly exhausted the storage capacity of the computer. The same factor limited us to a consideration of only three planting dates for tomatoes, though it can be argued that in practice planting can be spread over the period February to May and that it would have been more realistic to have allowed for at least five planting dates in the mathematical model. Further comments on some of these aspects are made later in the discussion of the results.

(*e*) *Soil Sterilisation*

When tomatoes are included in a glasshouse rotation partial soil sterilisation is essential, otherwise the build-up of root-knot eelworm and other soil-borne troubles soon reduces yields to very low levels. For a variety of reasons, not all growers are able to sterilise the whole of their tomato acreage each year, but in this study we have assumed that *annual* sterilisation is necessary for all of the area under tomatoes.

Two methods of soil sterilisation have been introduced into the model, steam sterilisation using Hoddesdon grids, and chemical sterilisation with Metham Sodium. The first of these is the more expensive but the whole operation, including preparation of the soil for the following crop, can be completed in approximately two weeks. Chemical sterilisation is considerably cheaper but as the houses must remain empty for about ten weeks to allow phytotoxic fumes to disperse, the use of this method may mean the loss of one crop in a rotation. This may not be crucial in cold houses where really tight cropping schedules cannot be practised; but as we did not wish to prejudge the economics of the two methods the computer was allowed to choose between them in such a way that profits on the whole of the holding are maximised.

The timing of soil sterilisation is not critical and the operation can be performed at virtually any time between the pulling-out of one tomato crop and the planting of the next. Thus, to avoid prejudging the best timing, several soil sterilisation " enterprises " had to be incorporated in the model to allow sterilisation to be carried out between October and May, that is between the date at which the full-term tomato crops are pulled out and the latest date at which tomatoes are planted[1]. To account for all the various possibilities ten steam sterilisation and six chemical sterilisation " enterprises " were found to be necessary. Appendix II contains the technical information showing how these enterprises were linked to the tomato crop enterprises outlined above, giving a final total of 138 activities for each of the fourteen models considered.

Alternative methods of steam and chemical sterilisation could have been admitted to the basic model but their inclusion would have added still further to the size of the model. As different techniques are not equally effective, we were not very sure of the effects of some of these other techniques on subsequent tomato yields, and consequent data limitations restricted our choice to some extent.

3. Resource Restrictions

(*a*) *Cropping House Area*

It has already been noted that the total area of cropping houses is assumed to be one acre, and that the ratio of heated to unheated structures has been allowed to vary within the overall limit. It is also obvious from earlier remarks in this chapter that different enterprises require land at different times of the year. Therefore, for each model a system of equations must be developed which recognises these restrictions and which enables the computer to allocate land to various crops at any particular time of the year[2].

As a simple example of the problem, let us suppose that there are only three crops, designated " A ", " B " and " C "; and assume that " A " requires land during the whole year, that " B " requires land for the first half of the year and that " C " requires land during the second half of the year. Crop " A " therefore " competes " against crop " B " for land in the first half and against crop " C " in the second half of the year, but crops " B " and " C " do not compete against each

[1] It was assumed that when a tomato crop is pulled out early to make way for some other crop that soil sterilisation follows this second crop.

[2] If there were no other restrictions apart from land then the computer would allocate land to those crops yielding the highest profit per acre. In this study, though, there are other resources (e.g. labour) which may be even scarcer at certain times of the year and these factors must also be taken into account by the computer as it allocates resources to maximise profits.

other for the scarce resources because their requirements do not overlap. We can represent the problem mathematically in one of two ways:

(i) we can say that the acreage of " A " *plus* the acreage of " B " must not exceed the total available acreage in the first half of the year *and* that the acreage of " A " *plus* the acreage of " C " must not exceed the total acreage available in the second half of the year. Thus, we need two equations—one to allocate land in the first half of the year and another to ensure that the land allocated in the second half of the year does not exceed the fixed amount of land available;

(ii) alternatively, we can say that on any single piece of land it is possible to grow in the space of one whole year *either* crop " A ", *or* crop " B ", *or* crop " C ", *or* crop " B " *plus* crop " C ", *or* any combination of these alternatives so long as the available quantity of land is not exceeded. In this case one equation suffices to allocate the land between single crops or specified crop rotations.

On a larger scale, the use of this second method requires the formulation of all possible crop rotations and sequences before computation takes place and in the context of our present model this would have been virtually impossible without some prejudgment of the solution to the problem.

The first approach was therefore adopted, for although that method involves more equations it does enable the computer to select profit maximising crop rotations automatically. The requirements through time of the different crops for cropping house space are expressed by fifty-two equations (twenty-six for the heated houses and another twenty-six for unheated houses), with each equation representing " claims " on land by the various enterprises within a given period of two weeks. With the enterprises permitted in the model it proved possible to dispense with some of the equations;[1] and, finally, eighteen equations were found necessary to account for restrictions imposed by the area of heated glasshouses and a further ten equations were necessary to allocate the unheated area throughout the year.

(b) Labour

Besides land, the other major factor influencing the scale and intensity of cropping, and hence the level of profits, is the quantity of labour assumed to be available at any time of the year. The distribution of the labour requirements of the various enterprises over time has therefore been disaggregated into thirteen periods each of four weeks; thus thirteen equations were needed in the programming model to prevent cropping plans from using more labour than is assumed to be available at any time of the year.

The labour requirements of each enterprise are expressed in units of man-days (of eight hours) per tenth of an acre of the enterprise, and it is assumed that the maximum number of man-days (including overtime) which each worker can " supply " per four-week period is as follows:

Periods 1 (i.e. January), 2, 12 and 13 (i.e. December)	25 man-days
Periods 3 and 11	26 man-days
Periods 4 to 10 inclusive	29 man-days

The size of the regular labour force on the holding is used as the second variable to distinguish the fourteen different models (the first variable being the ratio of heated to unheated glass), and four different levels are considered, corresponding to a regular labour force of three, four, five or six men per acre of cropping houses.

It should be noted that no account has been taken of the labour required for " unproductive " work on the holding such as maintenance and repairs. It was assumed that these demands could be met by utilising labour at those times of the year when manpower is not fully occupied on productive work. The effects of this procedure are fully discussed in the next chapter; but, as an alternative it would have been simple to have adjusted the assumed labour supply level at any particular time of the year to allow time to be devoted to specific " unproductive work."

Whilst the breakdown of labour supply and demand into thirteen four-week periods is adequate to account for most of the restrictions on cropping, this amount of disaggregation is insufficient if some particular problems of labour management are to be represented realistically within the

[1] Where all enterprises requiring land in a particular two-week period have the same requirement in one or more of the preceding or following periods.

mathematical model. Two further equations were therefore introduced to satisfy the situations described in sections (*c*) and (*d*) below, and although these additional relationships are not expressed in terms of man-days they are basically determined by supplies of labour available on the holding.

(*c*) *Restrictions on the Area of Early Tomatoes*

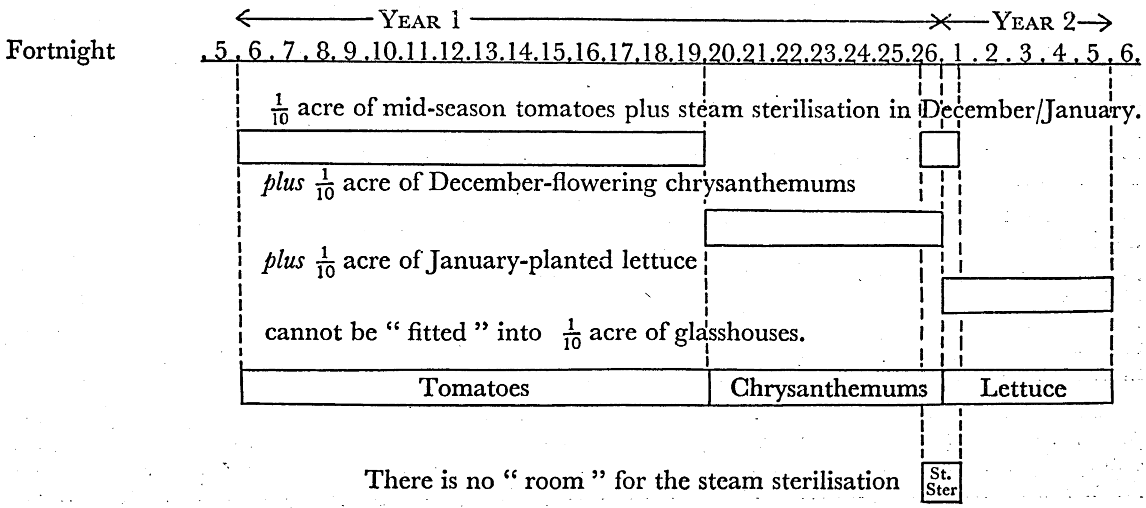
The input/output data representing early tomato enterprises refer to crops planted out in early February into whalehide pots stood out in the glasshouse borders. It has been assumed that these data only are applicable if the planting of these crops is completed within two weeks. Since the planting operations (including the filling of whalehide pots with soil) take an estimated ten man-days per tenth of an acre, there is in effect a limit imposed on the acreage of early tomatoes by the amount of labour available over a period of two weeks, and this restriction is not necessarily accounted for by the main labour restriction which covers a period of four weeks. An equation is therefore included in the model to limit the scale of these enterprises to a maximum of one tenth of an acre per man in the labour force. This is a convenient limit since the time required to plant one tenth of an acre approximates to two weeks' work for one man after allowing some time for other tasks which may need completion at that time of the year.

In practice it may be possible to avoid the labour " bottleneck " at planting time by having the whalehide pots already filled with soil before planting commences, thus facilitating the planting of a larger acreage in the time available. Again, though, the introduction of further modified enterprises into the theoretical model was not thought particularly worthwhile so these techniques were excluded from the study.

(*d*) *Restrictions on the Area of Some Three-Crop Rotations*

Certain three-crop rotations followed by some growers, such as January-planted lettuce succeeded by tomatoes which are pulled out to make way for December-flowering chrysanthemums or lettuce cut around Christmas time clearly involve tight cropping schedules; and it is usual in this case for steam sterilisation to be carried out immediately before the planting of the lettuce crop in January.

In the mathematical model, though, the requirements of enterprises for land are set out in distinct fortnightly periods. Thus, as far as the computer is concerned, December-flowering chrysanthemums and autumn lettuce both occupy the glasshouse until the end of the last fortnight in December whilst the January-planted lettuce crop occupies the glasshouse from the beginning of the first fortnight in January. Therefore, as the diagram below illustrates, the computer is unable to



select three-crop rotations of the kind mentioned above because it is unable to " find room " for steam sterilisation between the chrysanthemums or autumn lettuce and the January-planted lettuce.

To prevent the computer from choosing such a rotation is unrealistic, however, since we know that in practice certain growers adopt precisely this pattern of cropping. In order to overcome the problem we have therefore treated each of these three-crop rotations as a single enterprise by combining the input/output data of the constituent crop and sterilisation enterprises, it being taken that the rotation requires glasshouse space throughout the year.

The area of glasshouses which can be set down to these rotations is limited either by the labour supply in the ten to fourteen days required for soil sterilisation or, when the labour force is relatively large, by the capacity of the steam boiler being used. A restriction is therefore included in the model which limits the total level of these three-crop rotations to a maximum of one fifth of an acre in each of the fourteen models.

(*e*) *The Propagating Area*

The available area of propagating space was considered unlikely to constrain the scale of cropping throughout the year. Given the crops introduced into the model, the greatest demands on propagating space occur between October and April, and only ten equations appeared necessary to account for requirements during that period. Six equations allocated this potentially scarce resource during fortnightly periods in November, December and January, and the remaining four equations limit the use of the available area in the month-long periods of October, February, March and April.

The requirements of crop enterprises for propagating space are expressed in units of 100 square feet of bench space or 150 square feet of glasshouse space (since pathways etc., account for about one third of the floor area for convenience of working) per tenth of an acre of the ultimate crop. One tenth of an acre of propagating houses therefore provides thirty units of propagation space.

The cropping houses themselves can be used for propagation should the need arise, and this is permitted by the inclusion of ten " activities " within the model which allow heated glasshouse area to be used for this purpose. The method for achieving this is indicated in Appendix I. It should be noted that this change in function of the heated houses is assumed to carry no cost in terms of labour used, for example, in erecting temporary benching in cropping houses; but this cannot be considered a very important factor affecting the final solutions to the models.

4. Input/Output Data

(*a*) *Preliminary Considerations*

Hitherto an outline has been given of the production possibilities on our hypothetical holding in terms of the number and type of crop enterprises from which the computer can select profit maximising cropping policies, and a description has been given of the restraints to which cropping programmes are subjected. In the remainder of the chapter the necessary input/output relationships are quantified, mainly for reference purposes, since an understanding of the following chapters does not depend upon readers memorising all of these details.

For the most part the data given here are based on costings prepared by N.A.A.S. officers for the Ministry of Agriculture horticultural management handbook, *Horticulture as a Business*, and in particular on those costings which refer especially to Lancashire. Many other sources of information have been drawn upon, however, and all of the costings have been modified to some extent to make the basic data compatible with the forms required for linear programming. This applies not least to the labour requirements of enterprises, since in the original costings these are given per calendar month whereas they are required in terms of four-week periods in this study.

Furthermore, a single costing has often been used as the basis for several different crop enterprises. Lettuces provide a good example of this, and the labour requirements for all nine of the enterprises considered have been derived, with some confidence, from one basic costing. The data for the delayed direct-planted chrysanthemum crop (i.e. plants propagated in May and held outdoors until August when they are planted into the cropping houses) were synthesised from various sources; and the data relating to production on the holding of cuttings for the late-struck chrysanthemum crops were similarly " engineered ".

With respect to financial information, we have depended greatly on the price data given by the N.A.A.S. syndicate costings, which are average prices based on several years, and these do not refer to any specific crop year. These data are used in our analysis as the basis for assessing market returns from all three of the basic types of tomato crops. Variations in revenue between individual crop enterprises within these groups have been determined by valuing differences in estimated yields on a monthly basis.

The method of price estimation for the lettuce enterprises is rather different. Glasshouse lettuce prices vary considerably over the whole season, whilst the N.A.A.S. costing refers to a crop cut in mid-March. Reference was therefore made to the *Horticultural Supplement* of the weekly *Agricultural Market Report* prepared by the Ministry of Agriculture, Fisheries and Food over a period of three years in an attempt to establish a seasonal price pattern for lettuces for valuing the enterprises in our model.

The several chrysanthemum crops presented a more intractable problem since at any single time a much larger price range, associated with quality differentials, is found for flower crops than for vegetable crops grown under glass. As different production techniques tend to produce flowers of different qualities, the *Horticultural Supplement*, which gives price data for *all* chrysanthemums marketed in a given week, does not necessarily yield a valid measure of the average price received for flowers grown by a " direct-planted " method as opposed to that for blooms produced, for example, by a " lifted " crop. The problem of assessing separately the likely levels of returns for mid-season and late crops of both pot-grown and lifted chrysanthemums necessarily had to be solved by a rather *ad hoc* method because the basic N.A.A.S. costing refers to a mixture of mid-season and late varieties in each case. In estimating the individual market prices for the four types of enterprise it was therefore necessary to assume that the market reports give a reasonable indication of the *relative* price levels of mid-season and late varieties.

To simplify the problem of cross-reference and to shorten the subsequent discussion a shorthand notation is used to refer to specific activities in the model and this is shown in tabular form below. The shorthand notation is summarised on a fold-out sheet at the back of the monograph so that the reader will not need to continually refer back to this section when reading through the subsequent discussion.

(i) Tomatoes (T)

Notation	*Description of enterprise*
eT	Early heated tomatoes. The subscripts e.g. eT_1, eT_2, eT_3, eT_4 refer to the time of pulling out (see Ch. II, Section 2 (*a*) above and Table II (i) below).
mT	Mid-season heated tomatoes. Similar subscripts (1, 2, 3, 4) are used to designate time of pulling out.
cT	Cold-grown tomatoes. Only three subscripts (1, 2, 3) are necessary (see Ch. II, Section 2 (*a*) above and Table II (iii) below). Only cT_1 and cT_3 can be grown in the cold houses (see Ch. II, section 2 (*a*) above).

(ii) Lettuces (*L*)

Notation	*Description of enterprises*
L	Heated lettuces. Subscripts (1, 2, 3, 4, 5, 6, 7) refer to the cropping period (see Ch. II, section 2 (*c*) above and Table II (iv) below).
cL	Cold-grown lettuces. There are only two subscripts (i.e. cL_1 and cL_2) referring to crops harvested in April and early May respectively (see Table II (iv) below).

(iii) Pot-grown Chrysanthemums (*PX*)

Notation	*Description of enterprises*
mPX	Pot-grown chrysanthemums of mid-season varieties (see Ch. II, Section 2 (*b*) and Table II (v) below).
lPX	Pot-grown chrysanthemums of late varieties (see Ch. II, Section 2 (*b*) above and Table II (v) below).

(iv) Lifted Chrysanthemums (*LX*)

Notation	*Description of enterprises*
mLX	Lifted crop of mid-season varieties flowered in heated houses (see Table II (v) below).
lLX	Lifted crop of late varieties flowered in heated houses (see Table II (v) below).
cmLX	Lifted crop of mid-season varieties flowered in cold houses (see Table II (v) below).

(v) Direct-planted Chrysanthemums (*DX*)

Notation	*Description of enterprises*
DX	Crop planted direct into heated houses from purchased cuttings (see Table II (vi) below).
$DX_{(p)}$	The same crop but grown from cuttings propagated on the holding (see Table II (vi) below).
cDx	Crop planted direct into cold or heated houses from purchased cuttings (see Table II (vi) below).
$cDX_{(p)}$	The same crop as *cDX* but grown from cuttings propagated on the holding (see Table II (vi) below).

(vi) Delayed Direct-planted Chrysanthemums (*DDX*)

Notation	*Description of enterprises*
DDX	Crop grown from purchased cuttings struck in late May in heated houses (see Table II (vi) below).
$DDX_{(p)}$	The same crop grown from cuttings propagated on the holding (see Table II (vi) below).

(vii) Sterilisation Activities (*S*)

Notation	*Description of activities*
stS	Steam sterilisation. The subscripts from 1 to 10 indicate the timing of the operation (see Table II (vii) below).
chS	Chemical sterilisation. The subscripts from 1 to 6 indicate the timing of sterilisation (see Table II (vii) below).

(viii) Other Definitions

In the following tables and accompanying text the data refer to inputs and outputs per one-tenth of an acre of a particular enterprise or activity.

The term *net returns* is the market value of sales from one-tenth of an acre of a particular crop *less* commission and other marketing costs. *Variable costs* are costs which vary directly with the acreage of any specific crop and these are disaggregated into their components. The *gross margin* of any enterprise is equal to net returns per tenth of an acre less variable costs per tenth of an acre. Finally, the term *gross profits* refers to the total profitability of the holding: it is equal to the sum of the gross margins of all enterprises in a cropping programme. Thus, if in a solution to the model there are seven-tenths of an acre of Crop A and three-tenths of an acre of crop B then the gross profits will be:

$7 \times$ gross margin of crop A *plus*
$3 \times$ gross margin of crop B

and this is the amount available to the grower to cover labour, depreciation and other fixed costs, and to provide him with a management and investment surplus.

(*b*) *Early Tomatoes* (see Table II (i))

The data for enterprise eT_1 are from the original N.A.A.S. costing, referring to a crop planted in February and yielding 55 tons per acre. The plants are under mercury vapour lamps for three to four weeks during propagation, picking starts in April and finishes in October. The plant density is 1,400 plants per tenth of acre and the crop is watered through trickle irrigation harness.

Net returns are estimated as market value (£926) *less* 10 per cent. commission (£93) and other marketing costs (£28). Variable costs, which are deducted from net returns to obtain the gross margin, amount to £235, and comprise fuel and electricity (£165), water (£4), potting composts and fertilisers (£18), whalehide pots (£13), seed and sundries (£7), one-fifth of the cost of trickle irrigation harness (£17), plus one-fifth of the cost of mercury vapour lamps (£11)[1].

If the crop is pulled out in time for a crop of autumn lettuce the input/output data are slightly changed, and a new enterprise eT_2 is derived. Compared with eT_1, there is a revenue loss of £50 due to reduced yield but there are corresponding reductions in costs (mainly of marketing and fuel costs) of £17; therefore the gross margin falls by £33 from £570 to £537 per tenth of an acre.

A third enterprise (eT_3) based on the original costing allows pot-grown or lifted chrysanthemums to follow, and in this case the gross margin falls to £516[2].

A final enterprise of the same *genre* (eT_4) allows direct-planted chrysanthemums to follow, and the gross margin for this crop is £450 per tenth of an acre, since compared with enterprise eT_1, the assumed reduction in yield depresses the value of sales by £165 which more than offsets reductions in costs of only £45.

The four crops differ not only in financial terms, but also with respect to the distribution of labour and land requirements. Labour requirements are determined by crop yields whilst land requirements depend upon the length of time the crop is in the cropping houses. The complete data are summarised in Table II (i).

[1] i.e. It is assumed that these items of equipment have a useful life of 5 years.

[2] Compared with eT_1, market returns are lower by £80 but there are savings of £26 due to lower marketing, fuel and other costs.

Table II (i)*
Early Tomatoes

Crop unit=one tenth of an acre

Enterprise		eT_1	eT_2	eT_3	eT_4
Net Returns	(£)	805	762	736	661
Variable Costs	(£)	235	225	220	211
Gross Margin	(£)	570	537	516	450
Glass Space Requirements (fortnightly periods)		3—22	3—20	3—19	3—16
Labour Requirements (man days per four-weekly period)	1	3·0	3·0	3·0	3·0
	2	11·5	11·5	11·5	11·5
	3	4·5	4·5	4·5	4·5
	4	4·5	4·5	4·5	4·5
	5	9·0	9·0	9·0	9·0
	6	11·0	11·0	11·0	11·0
	7	12·0	12·0	12·0	12·0
	8	8·5	8·5	8·5	11·0
	9	7·5	7·5	7·0	
	10	6·5	8·0	3·0	
	11	6·0			
	12	0·5	0·5	0·5	0·5
	13	3·0	3·0	3·0	3·0
Propagation Space Requirements (00's sq. ft. of bench area per fortnightly period)	21+22				
	23				
	24				
	25	1·5	1·5	1·5	1·5
	26	1·5	1·5	1·5	1·5
	1	3·5	3·5	3·5	3·5
	2	3·5	3·5	3·5	3·5
	3+4	5·0	5·0	5·0	5·0
	5+6				
	7+8				

* In this and in following tables (i) the glasshouse space requirements list the fortnights of the year (1—26) when the crop is under glass starting from 1=first fortnight of January, (ii) the propagation space requirements are also listed by fortnight (1—26); (iii) labour requirements are shown for each of the 13 four-week periods of the year starting from 1=January 1st to 28th.

(*c*) *Mid-season Tomatoes* (see Table II (ii))

Enterprises mT_1 to mT_4 are mid-season tomato crops. Crop mT_2 represents the original costing and refers to a crop planted in mid-March, with picking commencing in June and yielding 45 tons per acre by late-September. The plant density is 1,400 per tenth of an acre and the method of watering is again through trickle irrigation harness.

The market value of the crop is £490 and net returns amount to £418; variable costs[1] amount to £124 and the gross margin is therefore £294 per tenth of an acre.

If the same crop is carried on into October (mT_1) the yield increases and the market value rises by £60, but costs also rise by £19, so the gross margin, compared with mT_2, rises by £41 to £335 per tenth of an acre.

If, on the other hand, the crop is pulled out to make way for pot-grown or lifted chrysanthemums (mT_3), then compared with mT_2 the gross margin falls by £18 to £276. And, finally, crop mT_4 which can be followed by direct-planted chrysanthemums has a gross margin of £180 since in comparison with the basic costing the yield falls by the equivalent of £145 whilst costs only fall by £29.

All of these input/output data are condensed in Table II (ii), and again there are slight differences in labour and other requirements corresponding largely with variations in the time of harvesting and the length of the cropping season.

[1] Fuel (£85), water (£3), fertilisers and potting composts (£14), seeds and sundries (£5), and one-fifth of the cost of trickle irrigation equipment (£17).

Table II (ii)

Mid-Season Tomatoes

Crop unit=one tenth of an acre

Enterprise		mT_1	mT_2	mT_3	mT_4
Net Returns	(£)	469	418	400	300
Variable Costs	(£)	134	124	124	120
Gross Margin	(£)	335	294	276	180
Glass Space Requirements (fortnightly periods)		6—22	6—20	6—19	6—16
Labour Requirements (man days per four-weekly period)	1	1·5	1·5	1·5	1·5
	2	3·5	3·5	3·5	3·5
	3	6·0	6·0	6·0	6·0
	4	4·0	4·0	4·0	4·0
	5	5·0	5·0	5·0	5·0
	6	5·5	5·5	5·5	5·5
	7	10·0	10·0	10·0	10·0
	8	10·5	10·5	10·5	11·0
	9	10·0	10·0	9·5	1·5
	10	9·0	7·0	5·5	
	11	7·0			
	12				
	13				
Propagation Space Requirements (00's sq. ft. of bench area per fortnightly period)	21+22				
	23				
	24				
	25				
	26				
	1				
	2	1·5	1·5	1·5	1·5
	3+4	3·5	3·5	3·5	3·5
	5+6	5·0	5·0	5·0	5·0
	7+8				

(*d*) *Cold-grown Tomatoes* (see Table II (iii))

Enterprise cT_1 refers to a crop planted in May and pulled out in October, yielding 30 tons per acre, with picking starting in July. If the crop is grown in houses fitted with heating apparatus it is assumed that watering is through trickle irrigation harness, and in unheated structures it is assumed that watering is done by hosepipe. These assumptions are made on the grounds that a grower who plants a late catch crop of tomatoes in houses with heating system might already have trickle irrigation harness for the house and would therefore use it, whereas it is less common to find these installations in unheated structures.

Crop cT_1 is assumed to have a net return of £225 after deduction of commission (£27) and other marketing charges (£15). If the crop is grown in unheated houses the variable costs are estimated at £22, comprising fuel for propagation (£3), water (£3), fertilisers and potting composts (£12) and seeds and sundries (£4). If the crop is irrigated by trickle harness then variable costs are assumed to rise by £15. Thus, the gross margin of the enterprise in unheated houses is £203, and in heated houses it is £188.

In the heated houses the crop can be pulled out earlier to make way for autumn lettuce (cT_2), and in both types of cropping house the tomatoes can be followed by chrysanthemums (cT_3). For all of these situations the remaining fruit would be bench ripened and the actual loss in yield would be very small compared with cT_1. At the same time there would be no change in the assumed variable costs.

In Table II (iii) the input-output data vary not only because of factors outlined earlier, but also because variations in labour requirements reflect differences in time taken to irrigate by trickle harness or hosepipe according to the type of structure in which the crop is grown.

TABLE II (iii)

COLD-GROWN TOMATOES

Crop unit=one tenth of an acre

Enterprise		cT_1*	cT_2*	cT_3*	cT_1†	cT_3†
Net Returns	(£)	225	215	210	225	210
Variable Costs	(£)	37	37	37	22	22
Gross Margin	(£)	188	178	173	203	188
Glasshouse space requirements	Heated	9—21	9—20	9—19		
(fortnightly periods)	Cold				9—21	9—19
Labour Requirements	1					
(man days per four-weekly period)	2					
	3	4·0	4·0	4·0	4·0	4·0
	4	3·5	3·5	3·5	3·5	3·5
	5	4·0	4·0	4·0	4·5	4·5
	6	4·0	4·0	4·0	5·0	5·0
	7	4·5	4·5	4·5	5·5	5·5
	8	6·0	6·0	6·0	7·0	7·0
	9	9·0	9·0	9·0	10·0	10·0
	10	5·0	7·5	4·0	6·0	4·5
	11	4·5	0·5	0·5	4·5	0·5
	12					
	13					
Propagation Space Requirements	21+22					
(00's sq. ft. of bench area per	23					
fortnightly period)	24					
	25					
	26					
	1					
	2					
	3+4					
	5+6	1·5	1·5	1·5	1·5	1·5
	7+8	5·0	5·0	5·0	5·0	5·0

* Watered through trickle irrigation harness in heated houses.
† Watered by hosepipe in unheated structures.

(*e*) *Heated Lettuces* (see Table II (iv))

The data for all lettuce crops grown with heat are based on a single costing: it is assumed that production costs apart from fuel do not vary with the cropping period, and that labour requirements for the major tasks of planting, gapping-up and cutting are also constant. The data refer to a 7 in. by 7 in. planting, equivalent to 12,800 plants per tenth of an acre, and yielding 10,240 marketable heads after allowances of 12 per cent. for paths and 8 per cent. for wastage.

Heating costs for the various enterprises are estimated from the heat requirements of the crops on a day-degree basis, and assume a temperature regime of 60° F. by day and 50° F. by night for ten days after planting followed by a regime of 50° F. to 45° F. for the remainder of the cropping period.

The variations in the distribution of labour requirements are due to different planting dates, and the total labour requirement of a crop is dependent on the length of time it occupies the growing houses.

Apart from heating costs, the other variable costs amount to £15 comprising seeds and sundries (£1), lime, manure and fertilisers (£5·5), water (£1·5) and packing materials (£7) per tenth of an acre; and the full input/output data are tabulated below.

TABLE II (iv)

LETTUCE CROPS

Crop unit=one tenth of an acre

Enterprise		L_1	L_2	L_3	L_4	L_5	L_6	L_7	cL_1	cL_2
Net Returns	(£)	160	210	210	200	200	190	180	160	190
Heating Cost	(£)	35	65	65	60	50	50	35	—	—
Other Variable Costs	(£)	15	15	15	15	15	15	15	15	15
Total Variable Cost	(£)	50	80	80	75	65	65	50	15	15
Gross Margin	(£)	110	130	130	125	135	125	130	145	175
Glasshouse space	H	21—26	23—3	24—4	26—5	1—5	2—7	3—8	1—8	6—9
Requirements									*or*	*or*
(fortnightly periods)	C								1—8	6—9
Labour Requirements	1		2·0	2·5	4·0	9·5	8·5		8·0	
(man days per	2		10·5	11·5	3·0	2·5	2·5	8·0		0·5
four-week period)	3				9·5	10·5	2·5	3·5	1·0	8·0
	4						9·0	11·5	9·5	1·0
	5									9·5
	6									
	7									
	8									
	9									
	10	0·5								
	11	9·0	0·5							
	12	2·0	10·0	8·5	0·5					
	13	11·5	1·0	1·0	7·5	0·5	0·5		0·5	
Propagation Space	21+22	1·0								
Requirements	23		1·0	1·0						
(00's sq. ft. of bench	24			1·0	1·0					
area per fortnightly	25				1·0	1·0	1·0		1·0	
period)	26					1·0	1·0		1·0	
	1					1·0	1·0		1·0	
	2							1·0		
	3+4							1·0		
	5+6									1·0
	7+8									

(*f*) *Cold-grown Lettuces* (see Table II (iv))

Enterprises cL_1 and cL_2 again assume a 7 in. by 7 in. planting, and after allowing for paths and 15 per cent. wastage the yield is 9,900 marketable heads per tenth of an acre. Enterprise cL_1 refers to the " normal " cold house crop planted in January whilst cL_2 represents a much later crop, planted in March and cut in early May.

(*g*) *Pot-grown Chrysanthemums* (see Table II (v))

These crops are grown from cuttings propagated in January/February and bedded-out into frames from March to May. Final potting into 9 in. whalehide pots is in May and the crops are housed in late September, being watered by hosepipe. The data assume a density of £1,500 pots per tenth of an acre with a yield of £1,125 dozen blooms. The average net return for the mid-season crop (*mPX*) is 6s. 3d. per dozen blooms, and for the crop of late varieties (*lPX*) it is 8s. per dozen.

Variable costs for the late crop are £87[1] and for the mid-season crop (*mPX*) the figure falls to £76 because of a reduced fuel bill.

Table II (v)

Pot-grown and Lifted Chrysanthemums

Crop unit=one tenth of an acre

Enterprise		*mPX*	*lPX*	*mLX*	*lLX*	*cmLX*
Net Returns	(£)	350	450	300	410	260
Variable Costs	(£)	76	87	66	77	50
Gross Margin	(£)	274	363	234	333	210
Glasshouse Space	H	20—23	20—26	20—23	20—26	
Requirements	C					20—23
(fortnightly periods)						
Labour Requirements	1	3·0	3·0	4·0	4·0	4·0
(man days per four-week	2	3·5	3·5	2·5	2·5	2·5
period)	3	2·0	2·0	4·0	4·0	4·0
	4	1·0	1·0	2·0	2·0	2·0
	5	2·5	2·5	1·0	1·0	1·0
	6	26·5	26·5	9·0	8·0	9·0
	7	11·0	10·5	10·0	7·5	10·0
	8	14·0	13·0	12·0	10·5	11·0
	9	13·5	11·5	8·0	9·0	8·0
	10	20·0	18·5	25·5	25·0	24·0
	11	19·0	9·5	14·5	7·0	14·0
	12	14·0	15·0	13·5	12·5	13·0
	13	0·5	17·5	0·5	15·0	0·5
Propagation Space	21+22					
Requirements	23					
(00's sq. ft. of bench area	24	1·0		1·0		1·0
per fortnightly period)	25	1·0		1·0		1·0
	26	1·0	1·0	1·0	1·0	1·0
	1	2·0	2·0	2·0	2·0	2·0
	2	2·0	2·0	2·0	2·0	2·0
	3+4	2·0	2·0	2·0	2·0	2·0
	5+6	1·0	1·0	1·0	1·0	1·0
	7+8					

(*h*) *Lifted Chrysanthemums* (see Table II (v))

These data are for crops grown from cuttings taken in January/February and bedded-out into frames in March. Planting outdoors occurs in May and the crop is lifted into the houses in late September. Three thousand plants are assumed per tenth of an acre, yielding 1,500 dozen blooms. On average the net returns per dozen blooms are 4s. for the mid-season heated varieties (*mLX*), 5s. 6d. for the late heated varieties (*lLX*), and 3s. 6d. for the cold-grown mid-season varieties (*cmLX*).

For the late crop, variable costs total £77[2] and it is assumed that fuel savings reduce the variable costs to £66 for the mid-season heated crop (*mLX*) and to £50 for the unheated crop (*cmLX*).

[1] Fuel, including propagation (£37), whalehide pots (£14), peat, sand and manure for potting compost (£14), water (£5), spray materials, canes, etc. (£11), and packing materials (£7).

[2] Made up of Fuel, including that for propagation (£37), manure and fertilisers (£14), peat and sand (£3), water canes and sprays (£16), and packing materials (£7).

(*j*) *Direct-planted Chrysanthemums* (see Table II (vi))

Enterprises DX and $DX_{(p)}$ assume a 5 in. by 5 in. planting, giving 16,500 plants per tenth of an acre and yielding 1,250 dozen blooms at an average net return of 8s. per dozen. The crops are planted into the houses in early August and flower during November and December.

The first of these enterprises (DX) is grown from bought-in cuttings costing £14 10s. 0d. per thousand, and variable costs amount to £310 per tenth of an acre[1]. For enterprise $DX_{(p)}$ the cuttings are produced on the holding by retaining sufficient stools from the previous crop to give approximately 4,000 cuttings taken towards the end of March. The cuttings are boxed, then planted out in frames in mid-April at 6 in. by 4 in., with the first stopping being carried out in May. A final stopping is carried out in late June to provide suitable material for 17,000 cuttings taken in late July for planting into the cropping houses in August.

The variable costs associated with the production of cuttings are £25[2], and total variable costs are lower for crop $DX_{(p)}$ (compared with DX) by £214 per tenth of an acre, whilst net returns are identical. The consequently higher gross margin for the crop produced from " home-grown " cuttings does not, of course, mean that this crop is always to be preferred in a cropping programme since the crop also requires more labour and this resource may have more profitable uses in the production of other crops.

The two cold-grown direct-planted enterprises (cDX and $cDX_{(p)}$) may be grown in either type of cropping house. Cuttings are planted in May at 10 in. by 10 in. and the crop is grown without heat to be cut in September/October. An average of four blooms are taken per plant, yielding 1,500 dozen blooms per tenth of an acre with an average net return of 5s. per dozen.

Variable costs for enterprise cDX are estimated at £100[3].

Enterprise $cDX_{(p)}$ is grown from cutting produced on the nursery. Stools selected from the previous year's crop are transferred into the propagating house in late March, and subsequent growths are stopped in mid-April to produce cuttings for rooting in early May. The variable costs associated with these operations are £10, comprising fuel (£5), peat and sand (£2), and boxes (£3), and for the whole enterprise total variable costs amount to £54.

(*k*) *Delayed Direct-planted Chrysanthemums* (see Table II (vi))

The two enterprises designated DDX and $DDX_{(p)}$, are grown from cuttings struck in late May. The rooted cuttings are potted into peat pots which are embedded in spent mushroom compost or similar material at 6 in. by 6 in. in late June. The plants are stopped during the third week of July, five stems being taken per plant, and the crop lifted into the cropping houses at 12 in. by 12 in. in mid-August for flowering in November/December. This crop density requires 3,000 plants per tenth of an acre, and, with an average of four and a half blooms per plant, yields 1,125 dozen blooms for which an average net return of 7s. 6d. per dozen is assumed.

The crop grown from purchased cuttings (DDX) has variable costs of £140 per tenth of an acre[4]. The other crop ($DDX_{(p)}$) is grown from cuttings raised on the holding. Stock plants are selected from the previous year's crop and transferred into the propagating house in late March. Subsequent growth is stopped near the end of April to produce a crop of three to three and a half cuttings per plant in May. The variable costs of producing these cuttings are estimated at £10, to give total variable costs of £106 for enterprise $DDX_{(p)}$[5].

[1] Comprising cuttings (£239), fuel (£60), water (£2), fertilisers and pesticides (£3), a quarter of the cost of netting for support (£2), and packing materials (£4).

[2] Fuel for propagation house and for steam sterilisation of cold frame (£14), peat and sand (£6), boxes and other sundries (£5).

[3] Cuttings (£66), manure and fertilisers (£15), water (£5), pest control (£3), supports (£3), and packing materials (£8).

[4] Cuttings (£44), Fuel (£60), water (£3), compost and peat pots (£23), fertilisers and pesticides (£4), netting for support (£2) and packing materials (£4).

[5] Fuel (£5), peat and sand (£3), boxes (£2).

Table II (vi)

Other Chrysanthemum Crops

Crop unit=one tenth of an acre

Enterprise		*DX*	*DX*$_{(p)}$	*cDX*	*cDX*$_{(p)}$	*DDX*	*DDX*$_{(p)}$
Net Returns	(£)	500	500	375	375	422	422
Variable Costs	(£)	310	96	100	54	140	106
Gross Margin	(£)	190	404	275	321	282	316
Glasshouse Space Requirements (fortnightly periods)	H	17—26	17—26	11—22 *or*	11—22 *or*	17—26	17—26
	C			11—22	11—22		
Labour Requirements (man days per four-week period)	1		0·5				
	2		0·5				
	3		2·5		0·5		
	4		4·5		1·5		1·0
	5		1·0		3·0		0·5
	6		0·5	8·0	8·0	1·5	4·0
	7		2·0	6·5	6·5	2·0	2·0
	8		11·5	9·0	9·0	1·5	1·5
	9	11·5	11·5	10·0	10·0	7·5	7·5
	10	2·0	2·0	12·5	12·5	3·0	3·0
	11	11·0	11·0	12·5	12·5	12·0	12·0
	12	10·0	10·0			8·5	8·5
	13	8·0	11·0			8·5	9·5
Propagation Space Requirements (00's sq. ft. bench area per fortnightly period)	21+22						
	23						
	25						
	24						
	26	NIL		NIL		NIL	
	1		1·5				
	2		1·5				
	3+4		1·5				
	5+6		1·5				
	7+8		0·8		2·5		1·6

(*l*) *Soil Sterilisation* (see Table II (vii))

The input/output data for all sterilisation " enterprises " include the resource requirements for preparing the soil for the following crop, including the application and digging-in of farm yard manure and flooding.

Steam sterilisation (*stS*) is assumed to be done using Hoddesdon grids and it is assumed that the steam boiler and boilerman are both hired. The variable costs are estimated at £54 per tenth of an acre[1], irrespective of the period in which the operation takes place.

Chemical sterilisation (*chS*) is assumed to be done with Metham Sodium and the variable costs using this technique amount to £25 per tenth of an acre[2].

The labour requirements for all of these enterprises assume that the manure is dug into the soil rather than rotavated in, and that flooding is done by hosepipe and not by sprayline.

[1] Boiler hire and boilerman at 15s. per hour (£26), fuel and water for steaming (£20), manure (£6), and water for flooding (£2).

[2] Metham sodium (£17), manure (£6), water for flooding (£2).

Table II (vii)

Costs and Requirements for Sterilisation

Unit=one tenth of an acre

	STEAM STERILISATION										CHEMICAL STERILISATION					
Enterprise	stS_1	stS_2	stS_3	stS_4	stS_5	stS_6	stS_7	stS_8	stS_9	stS_{10}	chS_1	chS_2	chS_3	chS_4	chS_5	chS_6
Net Returns (£)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Variable Costs (£)	54	54	54	54	54	54	54	54	54	54	25	25	25	25	25	25
Gross Margin (£)	−54	−54	−54	−54	−54	−54	−54	−54	−54	−54	−25	−25	−25	−25	−25	−25
Glasshouse Space (H or C) Requirements (fortnightly periods)	22	23	24	25	1	3	4	5	6	8	22—26	23—1	24—2	25—3	1—5	4—8
Labour Requirements (man days per four-week period) 1					14·5							6	6		1	
2						14·5	14·5							6		1
3								14·5	14·5						6	
4										14·5						6
5																
6																
7																
8																
9																
10																
11	14·5										1					
12		14·5	14·5									1	1			
13				14·5							6			1		
Propagation Space Requirements (00's sq. ft. of bench area per fortnightly period) 21+22																
23																
24																
25				N	I	L						N	I	L		
26																
1																
2																
3+4																
5+6																
7+8																

5. A General Summary of the Mathematical Models

All of the foregoing input/output data have been built into a basic model expressing cropping possibilities on the holding.

The model consists of a system of equations, each of which describes the requirements of each feasible activity for one of the resources which could constrain the cropping plan. The form of each equation in the system is in essence very simple.

For example, there is one equation relating to labour supply in the first four-week period of the year which takes the form:

(The quantity of labour required in that period per tenth of an acre of enterprise " A " actually produced) *plus* (the quantity of labour required in that period per tenth of an acre of enterprise " B " actually produced) *plus* . . . etc. etc. *must not exceed* the total quantity of labour assumed to be available in that period of the year[1]. Similar equations exist in the model for all resources at each period of the year. Given all of these equations it is then the task of the computer[2] to determine the areas of each of the included enterprises which will maximise gross profits on the holding and at the same time to ensure that the solution does not require more resources than are assumed to be available.

Although only thirty crop enterprises and sixteen soil sterilisation enterprises were considered at the outset, it was found that 136 activities were needed in the basic programming model. This rather spectacular increase in the number of " enterprises " is largely a consequence of some technical difficulties which were encountered in ensuring the soil sterilisation is always included in any crop rotation featuring one of the tomato enterprises; and which necessitated that the feasible combination of tomato and soil sterilisation enterprises should be indentified and shown as a series of joint tomato/soil sterilisation activities in the programming model. This question is dealt with in some detail in Appendix II.

On the other hand some of the extra activities were required to take account of the possibility of using cropping house area for propagation. Details of the composition of the 138 activities used are given in Appendix IV.

Sixty equations were found to be necessary to describe the restraints imposed on the cropping programme. As described earlier in this chapter, eighteen equations deal with the heated glass area, ten with the cold glass area, thirteen with labour supplies, ten with the propagation area, one with the area of early tomatoes and one with the area of certain three-crop rotations. The remaining seven equations were found to be necessary for technical reasons to cope with the problem of linking soil sterilisation to the tomato enterprises. (See Appendix II).

The one basic model was used to develop optimum cropping programmes for fourteen resource combinations, each situation differing only in the amount of labour assumed to be available and in the proportion of the glasshouse area assumed to be heated. Three, four and five men per acre were considered for heated to cold glass ratios of 0·25: 0·75, 0·50: 0·50, 0·25: 0·75 and 1·0: 0, whilst a sixth man was also considered for H: C ratios of 0·75: 0·25 and 1: 0: 0. In subsequent chapters the optimum cropping programme for each resource combination is described and the implications of the effect which different resource combinations have on the composition of the optimum cropping plan and on the profitability of the holding are discussed.

[1] Mathematically the equations (or more precisely the inequalities) can be written

$$\sum_{j=1}^{n} a_{ij}X_j \leqslant b_i \text{ for } i=1,2,\ldots, n$$

where a_{ij} is the requirement for the ith resource per unit (1/10 acre) of the jth enterprise or activity, and where b_i is the total quantity of the ith resource (e.g. labour in a particular four-week period) assumed to be available. X_j is the area (to be determined) of the jth enterprise.

[2] We are indebted to the Manchester University Computing Laboratory for running the problems on the Atlas computer using programme Autosimmer C.

CHAPTER III

RESULTS: OPTIMUM SOLUTIONS, CROPPING PATTERNS AND LABOUR UTILISATION

1. Resource Combinations and Gross Profits

Profit maximising cropping programmes have been computed for each of the fourteen different resource situations developed in the preceding chapter, and Table III (i) shows how maximum gross profits on the holding change as the resource combinations are allowed to vary.

TABLE III (i)

RESOURCE COMBINATIONS AND GROSS PROFITABILITY (£)

Ratio of heated to unheated glass area (H:C. ratio)	*Men per acre* 3	4	5	6
0·25:0·75	4,648	5,460	5,774	—
0·5:0·5	5,161	6,062	6,462	—
0·75:0·25	5,463	6,515	6,980	7,134
1·0:0	5,595	6,784	7,338	7,643

Thus, for Case 1, with a complement of three men, 0·25 acres of heated glass and 0·75 acres of unheated structures, gross profits of £4,648 are attained if these resources are deployed in the most profitable way. After deducting fixed costs (e.g. labour and depreciation) from this sum the remainder comprises management and investment income for the grower. If the same grower hires an additional man and alters his cropping policy to accord with new recommendations then gross profits rise to £5,460; and, similarly, if a quarter of an acre of the unheated glass is converted into heated glass to give a H:C ratio of 0·5:0·5 then gross profits should rise from £4,648 to £5,161 if the cropping plan is suitably altered.

The economic implications of these basic results are fully assessed in the next chapter, whilst the remainder of this chapter describes and comments on the cropping policies and resource utilisation which must be practised if these gross profits are to be achieved. At this stage it should perhaps be mentioned that we have made no attempt to calculate the profitability of the hypothetical holdings in absolute terms and have been more concerned with assessing the *relative* profitability of different resource combinations. In Chapter IV we make estimates of the labour costs and of the annual share of the additional capitals costs associated with increasing the proportion of heated glass on the holding; and, by deducting these items from gross profits, derive a " net profit ". Our assumption is that all costs *still* not accounted for will be common to all the situations we have considered, and that their evaluation would shed no further light on the problems we set out to solve.

2. Optimum Cropping Programmes

Of the thirty crop enterprises originally considered feasible for the heated houses and the seven suggested as suitable for the unheated area, no fewer than seventeen and four, respectively, appear in at least one of the fourteen computed solutions. Details of the area of each of these crops in each solution are shown in Table III (ii); and the rotations which are built up from these data are illustrated diagramatically in Figures 1 to 14.

Thus, for Case 1 again, the areas of the enterprises (in tenths of an acre) necessary to maximise gross profits are read from the first column of table III (ii)[1], and the pattern of cropping associated with these results is displayed in Fig. 1. In this situation, the optimum cropping pattern for the quarter acre of heated houses consists of:

(i) Early tomatoes (eT_3) followed immediately by late lifted chrysanthemums (lLX), with steam sterilisation occurring at the beginning of the year (stS_5), and the whole rotation utilises about 0·88 tenths of an acre, and

[1] The computer gives results to four places of decimals and these are rounded to two decimal places to avoid excessive detail.

(ii) the remainder of the heated area is in the earlier months of the year divided between early tomatoes (eT_4) and a rotation of heated lettuce (L_5) and cold-grown lettuce (cL_2). In the later part of the year the whole of this remaining area is cropped by direct-planted chrysanthemums ($DX_{(p)}$) and delayed direct-planted chrysanthemums ($DDX_{(p)}$), both crops being grown from cuttings propagated on the holding.

The unheated structures in Case 1 are less intensively used. Part is occupied by lettuces (cL_1) followed by tomatoes (cT_3) with sterilisation at the end of the year (stS_4); and the remainder is devoted to another two-crop rotation, of lettuces (cL_2) followed by direct-planted chrysanthemums grown from cuttings propagated on the holding ($cDX_{(p)}$).

As the resource combinations available to the grower vary so the pattern of cropping also changes, and, although the changes do not follow any clear cut pattern, a number of generalisations appear to be valid.

TABLE III (ii)

CROP AREAS (IN TENTHS OF AN ACRE) IN THE OPTIMUM SOLUTIONS FOR VARIOUS RESOURCE COMBINATIONS*

Case	1	2	3	4	5	6	7	8	9	10	11	12	13	14
H: C Ratio	0·25:0·75			0·5:0·5			0·75:0·25				1·0:0			
Men per acre	3	4	5	3	4	5	3	4	5	6	3	4	5	6
Crop enterprises (heated structures														
eT_1+stS_2								0·24						
eT_2+stS_5				0·82			1·74	0·41			0·21	0·02		
eT_3+stS_5	0·88	1·00	2·16	1·00	1·82	3·18		2·41	3·97	3·24		2·41	2·93	3·76
eT_4+stS_5	0·67	1·31	0·34	0·31	1·13	1·34	0·32	0·95		2·76	0·53	0·95	0·91	1·62
eT_3+stS_4							0·94					0·63		
eT_3+chS_3				0·86							2·26		0·21	0·33
L_2				0·59			3·17					2·74	1·49	
L_3				0·24				1·15			2·85	0·76		
L_4								0·24						
L_5	0·95	0·18		1·18	2·05	0·42	1·32	2·11	3·42	1·07	1·44	2·33	4·35	3·78
L_7				0·59										
cL_1											2·38			
cL_2	0·95	0·18		1·41	2·05	0·48	4·5	3·5	3·53	1·50	4·62	6·00	5·96	4·29
mPX													0·21	0·33
lPX			2·16			1·56		0·97	2·58	3·24		0·89	2·93	3·76
lLX	0·88	1·00		1·00	1·82	1·62		1·44	1·39			1·52		
$DX(p)$	1·32	1·50	0·34	1·48	2·05	1·82	2·79	1·71	3·53	4·26	3·63	1·56	4·59	5·91
$DDX(p)$	0·30			0·84	1·13		0·60	1·99			1·26	1·91	0·78	
$cDX(p)$							0·58	0·75			1·84	3·48	1·49	
Crop enterprises (cold houses)														
cT_3+stS_4	1·31	1·10			0·61									
cL_1	2·97	1·10		1·52	0·61		1·98							
cL_2	4·53	6·40	7·50	3·48	4·39	5·00	0·52	2·50	2·50	2·50				
$cDX(p)$	4·24	6·40	7·50	3·55	4·39	5·00	2·50	2·50	2·50	2·50				

* In addition to these crop areas, a small part of the cropping area is devoted to propagating functions in some cases, but only for a short time and only when the area is not required for cropping. See Figs. 1 to 14.

Figures 1 to 14 Optimum Cropping Programmes

The optimum cropping programmes are shown in graphical form, the vertical axis measuring the area of each enterprise and the horizontal axis the time for which the various enterprises occupy glasshouse space. The stippled areas indicate when glasshouse space is not required for crops or soil sterilisation, in other words, when it is uncropped.

It should be noted that we show only one way in which the enterprises in the optimum solutions are fitted into the glasshouse area available. However, a careful study of the diagrams will show that it is possible in some cases to switch the areas shown under some crops for other areas at certain periods of the year, if this thought to be an advantage for any other reason.

FIG. 1 0·25 acs Heated ; 0·75 acs Cold
3 men per acre
Gross Profits £4647·81

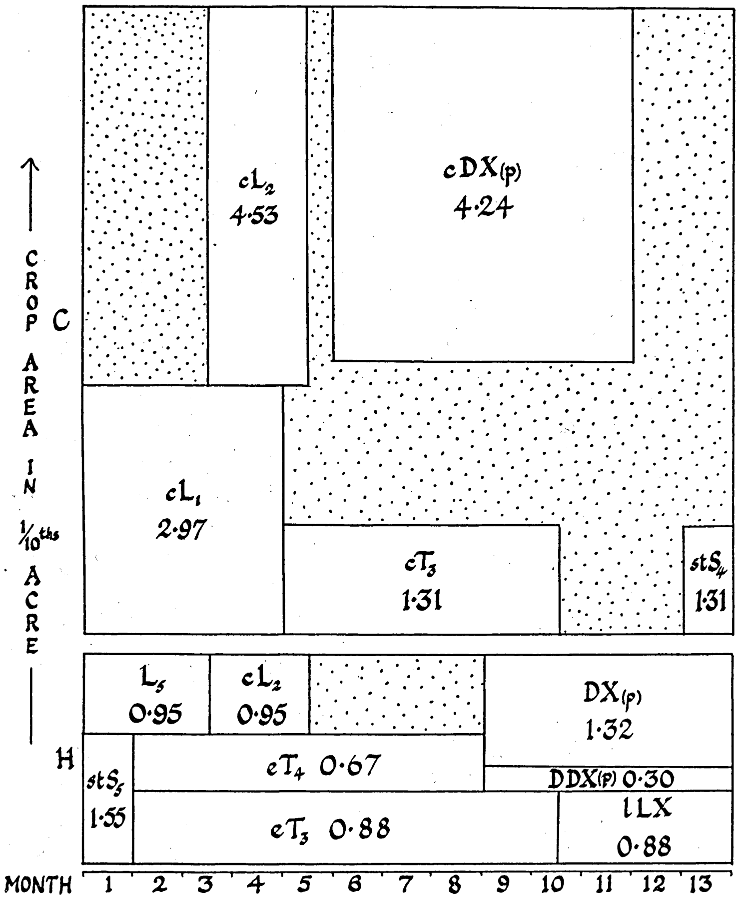


FIG. 2 0·25 acs Heated ; 0·75 acs Cold
4 men per acre
Gross Profits £5459·69

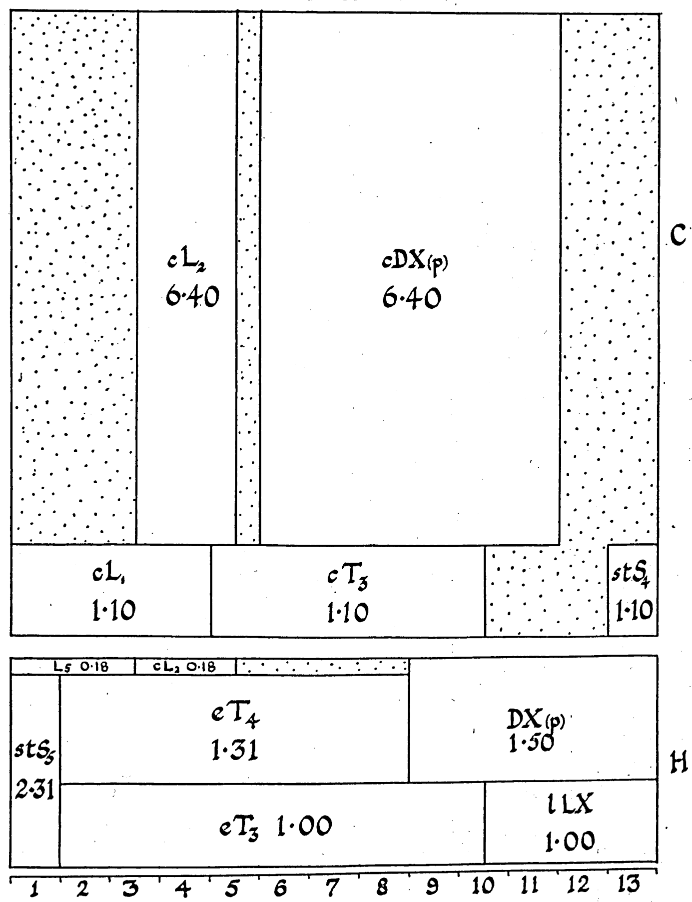


FIG. 3 0·25 acs Heated; 0·75 acs Cold
5 men per acre
Gross Profits £5774·09

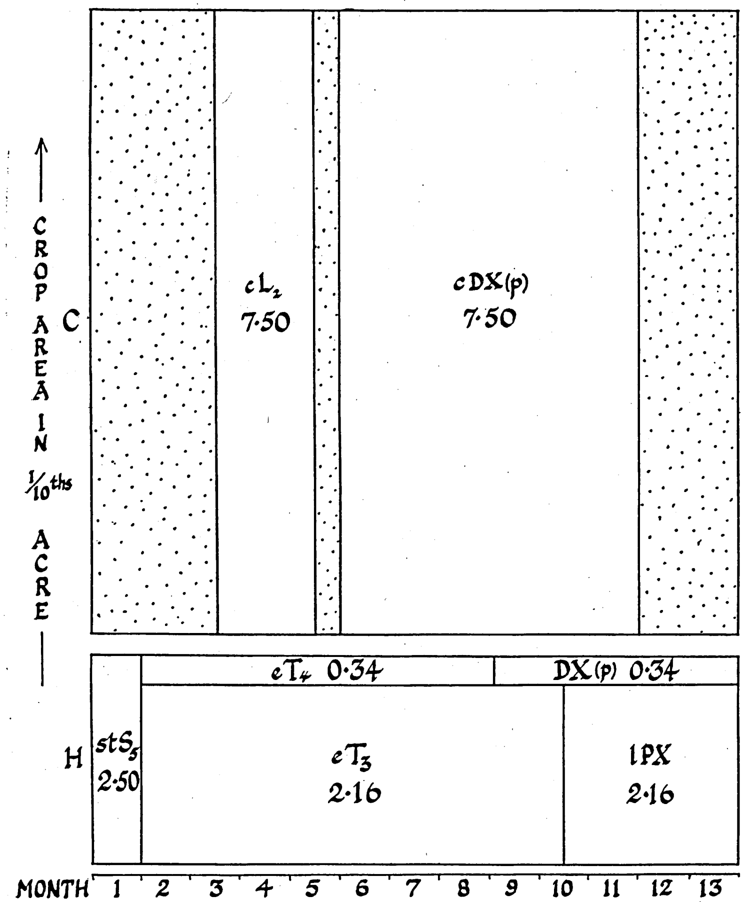


FIG. 4 0·50 acs Heated; 0·50 acs Cold
3 men per acre
Gross Profits £5160·80

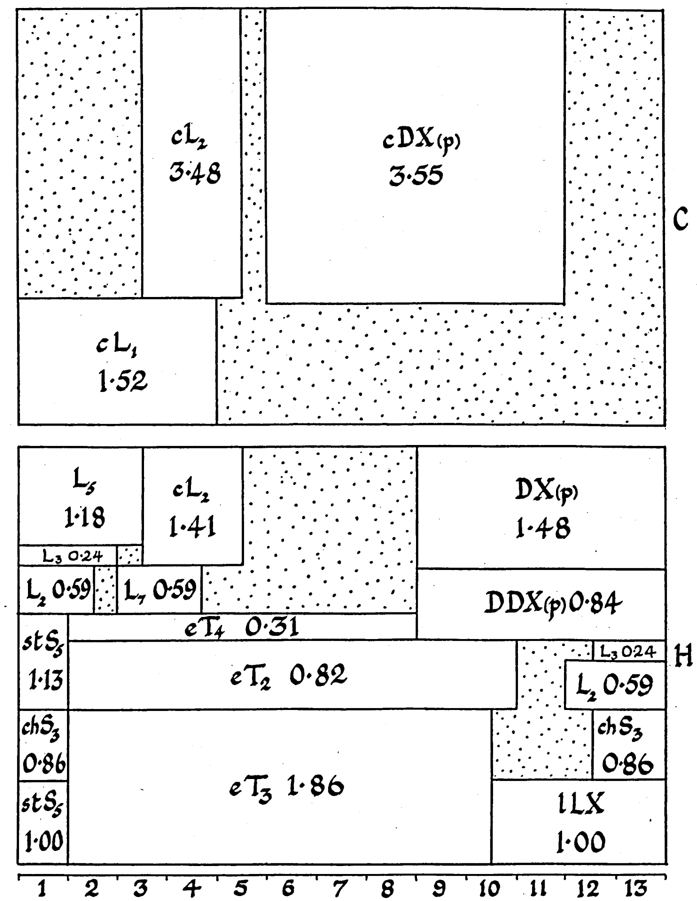


FIG. 5 0·50 acs Heated; 0·50 acs Cold
4 men per acre
Gross Profits £6061·60

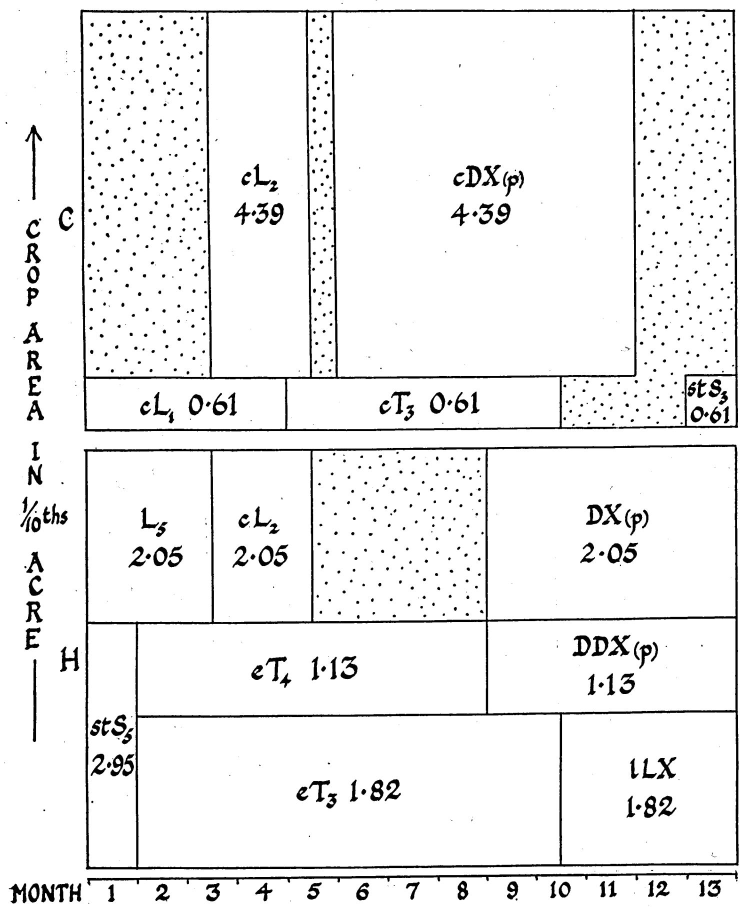
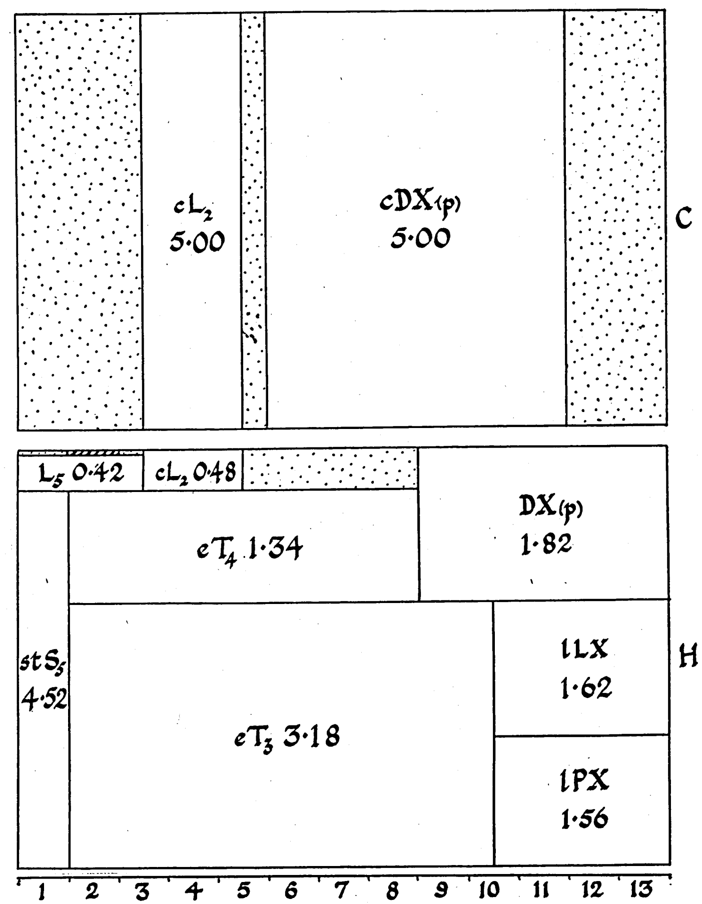


FIG. 6 0·50 acs Heated; 0·50 acs Cold
5 men per acre
Gross Profits £6462·13



Used for propagation

FIG. 7 0·75 acs Heated; 0·25 acs Cold
3 men per acre
Gross Profits £5462·86

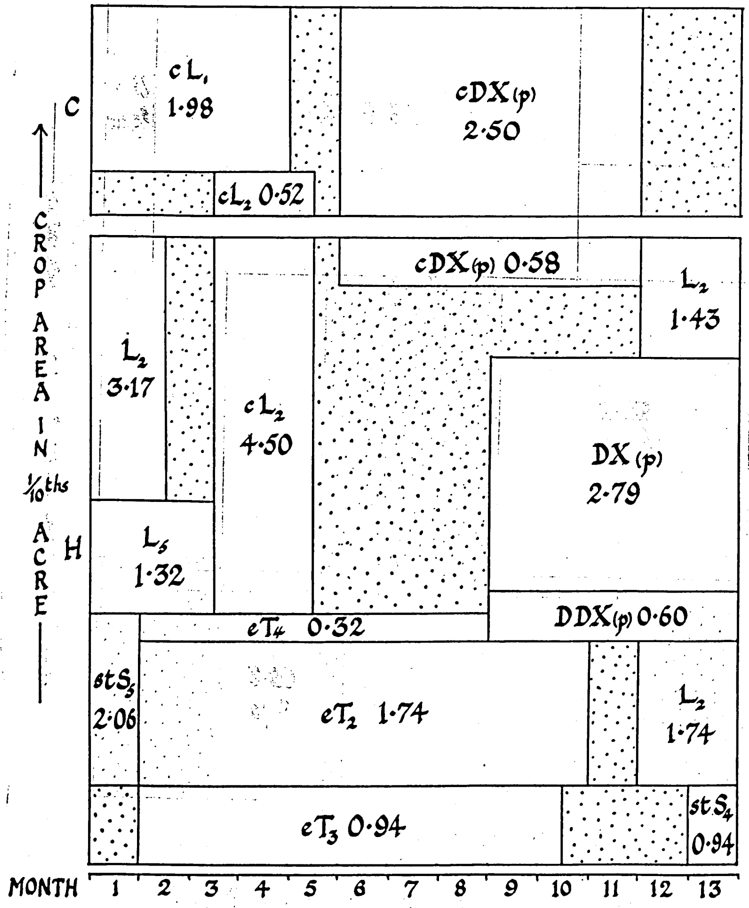


FIG. 8 0·75 acs Heated; 0·25 acs Cold
4 men per acre
Gross Profits £6515·34

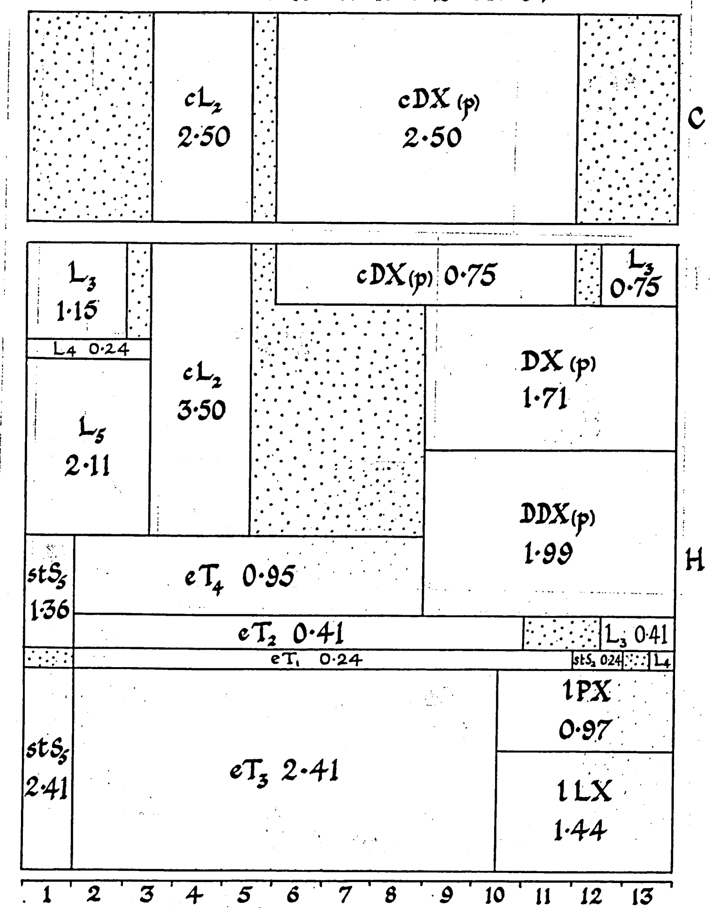


FIG. 9 0·75 acs Heated; 0·25 acs Cold
5 men per acre
Gross Profits £ 6980·29

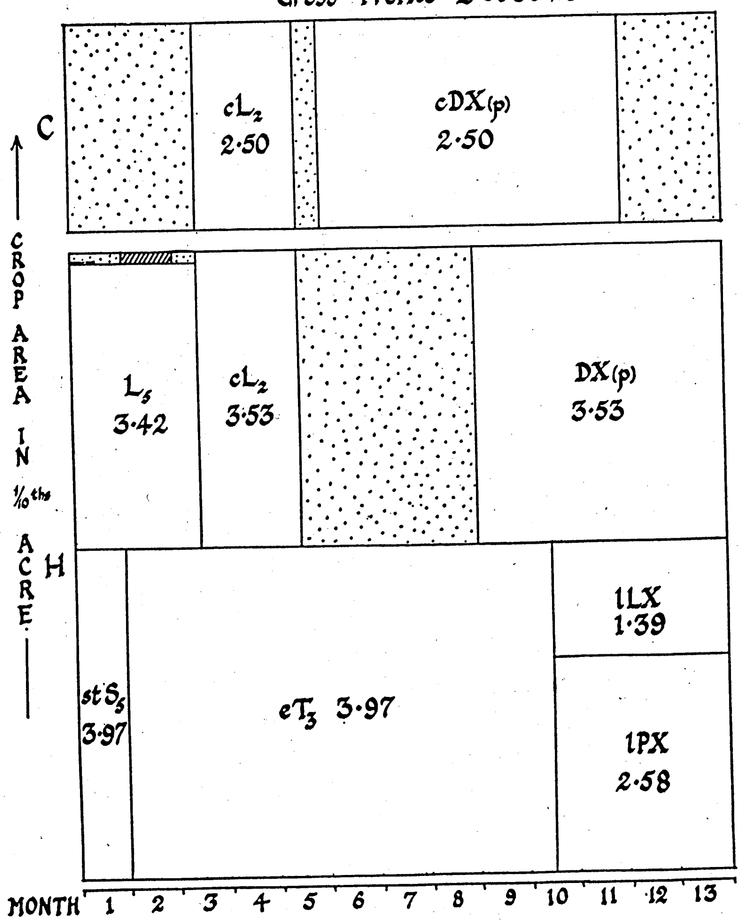
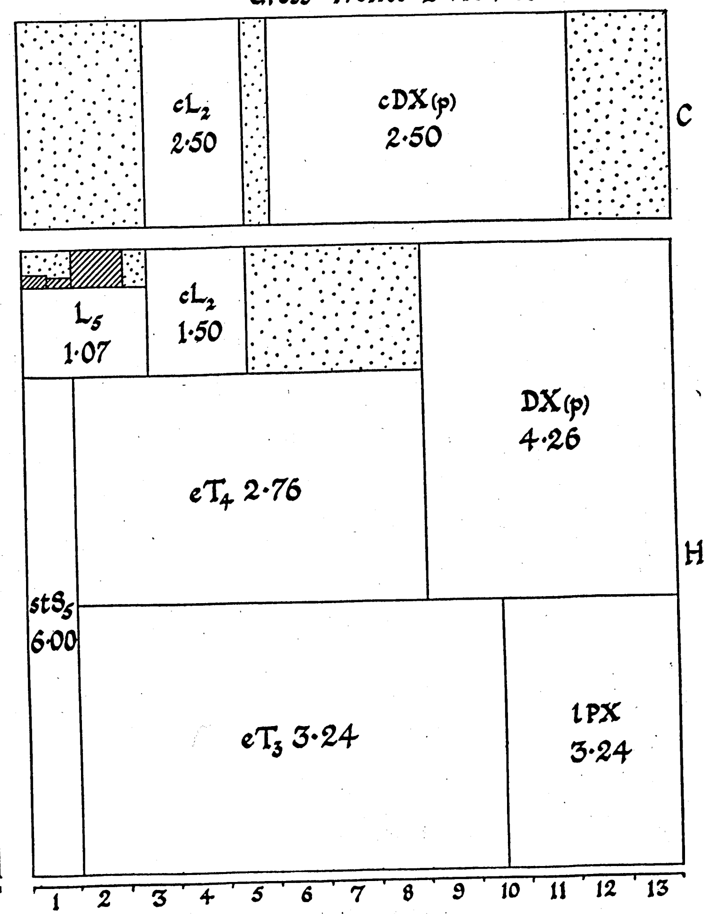


FIG. 10 0·75 acs Heated; 0·25 acs Cold
6 men per acre
Gross Profits £ 7134·09



Used for propagation

FIG. 11 All Heated
3 men per acre
Gross Profits £5594·74

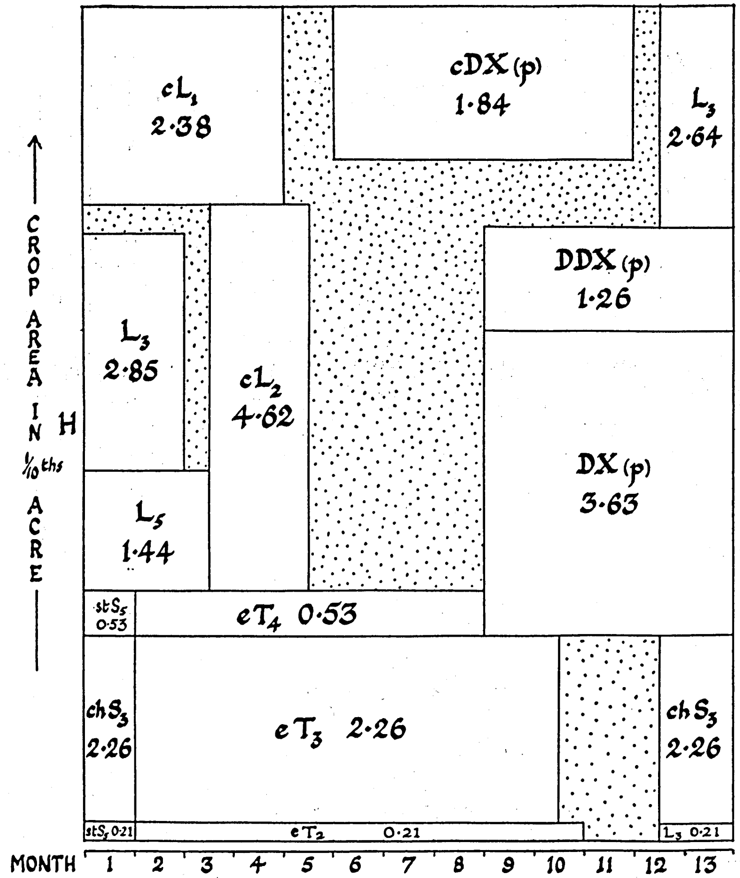
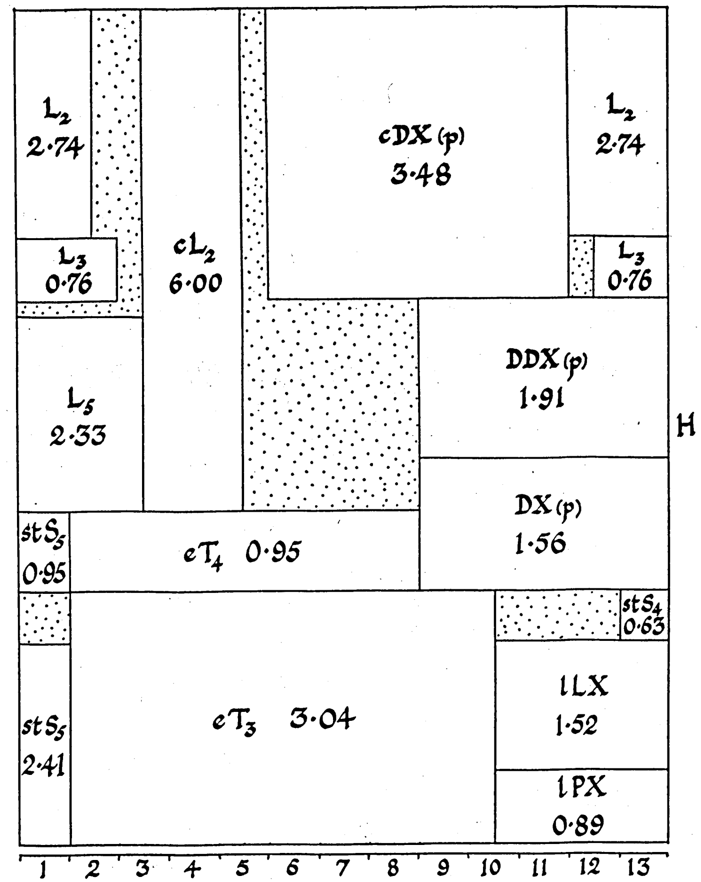


FIG. 12 All Heated
4 men per acre
Gross Profits £6784·38



Also includes 0·02 acres of eT_2.

FIG. 13 All Heated

5 men per acre

Gross Profits £7338·06

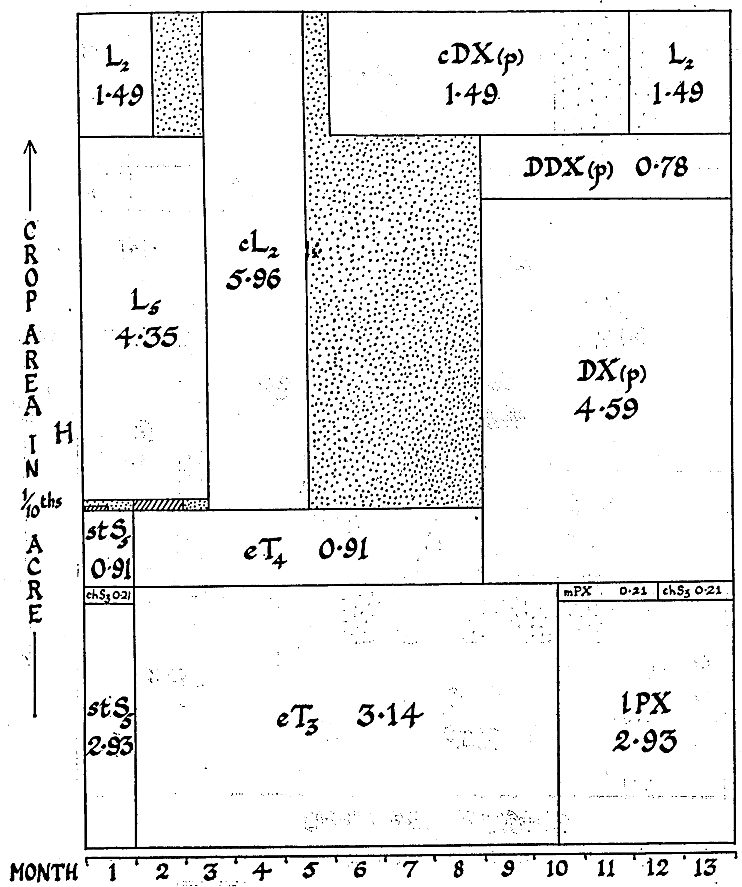
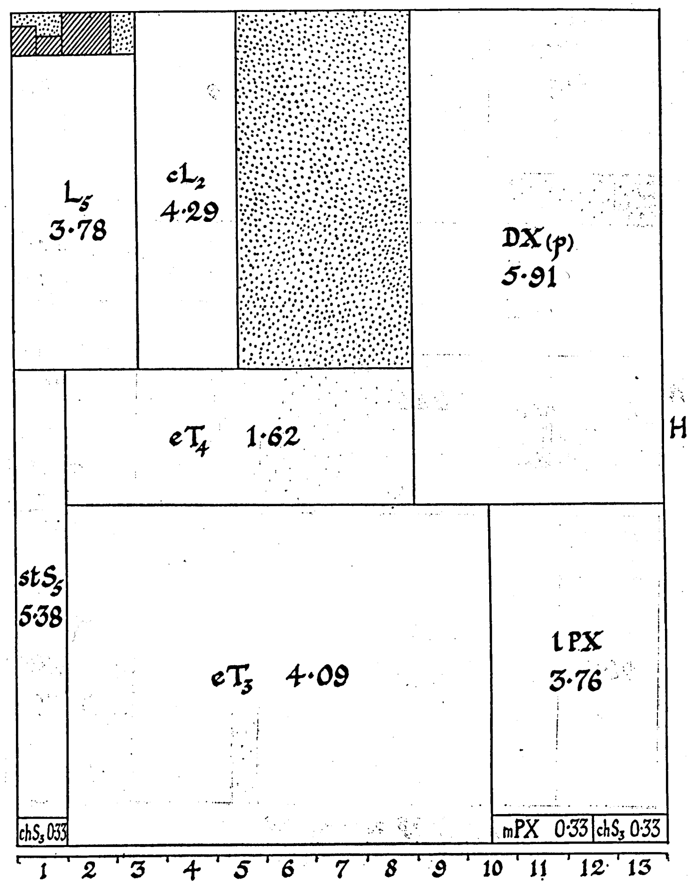


FIG. 14 All Heated

6 men per acre

Gross Profits £7643·11



Used for propagation.

(*a*) *Tomatoes*: The total area of early tomatoes in any solution was limited to a maximum of one tenth of an acre per man in the labour force since it was thought that labour supplies during the fortnight of February in which the crop is planted would impose this constraint on the cropping plan even if sufficient labour were available during the rest of the year to handle a bigger area of this crop. It can be seen from Table III (iii) that when the labour force is small (three or four men per acre) and more than 25 per cent of the glasshouse area is heated, the limit of one tenth of an acre per man which we have imposed does in effect restrict the area of early tomatoes. As we increase the labour force to five or six men, labour is less of a restriction on cropping plans (even with the one-tenth of an acre per man limit on early tomatoes). On these grounds we might have expected that the areas of early tomatoes in the optimum solutions would have increased consistently as we increase the size of the labour force for a given H : C ratio, since early tomatoes give a higher gross margin per unit of glasshouse area than any of the other enterprises considered. In fact, this does not prove to be the case; the restriction on the total early tomato area is rarely operative with labour forces of five or six men per acre, and in some situations an increase in the labour force even brings about a reduction in the area of early tomatoes. Compare, for instance, Cases 8 and 9 in Table III (iii). The reason for this is that the computer is looking for the most profitable *combination* of crops, and as the labour force is increased glasshouse area becomes increasingly important in the selection of crops, and enterprises which individually yield high gross margins do not necessarily feature in the most profitable crop rotations. When viewed in this context a clearer pattern emerges as manpower increases.

Reference to Figures 1—14 will show that three broad types of rotation are recommended for the heated houses:

(*A*)—Early tomatoes either as a self-crop or followed by lettuce as part of a two-year rotation.

(*B*)—Early tomatoes followed by chrysanthemums.

(*C*)—Heated lettuce (L_5) followed by cold-grown lettuce (cL_2) and chrysanthemums grown from late-struck cuttings (e.g. $DX_{(p)}$),

By referring back to Table III (iii) it can be seen that when labour is in short supply (Cases 4, 7 and 11) the constraint on the early tomato acreage is operative. Rotations of type (*A*) are more important than those of type (*B*) in these circumstances (see Table III (iv)).

TABLE III (iii)

EARLY TOMATO CROP ACREAGES

Case	Men per acre	H: C Ratio	Maximum permissible area of early tomato crops (one-tenth acres)	Actual optimum area of early tomato crops (one-tenth acres)
1	3		2·5*	1·55
2	4	0·25: 0·75	2·5*	2·32
3	5		2·5*	2·50
4	3		3·0	3·00
5	4	0·5: 0·5	4·0	2·95
6	5		5·0	4·52
7	3		3·0	3·00
8	4	0·75: 0·25	4·0	4·00
9	5		5·0	3·97
10	6		6·0	6·00
11	3		3·0	3·00
12	4	1·0: 0	4·0	4·0
13	5		5·0	4·05
14	6		6·0	5·71

* In these cases the restraint on the area of early tomato crops is the total area of heated glass.

With an increase in the labour force (cases 8 and 12) the constraint still operates but type (*B*) rotations dominate those of type (*A*). As labour becomes relatively plentiful (Cases 5, 9 and 13) the optimum strategy which can be followed by the grower is evidently to combine a relatively small acreage of type (*B*) with a relatively large acreage of type (*C*) rather than a relatively large acreage of type (*A*) plus type (*B*) with a relatively small acreage of type (*C*). In these circumstances the constraint on the total early tomato acreage is not operative. When even more labour becomes available (Cases 10 and 14) the acreage of early tomato rotations (type *B* only) increases at the expense of type *C* rotations but only in Case 10 is sufficient labour available for the constraint to become operative again. This is not surprising since labour intensive rotations are not feasible for unheated houses and six men per acre coupled with a H : C ratio of 0·75 : 0·25 (Case 10) means that, in effect, more labour is available per unit area of the heated houses than when six men per acre are coupled with a H : C ratio of 1·0 : 0 (Case 14). Similar reasoning probably explains why the heated area is not all put down to early tomato rotations in Cases 1 and 2, which may be considered as being somewhat similar to Case 5 in so far as the effective combination of labour and heated glass is concerned.

TABLE III (iv)

PROPORTIONS OF EARLY TOMATO CROP FOLLOWED BY VARIOUS CROPS

Case	Men per acre	Early Tomatoes as a one-crop rotation or followed by lettuces (%)	Early Tomatoes in rotation with lifted Xanths (%)	Early Tomatoes in rotation with pot-grown Xanths (%)	Early Tomatoes in rotation with late-struck Xanths (%)
1	3	0	56·7	0	43·3
2	4	0	43·0	0	56·7
3	5	0	0	86·5	13·5
4	3	56·3	33·2	0	10·5
5	4	0	61·7	0	38·3
6	5	0	35·9	34·3	29·8
7	3	89·3	0	0	10·7
8	4	16·0	36·1	24·2	23·7
9	5	0	35·0	65·0	0
10	6	0	0	54·0	46·0
11	3	82·6	0	0	17·4
12	4	16·1	37·9	22·3	23·7
13	5	0	0	77·6	22·4
14	6	0	0	71·6	28·4

Table III (iv) shows the changes which take place in early tomato rotations as manpower increases. As has already been pointed out, early tomatoes appear as a single-crop rotation, or in combination with a lettuce crop planted before Christmas (i.e. L_2, L_3 or L_4) to form part of a two-year rotation, only when labour is relatively scarce. As rotations of this nature drop out of the optimum cropping plans with increasing labour supplies, they tend to be replaced by early tomatoes in rotation with chrysanthemums grown from late-struck cuttings (i.e. $DX_{(p)}$ or $DDX_{(p)}$) or lifted chrysanthemums. Although pot-grown chrysanthemums have the same glasshouse space requirements as the lifted crop and show greater profitability per unit area they have higher labour requirements in period 6 (i.e. 21st May to 17th June). Since tomatoes also require relatively high labour inputs at this time, labour supplies in this period are often a constraint on output. Hence, pot-grown chrysanthemums do not displace the lifted crop until labour is in plentiful supply.

It is notable from Table III (ii) that mid-season heated tomatoes do not appear in any of the prescribed profit-maximising plans, and further comments on this feature are made in Chapter IV.

(*b*) *Lettuces*: As a generalisation, tomatoes and chrysanthemums exhibit higher returns per unit of land and labour than do lettuces: resources thus tend to be allocated initially to the higher value crops. But, since tomatoes and chrysanthemums show marked seasonal variations in their demands for labour in particular, there are some periods of the year in which labour resources are fully utilised in the cropping of these two types of crop, and other periods when surpluses of land and labour are available. Lettuce enterprises, with their short cropping cycle, are admirably suitable for using these excess supplies of resources, and the unheated late crop (cL_2) sometimes in combination with the heated crop L_5, tends to fill up any of the heated cropping house area not occupied by early tomatoes. In cases where overall labour supplies are low (e.g. three or four men per acre) other lettuce crops (L_2, L_3 and L_4 especially), planted in late autumn for cutting in February and March, can also enter the solution; but as the number of men per acre increases so the area devoted to lettuces diminishes in favour of higher-value labour intensive enterprises (see Table III (ii)).

(*c*) *Chrysanthemums*: Some of the features associated with changes in the area and type of enterprise found to be most profitable are already apparent from earlier comments. With only three or four men per acre the area of heated chrysanthemum crops in the optimum cropping programme is dominated by crops grown from late-struck cuttings, with the direct-planted crop, $DX_{(p)}$, being more important than the delayed direct-planted crop, $DDX_{(p)}$. The late lifted chrysanthemum enterprise, lLX, also shows relatively high returns to labour inputs except in period 10 (i.e. 7th October to 4th November) and tends to be present in those solutions. But, as manpower increases to five or six men per acre, and labour becomes less of a constraint on production decisions, the lifted crop and the delayed direct-planted crop are replaced by the late pot-grown crop (lPX) which has a higher gross margin (see Table III (ii)).

(*d*) *Cold-house Crops*: Optimum cropping practices in the unheated houses are relatively simple to explain. Only four enterprises enter the solutions, and broadly these constitute two two-crop rotations. The lettuce crop cL_2 followed by direct-planted chrysanthemums $cDX_{(p)}$ form the predominant rotation, with a combined gross margin of £496 per tenth of an acre; whilst the rotation of January planted lettuce (cL_1) with cold-grown tomatoes (cT_3) only has a total gross margin of £333. The latter rotation, however, requires less labour in those months of the year when the heated chrysanthemum crops require labour: hence, for situations in which only three or four men are available this rotation does appear to have more merits than are obvious from a simple comparison of gross margins.

(*e*) It is also interesting to note that for all combinations of heated and unheated glass a labour force of three men per acre of cropping houses is insufficient to keep the whole of the glasshouse area fully cropped during the summer months. Thus in Cases 7 and 11 (see Figs. 7 and 11) the area of cold-grown direct planted chrysanthemums ($cDX_{(p)}$) could clearly be increased without making any other alterations to the cropping programme if sufficient labour were available; and the same comment applies with respect to the same crop grown in the unheated structures in Cases 1 and 4 (Figs. 1 and 4). With a labour force of four men per acre, however, the whole of the glasshouse area can be cropped during the summer months (Figs. 2, 5, 8 and 12). Note that no crops were considered which could be fitted in between the late cold lettuce crop (cL_2) and direct-planted or delayed direct-planted chrysanthemums ($DX_{(p)}$) or $DDX_{(p)}$.

3. Labour Utilisation

The amounts of labour required for the implementation of each of the fourteen optimum cropping policies are shown by four-week periods in Figs. 15 to 28. Not unexpectedly, as the size of the overall labour force increases so labour becomes less of a constraint on the choice of crops and surplus labour becomes available in most months of the year: likewise, with only three or four men per acre there are more months in which all available labour is used for cropping.

Figures 15 to 18 take no account of additional labour which would inevitably be required for overhead tasks such as repairs and maintenance on the holding, and, as explained in Chapter II, it was initially assumed that these jobs would be carried out at undefined "off-peak" periods. At this stage it is therefore necessary to enquire whether or not the assumed overall availability of labour is sufficient to meet overhead requirements as well as the computed cropping requirements.

It is, however, unrealistic to assume that overhead labour requirements can be represented by a specific number of man-days since intuitively one would not expect that overheads would account for the same proportion of total labour requirements on all holdings. Indeed, in practice, the age and type of glasshouses on the holding are important determinants of the time really *required* for maintenance and repairs, whilst the amount of time actually spent on these jobs may be related to the amount of daywork (as opposed to overtime) not required for cropping. Variations in the proportion of total labour inputs used for overhead work are therefore potentially large: and in one study[1] of labour utilisation on five glasshouse holdings overhead labour was found to vary between 8·28 per cent and 25·75 per cent. of total inputs, or in absolute terms from sixty-four to 705 man-days per acre of glass.

Thus, in Table III (v) we show whether (*a*) day work or (*b*) day work plus overtime which is surplus to crop requirements is sufficient to satisfy overhead needs when these amount to:

(i) 10 per cent.

(ii) 15 per cent. and

(iii) 20 per cent.

of labour requirements for crop production (i.e. 9·1 per cent. 13·0 per cent. and 16·7 per cent., respectively of total labour requirements). For those cases in which neither surplus daywork (*A*) nor surplus daywork plus surplus overtime (*B*) are sufficient, the deficit is shown in man-days.

TABLE III (v)

OVERHEAD LABOUR AND LABOUR SURPLUS TO CROP REQUIREMENTS (MAN-DAYS)*

Case	No. of men	A	B	C	A or B adequate to meet C	D	A or B adequate to meet D	E	A or B adequate to meet E
		Surplus Daywork	Surplus daywork plus surplus overtime	Overhead labour requirements of 10%		Overhead labour requirements of 15%		Overhead labour requirements of 20%	
1	3	110	199	87	A	130	B	173	B
2	4	240	384	104	A	155	A	207	A
3	5	395	616	116	A	174	A	232	A
4	3	64	135	93	B	140	(−5)	186	(−51)
5	4	138	269	115	A	173	B	230	B
6	5	236	429	135	A	202	A	269	B
7	3	33	126	94	B	141	(−15)	188	(−62)
8	4	70	152	127	B	190	(−38)	254	(−102)
9	5	136	320	145	B	218	B	291	B
10	6	314	613	152	A	227	A	303	A
11	3	56	148	92	B	138	B	183	(−35)
12	4	48	92	133	(−41)	199	(−107)	266	(−174)
13	5	113	295	148	B	222	B	296	(−1)
14	6	231	491	164	A	246	B	328	B

* All figures rounded to nearest whole number.

It can be seen that if overhead requirements can be kept as low as 10 per cent. of the time spent on crop work then only case 12 requires more labour than is assumed to be available in total. If

[1] University of Reading, Department of Agricultural Economics, *The Use of labour on fruit farms and glasshouse holdings*, Miscellaneous Studies No. 10.

overhead labour requirements are established at 15 per cent. or 20 per cent. then insufficient labour is available to operate the cropping programmes calculated for cases 4, 7, 8, 11 and 12; though, as will be seen in Chapter IV, none of these cases represent an optimum combination of factors of production[1].

Apparently, then the original assumption that overhead requirements are to be met in off-peak periods is justified for all situations in which the quantity of manpower available is optimal for the ratio of heated to unheated glass in question, that is, for cases 2, 5, 9 and 13 (see Chapter IV, esp. sections (1) and (2)). For these four situations reference to figs. 16, 19, 23 and 27 indicates that there are no periods of year in which essential overhead work would have to be delayed for more than two months.

4. Utilisation of Propagation Area

Figures 29 to 42 summarise the requirements of the fourteen optimum cropping policies for propagation space. Evidently, the availability of propagating area is a critical factor only in the months of January and February, given the crop enterprises which are considered feasible. The original propagating area only needs to be supplemented by small parts of the cropping area in those cases where the labour force is sufficient to crop substantial acreages of early tomatoes (0·4 acres or more) and heated chrysanthemums.

[1] Case 13, with five men, one acre of heated glass and no unheated glass, does have the optimum complement of men for that particular H : C ratio, but the annual manpower deficit of one man-day (when overhead requirements are 20 per cent.) is negligible.

FIGURES 15—28 LABOUR REQUIREMENT OF OPTIMUM CROPPING PROGRAMMES

The labour requirements of the optimum cropping programmes are shown in histogram form, the outline indicating the labour supply in the various periods of the year, the blocked areas the labour required in each period and the dotted line the divisions between daywork and overtime.

FIG. 15 0·25 acs Heated; 0·75 acs Cold
3 men per acre
Gross Profits £4647·18

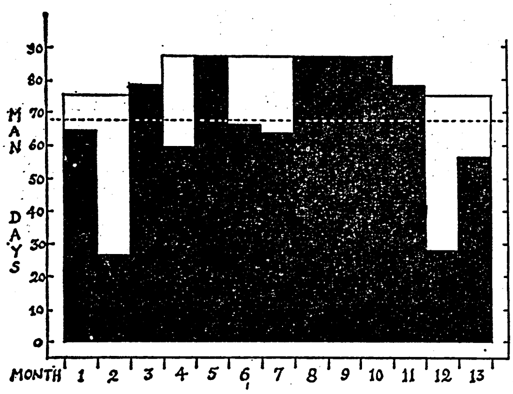


FIG. 16 0·25 acs Heated; 0·75 acs Cold
4 men per acre
Gross Profits £5459·69

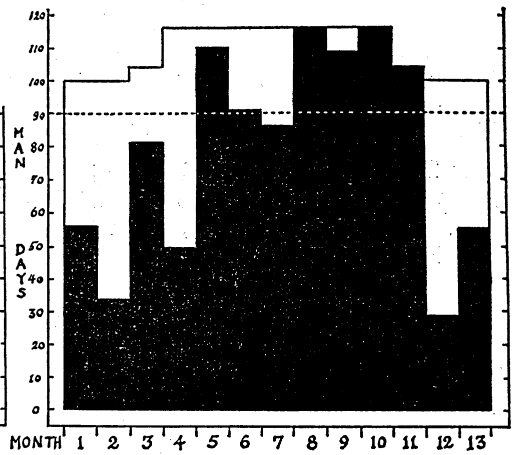


FIG. 17 0·25 acs Heated; 0·75 acs Cold
5 men per acre
Gross Profits £5774·09

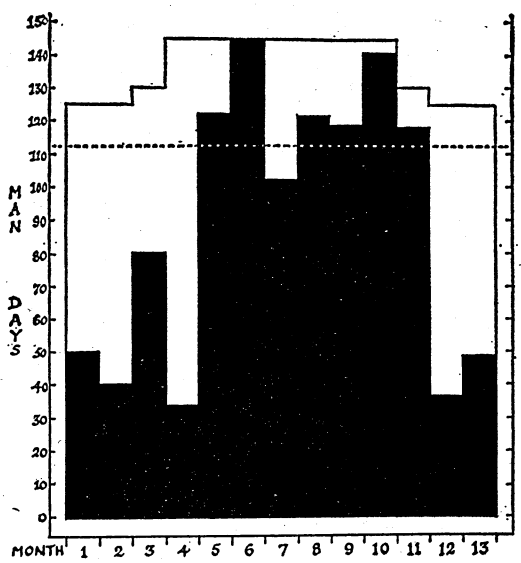


FIG. 18 0·50 acs Heated; 0·50 acs Cold
3 men per acre
Gross Profits £5160·80

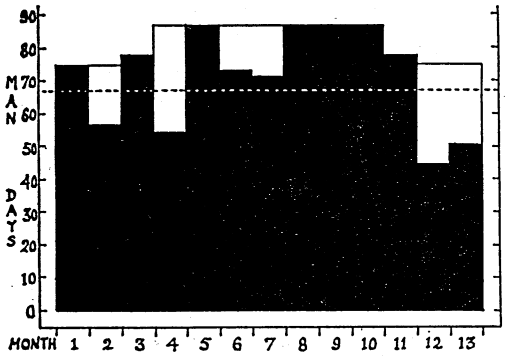


FIG. 19 0·50 acs Heated; 0·50 acs Cold
4 men per acre
Gross Profits £6061·60

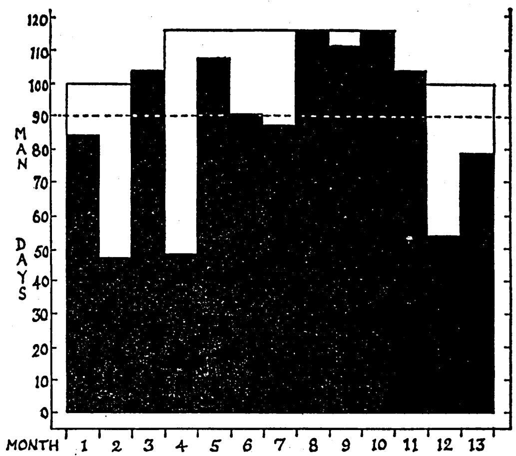


FIG. 20 0·50 acs Heated; 0·50 acs Cold
5 men per acre
Gross Profits £6462·13

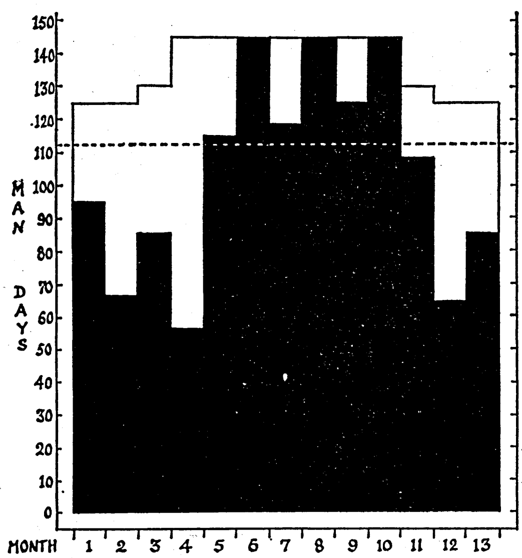


FIG. 21 0·75 acs Heated; 0·25 acs Cold
3 men per acre
Gross Profits £5462·86

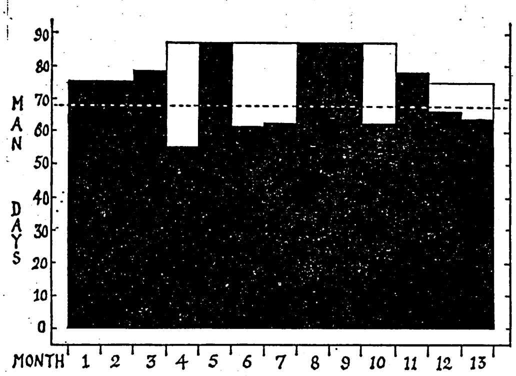


FIG. 22 0·75 acs Heated; 0·25 acs Cold
4 men per acre
Gross Profits £6515·34

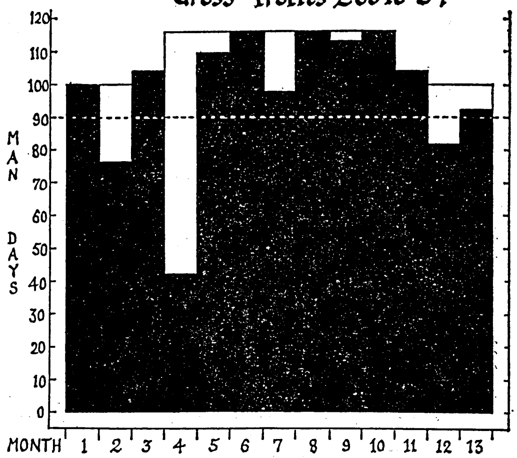


FIG. 23 0·75 acs Heated; 0·25 acs Cold
5 men per acre
Gross Profits £6980·29

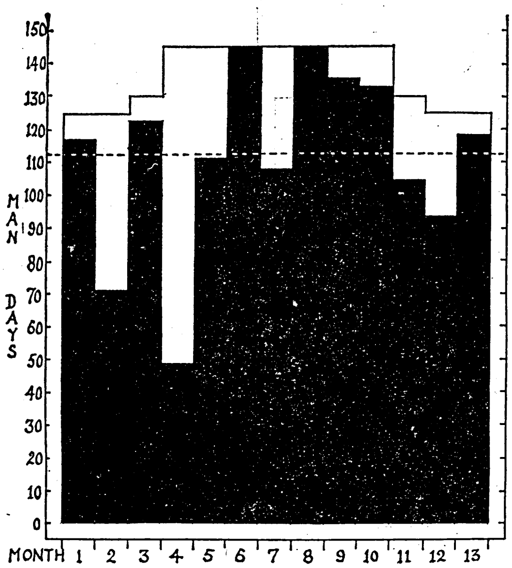


FIG. 24 0·75 acs Heated; 0·25 acs Cold
6 men per acre
Gross Profits £7134·09

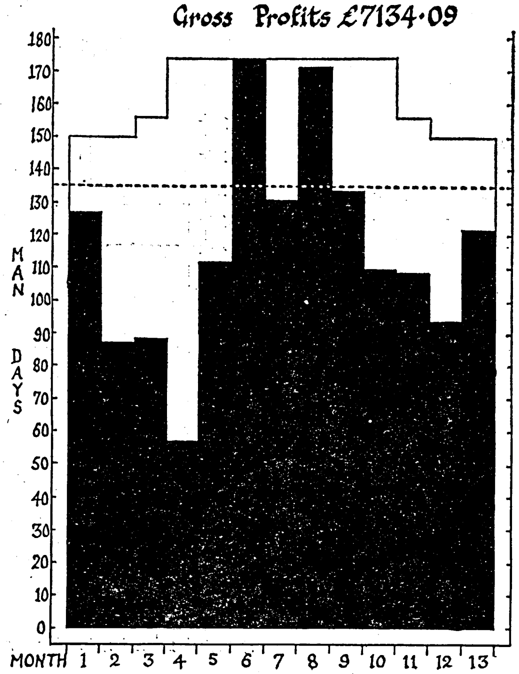


FIG. 25

All Heated
3 men per acre
Gross Profits £5594·74

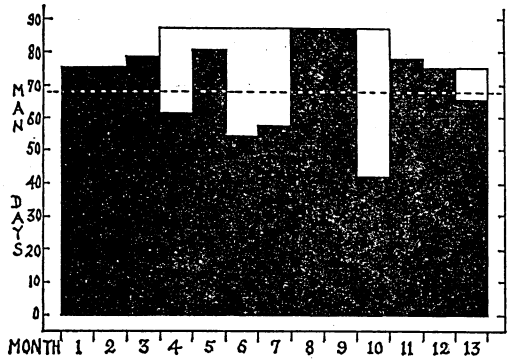


FIG. 26

All Heated
4 men per acre
Gross Profits £6784·38

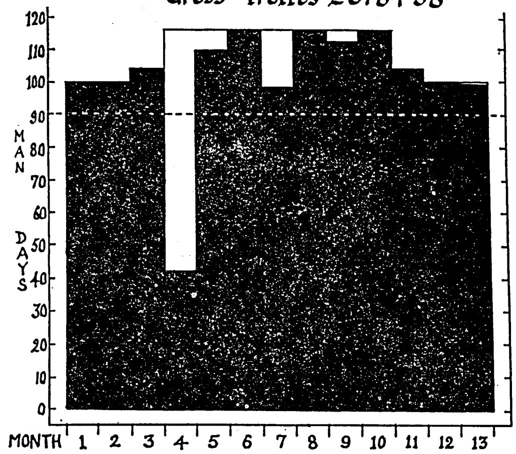


FIG. 27

All Heated
5 men per acre
Gross Profits £7338·06

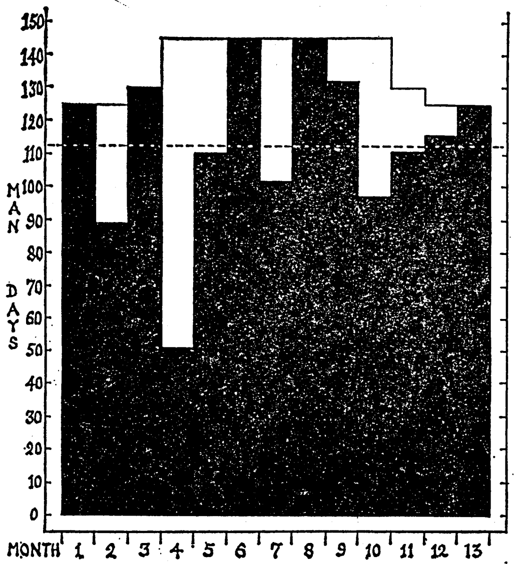
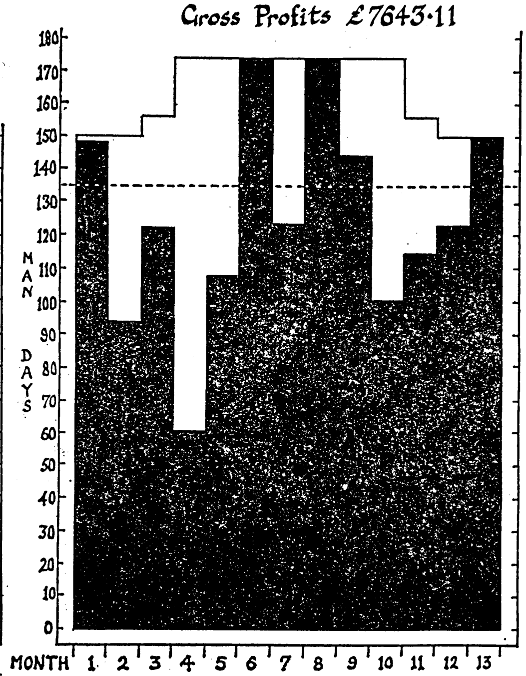
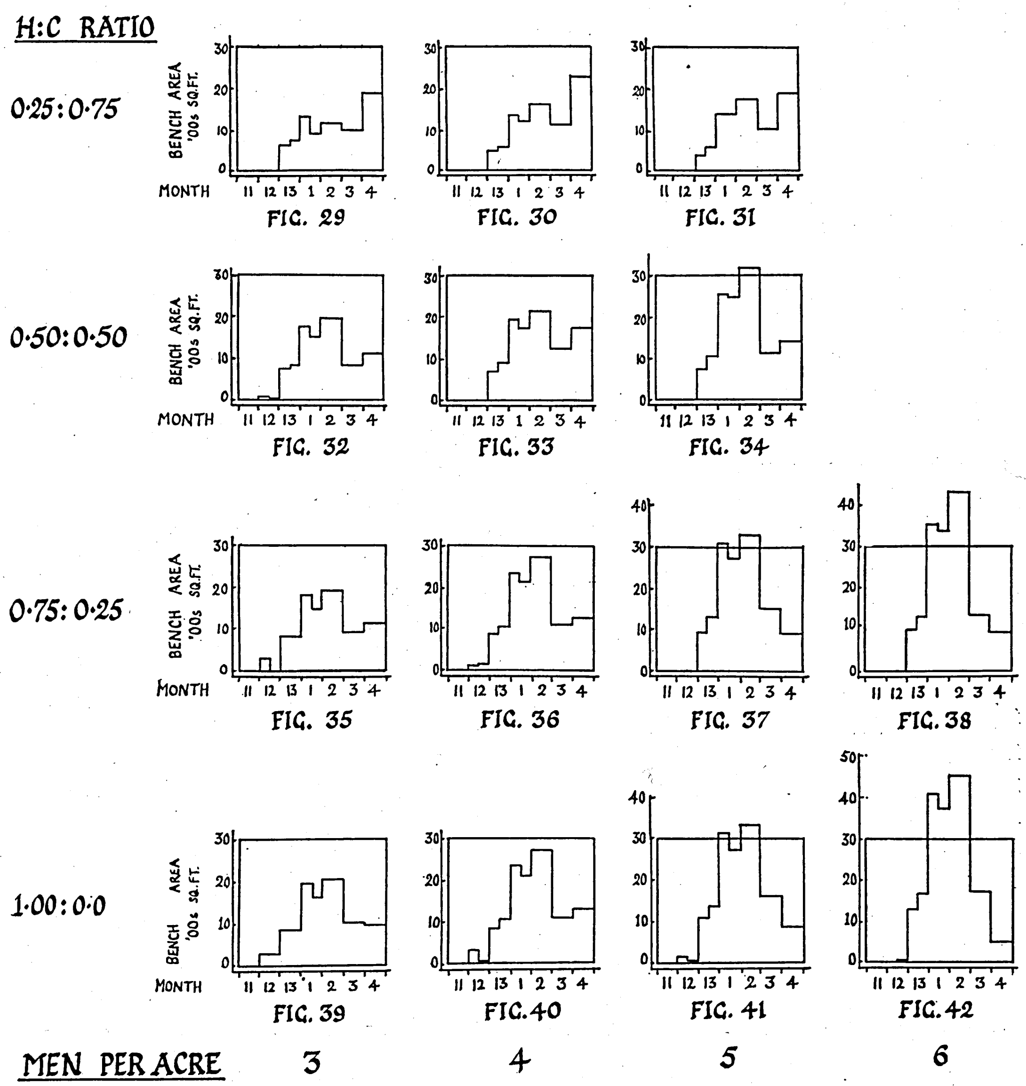


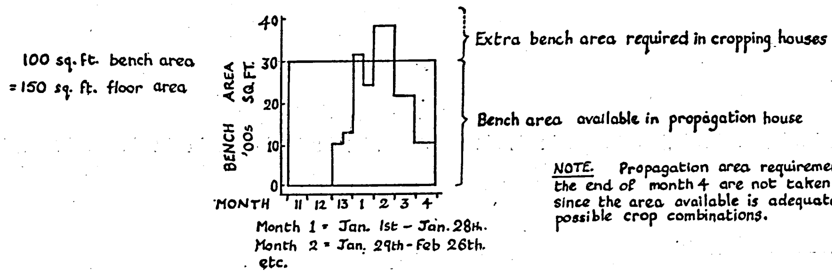
FIG. 28

All Heated
6 men per acre
Gross Profits £7643·11



FIGS. 29-42 Propagation area requirements of optimum cropping programmes per acre of cropping houses.





NOTE. Propagation area requirements after the end of month 4 are not taken into account since the area available is adequate for all possible crop combinations.

CHAPTER IV

ECONOMIC IMPLICATIONS OF THE RESULTS

Hitherto we have simply assumed that a grower has at his disposal a *fixed* quantity of resources (e.g. three men, half an acre of heated glass and half an acre of unheated structures, together with propagating space), and that subject to these constraints he can maximise gross profits by following a computed cropping policy.

More realistically, however, growers are free to alter their combinations and quantities of resources in an attempt to increase the profitability of the holding still further, for example, by hiring more men or by installing additional heating apparatus. In the following sections we therefore examine the implications for the grower of changing the levels of resources on the holding.

1. Labour Productivity

Firstly, assume that a grower has a *fixed* ratio of heated to cold glass, but that he is free to *vary* the size of his labour force. In this situation, an answer is required to questions of the type: " I have half an acre each of heated and cold glass. Should I employ two, three, four or more men in order to maximise profits? "

Reference to table III (i) gives a rough solution to problems in this category, and the same information, slightly rearranged, is tabulated again in Table IV (i). These data must be interpreted in the context of current minimum agricultural wages which amount to approximately £520 per annum[1]. Consequently, a grower with a quarter of an acre of heated glass and three-quarters of an acre of cold glass can *increase* his gross profits by £812 if he hires four men instead of three men and if he also changes his cropping policy in accordance with Table III (ii), but since costs only rise by £520 the *net income* of the grower is enhanced by £292. However, if the same grower hires five men instead of four then his net income will fall since the wage bill increases by a further £520 whilst gross profits only rise by a further £314. It follows that this hypothetical grower with a H : C ratio of 0·25 : 0·75 should hire a labour force of four men—no more and no less—if he wishes to maximise profits. An identical conclusion is derived from Table IV (i) for holdings with a H : C ratio of 0·5 : 0·5 or 0·75 : 0·25, but when the whole of the one acre of cropping houses is fitted with heating apparatus the optimum size of labour force rises to five men. The increase in gross profits for the fifth man, however, is only a little more than his wage, whilst the sixth man's wages more than offset the contribution he could make to gross profits.

TABLE IV (i)

EFFECTS OF SIZE OF LABOUR FORCE ON GROSS PROFITS (£)

Ratio of heated to cold glass (acres)	Maximum gross profits with labour force of three men	Increase in maximum gross profits if a fourth man is employed	Further increase in maximum gross profits if a fifth man is employed	Further increase in maximum gross profits if a sixth man is employed
0·25:0·75	4,648	812	314	—
0·5:0·5	5,161	901	400	—
0·75:0·25	5,463	1,052	465	154
1·0:0	5,595	1,189	554	305

These simple conclusions depend on the valid assumption that each full-time member of the labour force is paid the minimum standard wages of £520 per annum, but so far no account has been taken of overtime working on the holding. This latter refinement is important, for the employment of an additional man and a concurrent alteration of the cropping programme may mean that less overtime is necessary on the holding as a whole, and therefore the *effective* cost of the additional man will be less than the basic wage rate.

[1] Inclusive of employer's N.H.I. contributions, but excluding overtime pay. The basic rate for male workers over twenty-one years of age for a forty-five hour week was 190s. at the time when this monograph was written; and employer's N.H.I. contributions were 9s. 8d. per week.

Tables IV (ii) and IV (iii) evaluate the impact of this consideration on the optimum size of labour force for any given combination of heated and cold glass. The *total* wage bill estimated in Table IV (ii) for each of the fourteen cases assumes that (i) each man receives £520 per year including N.H.I. contributions, (ii) that overhead labour requirements are equal to 15 per cent. of the cropping requirements, (iii) that overtime wage rates are 50 per cent. greater than the minimum daywork rate at 6s. 4d. per hour, and (iv) that the amount of overtime worked on the holding is as low as possible.

TABLE IV (ii)

TOTAL WAGE COSTS (£)

H: C Ratio	Men per acre			
	3	4	5	6
0·25/0·75	1,861	2,346	2,842	—
0·5/0·5	2,047	2,470	2,903	—
0·75/0·25	2,073	2,811	3,135	3,311
1·0/0	2,009	2,984	2,954	3,412

The results, presented in Table IV (iii) can be interpreted in the same manner as Table IV (i). The grower with a quarter of his one-acre holding under heated glass who increases the size of his labour force from three to four men and adjusts his cropping pattern can expect additional gross profits of £812; but because less overtime is now worked on the holding the total wage bill only rises by £485, and the grower's net income (last column of Table IV (ii) therefore rises by £327. But, with five men the same grower will be worse off than if he were to employ only four men. In summary, then, Table IV (iii) reaches the same conclusions as Table IV (i) except that the grower with a H : C ratio of 0·75 : 0·25 now finds it more profitable to hire five men compared with the optimum complement of four men derived from the initial simple assumptions.

For a number of reasons, including the existence of alternative employment in nearby towns and cities, many growers may need to pay more than the statutory minimum wage rates to attract labour. The assumptions on which Table IV (iii) is based are therefore modified to include situations in which the daywork wage payable is equal to the minimum plus (i) 10 per cent. and (ii) 20 per cent. corresponding to approximately an extra £1 and £2, respectively, per man per week, and in which the overtime rates are similarly adjusted. The optimum size of labour force in these new conditions is examined in Table IV (iv). Thus, even if labour costs are 20 per cent. greater than the minimum, or if the statutory minimum were raised by 20 per cent., there are no changes in the optimum size of labour force for any given ratio of heated to cold glass, though the *absolute* size of the grower's net income does, of course, depend upon the wage costs. In conclusion, then, for a holding of one acre the optimum complement of manpower is four men if half or less of the cropping area is heated, and five men if at least three-quarters of the glass area is fitted with heating apparatus; but it must be emphasised that these recommendations are subject to the validity of the assumption made above about overhead labour requirements amounting to 15 per cent. of crop requirements, and the whole body of crop possibilities and input/output data defined in Chapter II.

Finally, it must be noted that throughout the study the overall size of the holding is assumed to be one acre, and that the optimum areas of individual crops and the optimum complement of labour force for any H : C ratio are dependent upon this assumption. Intuitively, one might suppose that the results are therefore of little use in reaching management decisions on holdings larger or smaller than one acre in extent. However, and fortunately, the characteristics of linear programming methods are such that, for any given ratio of heated to cold glass, if the total area of the holding is halved or doubled, for example, then the profit maximising areas of crops and the optimum amount of manpower are also halved or doubled respectively. Extrapolation of the results in this way is satisfactory so long as the holding to which the procedure is applied is not so large that it has a dominant market power in the area in which it is situated, and so long as the market prices and other data on which the study is based are not significantly influenced by the cropping decisions of any single grower.

TABLE IV (iii)

VARIATIONS IN NET INCOME WITH SIZE OF LABOUR FORCE

H: C Ratio	Change in number of men per acre	(A) Increase in gross profits (£)	(B) Increase in Labour costs (£)	(C) = (A) – (B) Increase in grower's net income (£)
0·25: 0·75	3 to 4 4 to 5	812 314	485 496	327 – 182
0·5: 0·5	3 to 4 4 to 5	901 400	423 433	478 – 33
0·75: 0·25	3 to 4 4 to 5 5 to 6	1,052 465 154	738 324 176	314 141 — 22
1·0: 0	3 to 4 4 to 5 5 to 6	1,189 554 305	975 – 30 458	214 584 – 153

TABLE IV (iv)

NET INCOME AND SIZE OF LABOUR FORCE AT ALTERNATIVE WAGE RATES

H: C Ratio	Change in number of men per acre	(A) Increase in Gross Profits (£)	Labour cost per man = £520 + 10%		Labour cost per man = £520 + 20%	
			(B) Increase in labour costs (£)	(C) = (A) – (B) Increase in grower's net income (£)	(D) Increase in labour costs (£)	(E) = (A) – (D) Increase in grower's net income (£)
0·25: 0·75	3 to 4 4 to 5	812 314	534 545	278 – 231	582 595	230 – 281
0·5: 0·5	3 to 4 4 to 5	901 400	465 476	436 – 76	508 520	393 – 120
0·75: 0·25	3 to 4 4 to 5 5 to 6	1,052 465 154	812 357 193	240 108 – 39	885 389 211	167 76 – 57
1·0: 0	3 to 4 4 to 5 5 to 6	1,189 554 305	1,072 – 33 504	117 587 – 199	1,170 – 36 549	19 590 – 244

2. Some Aspects of Capital Investment

In the same way that a grower can hire more or less labour than previously so he can improve the productive potential of his holding by increasing the ratio of heated to cold glass, either by installing heating apparatus or by constructing suitable new structures. Capital investment projects of this type may involve the grower in heavy financial outlays and it is important that these schemes should be profitable.

It is possible to assess the optimum level of such investment by referring back to Table III (i) which shows the changes in maximum gross profits associated with changes in the H: C ratio.

For example, if the size of the labour force is held constant at, say, three men then with a H : C ratio of 0·25 : 0·75 gross profits can reach £4,648 if these resources are organised in the most economic way, whilst with a H : C ratio of 0·5 : 0·5 optimum gross profits amount to £5,161. Thus, the conversion of a quarter of an acre from cold to heated glass can result in *increased* gross profits of £5,161 *less* £4,648, or £513. Consequently, if the annual cost of investment in the conversion is less than £513 then the grower's net income will rise if he operates with more heated glass and less cold glass.

The worthwhileness of the above investment project can be determined in a number of ways and subject to a number of assumptions, though, for purposes of exposition, only simplified criteria are used here. We assume that the funds required are borrowed at an interest rate of 6 per cent. and that repayments are made annually in equal amounts with interest being paid on the balance outstanding. Calculations are made on the assumption that the repayment period is 10, 15, 20 or 25 years, that the capital equipment has no value at the end of the repayment period, and that maintenance costs are ignored. Initial investment allowances and other taxation advantages are neglected; and no allowances are made for the fact that the grower will be subjecting himself to a degree of risk by being indebted for ten or more years during which time his ability to make repayments will depend upon crop prices, costs and, thus, upon profits.

Using these assumptions it can be shown that the annual repayment per £100 invested amounts to £7·82 if the repayment period is 25 years. Thus if a grower switches from a H : C ratio of 0·25 : 0·75 to one of 0·5 : 0·5 and gross profits rise by £513 then the maximum sum which it is worthwhile to borrow is

$$\pounds\left(513 \times \frac{100}{7{\cdot}82}\right) = \pounds 6{,}560$$

if more than £6,560 is borrowed then the annual repayment exceeds the increase in gross profits, and therefore net income falls. Consequently, so long as the cost of the conversion of one quarter acre is less than £6,560 repayments will be lower than £513 and net income rises if the project is undertaken. Similar estimates of the maximum worthwhile investment are shown in Table IV (v) for all of the resource situations which arise in the study.

The data in Table IV (v) must be read in conjunction with estimates of the actual capital cost of heating or converting a quarter of an acre, which varies with a number of factors. For purposes of illustration it can be assumed that a heating system with an efficiency level consistent with the input/output data of this study costs approximately £2,500 per quarter acre. Thus, reference to Table IV (v) suggests that this outlay is worthwhile except where the grower either has a labour force of three men per acre and is already able to heat 75 per cent. of his glasshouse area, or, with some resource combinations, where he requires that the loan must be repaid within ten years.

However, it is not necessarily true that existing cold glasshouses can be heated with an acceptable degree of efficiency. For instance, it can be argued that standard dutch-light structures do not have sufficiently good heat retention characteristics to justify the installation of heating systems capable of producing a 30°F temperature lift. Indeed, it would seem that most growers would spend at least £500 per quarter acre over and above the cost of these simple structures in erecting any new glass which they intended to heat. Or, at the other extreme, if aluminium alloy type houses are considered as an alternative then the additional capital investment might be about £1,500 per quarter acre[1]. Consequently, it may be more realistic to interpret Table IV (v) on the assumption that the total cost of a heating installation for a quarter of an acre is between £3,000 and £4,000, or, for simplicity, £3,500.

If this is accepted, and if repayments are made over 20 years, then it is not worthwhile for a grower to heat more than 50 per cent. of the holding if the labour force consists of three men. If four men are employed then it is profitable to heat a further quarter of an acre; and for labour intensive holdings it is profitable to heat the whole of the cropping area.

[1] These estimates are based on the price lists of a leading glasshouse manufacturer. They do not take account of the erection costs since many growers would undertake the erection of new glass themselves at slack times of the year.

Table IV (v)

Maximum Worthwhile Investment for Heating a Quarter of an Acre of Cold Glass

Men per acre	Change in H: C ratio	Increase in gross profits (£)	Maximum worthwhile investment (£) when repayment is over: 25 years	20 years	15 years	10 years
3	0·25:0·75 to 0·5:0·5 0·5:0·5 to 0·75:02·5 0·75:0·25 to 1·0:0	513 302 132	6,560 3,862 1,688	5,887 3,466 1,515	4,985 2,935 1,283	3,783 2,227 973
4	0·25:0·75 to 0·5:0·5 0·5:0·5 to 0·75:0·25 0·75:0·25 to 1·0:0	602 453 269	7,698 5,793 3,440	6,908 5,199 3,087	5,850 4,402 2,614	4,440 3,341 1,984
5	0·25:0·75 to 0·5:0·5 0·5:0·5 to 0·75:0·25 0·75:0·25 to 1·0:0	688 518 358	8,798 6,624 4,578	7,895 5,944 4,108	6,686 5,034 3,479	5,074 3,820 2,640
6	0·75:0·25 to 1·0:0	509	6,509	5,841	4,947	3,754
Annual Repayment per £100 invested*			£7·82	£8·71	£10·29	£13·56

* Calculated from $100\,(1+i)^n - X\left(\sum_{n=0}^{n-1}(1+i)^n\right)=0$

where i=rate of interest
n=number of years
X=repayment (£%)

3. Optimum Combinations of Resources

So far, the results have been analysed on the assumption that the grower can *either* alter the size of his labour force *or* that he can change the proportions of heated and cold glass on his one acre holding. We now assume that all of these resources can be varied, and an attempt is made to select the best possible combination of labour *and* heated and unheated glass. This is done in Table IV (vi) in which labour and capital charges are deducted from gross profits to yield an estimate of the margin (before tax deductions and some common charges) for each of the fourteen resource situations considered.

In compiling the table it is assumed that

(i) each man receives £520 per annum plus overtime at 6s. 4d. per hour

(ii) overhead labour requirements are 15 per cent. of crop requirements, and the total amount of overtime worked on the holding is minimised

(iii) the extra capital investment required to install a heating system in each additional quarter acre of glass is £3,500 and that this is repaid over 20 years at 6 per cent. interest by annual payment of £305.

Thus, if a grower has a labour force of three men with a quarter acre of heated glass and three-quarters of an acre of cold glass his " net "[1] profits amount to £2,787 if he follows the optimal cropping plan suggested in Chapter III. If, however, he hires two more men *and* heats the remainder of his holding his " net " profits will rise to £3,469 if he adopts the new resource combinations; i.e. net profits (last column of Table IV (vi)) rise by £682. No other resource combination is capable of yielding such a large increase in net profits, and it can be concluded that the best possible combination of resources consists of five men to an acre of heated glass with no cold glass (Case 13).

[1] Before any charges have been made for overheads which are common to all fourteen resource situations; e.g. machinery costs, office expenses, maintenance and repairs, and in particular, rent or interest on existing capital (one-quarter acre heated glass, three-quarter acre unheated structures and one-tenth acre of propagation houses).

TABLE IV (vi)

PROFIT MARGINS FOR ALTERNATIVE RESOURCE COMBINATIONS*

Case	H: C Ratio	Men per acre	A Basic Wage Costs £	B Overtime Wage Costs £	C Extra Capital Charges† £	D Total (A+B+C) £	E Gross Profits £	Margin (E—D) £	Extra Net Profit† £
1		3	1,560	301	0	1,861	4,648	2,787	0
2	0·25:0·75	4	2,080	266	0	2,346	5,460	3,114	327
3		5	2,600	242	0	2,842	5,774	2,932	145
4		3	1,560	487	305	2,352	5,161	2,809	22
5	0·5:0·5	4	2,080	390	305	2,775	6,062	3,287	500
6		5	2,600	303	305	3,208	6,462	3,254	467
7		3	1,560	513	610	2,683	5,463	2,780	−7
8		4	2,080	731	610	3,421	6,515	3,094	307
9	0·75:0·25	5	2,600	535	610	3,745	6,980	3,235	448
10		6	3,120	191	610	3,921	7,134	3,213	426
11		3	1,560	449	916	2,924	5,595	2,671	−116
12		4	2,080	904	915	3,899	6,784	2,885	98
13	1·0:0	5	2,600	354	915	3,869	7,338	3,469	682
14		6	3,120	292	915	4,327	7,643	3,316	529

* A resource combination of three men and a H: C ratio of 0·25: 0·75 (Case 1) is taken as a base.

† Compared with Case 1.

Although the financial costs of the additional heated glass are taken into account in reaching this conclusion it must be emphasised that the additional income is gained at the expense of being indebted to the extent of £10,500 (the capital cost of heating three-quarters of an acre of glass) if we assume that only one quarter of an acre of glass is heated to begin with. However, if the whole of the holding is already fully equipped with heating apparatus, then this factor is of no importance, since only the size of the labour force may require adjustment. Likewise, no account has been taken of the possibility that factor costs and market prices may change in future in such a way that Case 13 no longer represents the best possible resource situation[1].

4. The Marginal Value of Resources

The analysis up to this point has assumed that the grower can expand his business only by increasing the size of the regular labour force and by altering the proportions of heated and cold glass, whilst the size of the holding remains constant at one acre of cropping houses. In practice, alternative methods of expansion are feasible, for the grower may be able to hire casual labour during critical periods, or, as a longer-term possibility, he may be able to increase the total size of his holding by buying more land and erecting more glass.

Linear programming solutions provide some information about the effects on gross profits of pursuing these alternative policies, allowing us to calculate, for example, the " marginal value " of additional labour employed in any single period of the year.

In Table IV (vii) we show the marginal value product of labour (i.e. the financial gain which could be expected if an extra man day were available) in the various periods of the year for each of the fourteen case studies. This table should be read while bearing in mind that the cost of employing

[1] E.g. If unit labour costs were to rise by 38 per cent. above the current statutory minimum, the total wage bill for case 13 would rise by £1,103 whilst the wage bill for case 5 would only increase by £939. The difference, £183, more than offsets the advantage that case 13 has over case 5 in Table IV (vi). Thus, in a dynamic context, if wages rise rapidly in the future it may only be worthwhile heating half of the holding now and hiring a labour force of four men per acre, to approach the resource situation represented by case 5.

casual labour would be at least £1·4 and probably about £1·5 per man day[1]. Thus, for case 1, extra labour which is made available in period 3 (26th February to 25th March) will add £0·29 to gross profits per additional man day[2], an amount which does not cover the cost of hiring the extra labour.

The marginal value of labour is highest in period 11 (8th October to 4th November) when it is scarce in relation to the demands made on it in the optimal cropping plans. Labour supply is not quite so restrictive in other months, though as the amount of regular labour increases period 8 (16th July to 12th August) or period 6 (21st May to 17th June) becomes the most important month when labour constitutes a bottle-neck. As we might expect, the marginal value of labour tends to decline as the quantity of regular labour for any given H : C ratio increases for labour then becomes less of a restraint on the incorporation of the most profitable crops into the cropping plans.

Table IV (vii)

Marginal Value of Labour (£ per man day)*

Case	H: C Ratio	Men per acre	January 1st				Four-weekly Periods						December 31st
			1	2	3	4	5	6	7	8	9	10	11	12	13
1		3			0·29		2·95			8·32	4·50	2·16	13·21		
2	0·25 : 0·75	4								7·82		3·12	14·70		
3		5						0·96							
4		3	3·29		2·50		4·09			6·52	6·83	0·99	13·46		
5	0·5 : 0·5	4			1·76					10·06		3·18	13·78		
6		5						1·00		4·77		0·07			
7		3	5·32	4·81	6·90		2·31			2·74	12·51		12·87		
8	0·75 : 0·25	4	5·55		4·54			0·39		8·65		1·36	9·84		
9		5						0·91		5·25					
10		6						0·87							
11		3	3·72	5·66	8·14					2·49	12·43		13·62	1·30	
12	1·0 : 0	4	5·58	3·87	6·89			0·17		7·73		0·95	10·89	0·81	
13		5	0·27		1·90			0·23		7·26					3·82
14		6						0·11		4·83					3·81

* Where no value is given there is a surplus of existing labour in excess of cropping requirements.

The lesson to be drawn from this analysis is that there are times in the year when additional labour for short periods would be extremely valuable as it would enable the present optimal programmes to be improved so as to give even higher profits. During these periods it would be well worth searching for casual labour and paying it high wages provided that this could be done without upsetting the regular labour force. But, to reap the benefit of additional labour it would be necessary to amend any given optimal plan so as to include a higher proportion of high gross margin crops. Although we have not systematically analysed the consequences of this, some indication of the necessary modifications can be obtained by reading Table III (ii) and consulting Figures 1 to 14 in Chapter III. Consider, for example, case 2. By reference to the input/output data in Chapter II it can be shown that the rotation $cL_2+cDX_{(p)}$ yields a gross margin of £496 per tenth of an acre

[1] The wage rates quoted here are for female casual labour but the term "man day" has been retained for the unit of labour for convenience. For several operations on glasshouse crops, particularly chrysanthemums, the work output per hour is as high for female workers as for male workers. There is therefore no need to recalculate these wage rates in terms of man-day equivalents.

[2] These figures must be used with caution, for in the first place the additional gross profits will be achieved only if the cropping plan is changed slightly; and, secondly, if for example ten extra man days are hired it does not necessarily follow that gross profits will rise by £0·29 × 10 since although the first additional man day might add £0·29 to gross profits subsequent additional man days might be less valuable because a shortage of other resources might preclude more profitable cropping programmes.

whilst the rotation $cL_1+cT_3+stS_4$ yields only £279 per tenth of an acre. From Figure 2 it is evident that the former rotation could be substituted for the latter in the unheated houses of labour supplies permitted (propagation space would not be a constraint), and the input/output data show that extra labour would be involved in periods 2, 3, 5, 6, 7, 8, 10 and 11 to the extent of 0·5, 3·5, 8·0, 3·1, 1·0, 2·0, 8·0 and 12·0 man days respectively per tenth of an acre substituted. However, this would only be of real significance in those periods in which the labour force of the holding is already fully committed or almost so, i.e. in periods 5, 8, 10 and 11 (see Figure 16). Therefore, if about 2 man days of casual labour could be hired in period 5, and 2·0, 8·0 and 12·0 man days in periods 8, 10 and 11 respectively, one tenth of an acre of rotation $cL_2+cDX_{(p)}$ could be substituted for rotation $cL_1+cT_3+stS_4$; and gross profits would rise by £496 less £279 or £217. Only 2 man days of casual labour are needed in period 5 since about 6 man days are surplus to requirements for the optimum plan. It should be noted, however, that this is not necessarily the best way in which this additional casual labour could have been used in Case 2. It may well be that the same amount of casual labour could have been more profitably used in some modification to the cropping of the heated glass area. In other words, the information available does not enable us to calculate, from the plans presented in Chapter III new optimum programmes for situations in which casual labour is available. In order to do this the basic mathematical model would have to be modified and the programmes re-run. The technical aspects of such modifications are discussed in Appendix III.

Similarly, a grower may be able to augment his income by operating on a larger scale with more land; and, here again, linear programming solutions yield some information about the advisability of purchasing additional land for the erection of more glass. In this context, Table IV (viii) shows the expected increase in net income if the total area of the holding were increased from 1 acre to $1\frac{1}{10}$ acres by the addition of a tenth of an acre of either heated or unheated glass. Thus, for case 1, if the grower were to purchase an extra tenth of an acre and erect heated glass his gross profits could rise by approximately[1] £380 per annum if he modified the cropping plan to reflect the change in the " resource mix ". The worthwhileness of the policy, as with the capital investment projects discussed earlier in this chapter, depends, of course, on the cost of the new land and glass, the rate at which borrowed funds are repaid and the importance of indebtedness. Nevertheless, the marginal value of more heated glass in particular is relatively high, especially in situations in which labour-intensive cropping is possible, that is, where five or six men are available.

5. The Effects of Changes in Crop Prices

The prices of horticultural products are subject to considerable short-term fluctuations and the prediction of future prices, which is necessary in forward planning for profit maximisation, is consequently hazardous. Sensibly, the majority of growers do not attempt to " chase the market " but select a cropping plan which they expect to give a high income over a period of years even if the results in some years are less encouraging than others, their selection being based on predictions of average future prices which are in turn based on past price experience. Even so, the predicted average prices may not be realised in practice and the selected cropping plan may therefore yield a lower income than some alternative combinations of crops would have done.

To illustrate this point, let us suppose that there are two crops, *A* and *B*, which require equal quantities of resources and which can be grown during the same period of the year. If the gross margin (per acre) for crop *A* is *expected* to average £80 and the average for crop *B* is *expected* to be £55 then the " profit maximising " plan should include *A* and exclude *B*. But if, in consequence of a rise in the price of product *B*, its gross margin increases by more than £25 above the expected average, whilst the expectations of crop *A* are correct, then the selected cropping plan is sub-optimal since a higher income could have been achieved if *B* had been selected in preference to *A*. Thus, if predicted values differ greatly from realised values then cropping plans believed to be optimal may well turn out not to be so in fact. An analagous, though more complex, form of this situation is present throughout our study, for we have devised and analysed fourteen optimal solutions on the assumption that the gross margins estimated in Chapter II will be realised in practice.

[1] The previous footnote has similar applicability to all of the marginal values given in Table IV (viii).

TABLE IV (viii)

MARGINAL VALUE OF GLASSHOUSE AREA (£ PER TENTH OF AN ACRE)

Case	H: C Ratio	Men per holding	Marginal value of heated glass (£)	Marginal value of cold glass (£)
1		3	380·0	144·7
2	0·25: 0·75	4	456·2	202·9
3		5	788·9	388·3
4		3	282·1	116·2
5	0·5: 0·5	4	403·5	178·6
6		5	651·7	444·1
7		3	158·0	95·5
8		4	352·1	236·4
9	0·75: 0·25	5	646·4	441·5
10		6	706·8	489·0
11		3	151·6	
12	1·0: 0	4	281·3	
13		5	538·3	
14		6	607·9	

At the same time, though, it should be noted that forecasted prices need not always be perfectly accurate: in the example cited crop *A* is preferred to crop *B* even if the future average value of *A* has been overestimated by £10 and that of *B* underestimated by £10. In other words, we go some way to minimising the hazards of selecting profit maximising plans in the face of price fluctuations if we can determine the price range over which a computed solution remains optimal.

A number of modifications to the basic linear programming technique have been evolved for estimating the extent to which physical plans need to be altered as prices change but the basic technique, as used in this study, only provides limited, but nevertheless useful, information on the sensitivity of the computed plans to price changes.

As a by-product, arising from the computation of an optimum cropping plan, the computer also calculates the " marginal cost " of each enterprise not already featured in the plan. What is meant by " marginal cost " here is the effect, in terms of reduced gross profits, of substituting a small area of a crop not in the optimum plan for a similar small area of a crop (or crops) which is already in, expressed in £ per tenth of an acre substituted. Alternatively, we can define " marginal cost " as the amount by which the assumed gross margin of a particular enterprise must rise before it can be substituted for some crop featured in the optimum plan without reducing gross profits.

Thus, if we have underestimated the price (and hence the gross margin) of a particular crop and its marginal cost is low, this crop could easily enter the true optimum plan and the computed optimum plan would thus be unstable. If, on the other hand, the marginal cost of a particular crop is very high in relation to the possible mistake we might have made in estimating prices, the likelihood of this crop entering the true optimum solution is remote and the computed optimum plan can be regarded as stable.

Before going into an analysis and discussion of the marginal cost data the reader should be warned that a limited study of this type gives no indication of the *extent* to which physical plans would be modified if the price of any crop were to be increased by more than its marginal cost. Secondly, the marginal cost data are only valid if the prices of enterprises already in the optimum plan do not change. Thirdly, the data presented can only be analysed one enterprise at a time. Thus, if the prices of two enterprises increase by more than their marginal costs then there is no guarantee that both enterprises will feature in a revised optimum plan. Fourthly, a price change for one activity sufficient to secure its inclusion in a revised plan may also imply price changes for other enterprises. Consequently, there is no guarantee that this enterprise will enter the revised plan even if its market price exceeds the expected price by more than the critical amount. Finally, an analysis of this sort gives no indication as to how an optimum plan should be modified if the price of some enterprise featured in it falls below the expected level. In spite of these limitations, however, a study of the marginal cost data gives a useful indication of the risks which a grower would be facing if he were to implement the computed optimum plans.

In Tables IV (ix), IV (x) and IV (xi) marginal cost data are presented for crops which are excluded from the heated houses of each of the fourteen optimal plans. In Table IV (ix), for example, in the first column the figure £60·6 indicates that it would only be profitable to introduce the early tomato enterprise (eT_1) into the optimal plan for case 1 if the price of the enterprise were £60·6 higher than the assumed net price of £805 and the variable costs of £235 were unchanged (see Table II (i)). Consequently, if all other crop prices have been accurately predicted whilst this particular crop price has been underestimated by 7·5 per cent. then the computed plan given for case 1 in Chapter III is not optimal. However, if other early tomato prices have also been underestimated this particular crop would require a price increase of rather more than 7·5 per cent. to ensure its inclusion in the plan in place of an alternative crop.

The full-term early tomato crop (eT_1) and the crop which can be succeeded by autumn lettuce (eT_2) both require only small percentage increases in price to bring them into solutions in place of other early tomato crops when only three men are available on the holding; but as the labour force increases in size (e.g. Case 3) the market value of eT_1 would need to rise by £254·5 (31·6 per cent.) per tenth of an acre before the crop replaces others in the solution. The reason for this is simply that as the available quantity of labour increases so it becomes possible to grow valuable chrysanthemum crops which cannot be produced if a full-term tomato enterprise is brought into the cropping plan. The price for the tomato crop must therefore rise substantially if the loss of income from not growing chrysanthemums is to be offset.

One of the most striking features of the fourteen solutions is the total omission of the mid-season heated tomato crops, and the data in Table IV (ix) give an indication of the price changes which would be required before their introduction became economic[1]. The full-term crop (mT_1) and that pulled out for autumn lettuce (mT_2) require particularly large price increases above the prices assumed in this study before they replace other crops in the optimum plans: the increases needed range from £115·3 (27·6 per cent.) to £282·4 (60·2 per cent.) depending on the quantities of resources available. Mid-season tomato crops which can be pulled out and followed by chrysanthemums (mT_3 and mT_4) do not require such large price increases to bring them into solutions in place of early tomato crops, but again it should be emphasised that if the prices for these crops do increase then the values of early tomato crops will also increase because of the overlapping of harvesting periods.

Intuitively, it does not seem sensible to produce late, cold-grown tomato crops (cT_1, cT_2 and cT_3) in houses fitted with efficient heating systems, but early in the study in was thought that these enterprises might appear in optimal solutions on account of their possible utilisation of spare labour at one particular time of the year. In practice, however, the cold-grown crops do not appear in any of the solutions in heated houses though evidently only a slight price increase is required to bring crop cT_3 into some solutions so long as it is cleared in time for chrysanthemums, and so long as other tomato crop prices do not also rise. In total, though, the marketing periods for all tomato enterprises overlap to some extent and it would require large seasonal price variations on top of the variations already allowed for before the specific crops selected as optimal in Chapter III became uneconomic.

In the heated houses the combination of a January-planted lettuce crop (L_5) followed by a late unheated lettuce crop (cL_2) appears useful, appearing in practically all of the fourteen solutions. The marginal costs in Table IV (x) of the other spring-harvested lettuce crops (L_2, L_3 and L_4) which could be grown in combination with the cold crop tend to equal the difference in gross margin between those crops and crop L_5 which they would displace from the solutions. Thus, for case 2, the marginal cost of crop L_4 is £10 per tenth of an acre: the gross margin of L_4 is £125 whilst the expected gross margin for L_5 is £135.

[1] The absence of these crops from optimal solutions tends to support the conclusions drawn in "Tomato Growers' Interests in a West European Market" by R. R. W. Folley, Wye College, July 1964.

Table IV (ix)

Marginal Costs of Tomato Crops* (£ per tenth of an acre)

Crop		Case 1	2	3	4	5	6	7	8	9	10	11	12	13	14
Early tomatoes	eT_1	60·6	86·1	254·3	32·2	55·3	181·3	5·7	†	178·6	247·8	33·9	‡	94·8	138·8
	eT_2	46·6	64·6	206·5	†	25·9	133·5	†	†	130·6	199·8	†	†	96·7	134·6
	eT_3	†	†	†	†	†	†	14·7	†	†	†	†	†	†	†
	eT_4	†	†	†	†	†	†	†	†	4·3	†	†	†	†	†
Mid-season tomatoes	mT_1	227·7	253·2	302·8	159·5	233·7	176·3	137·2	165·1	141·3	282·4	164·9	177·5	172·9	231·6
	mT_2	176·1	185·1	216·7	140·7	197·4	136·2	104·8	169·0	133·6	242·4	115·3	146·5	227·8	235·5
	mT_3	134·1	128·4	24·3	141·1	179·7	‡	122·8	170·8	‡	39·6	133·3	148·3	128·1	97·9
	mT_4	137·6	135·0	54·3	148·8	181·6	20·3	113·8	180·1	23·8	69·6	124·9	159·0	143·6	118·2
Cold-grown tomatoes	cT_1	127·1	126·5	244·4	92·6	116·8	211·8	66·3	68·3	373·6	237·3	72·9	101·7	295·3	189·1
	cT_2	105·5	99·8	222·5	61·2	86·7	149·3	48·3	60·5	302·6	215·8	42·2	86·3	261·3	150·6
	cT_3	48·4	23·9	‡	50·1	49·6	‡	53·3	46·5	137·0	‡	47·2	71·8	148·1	‡

* For programming, tomato crops were combined with soil sterilisation enterprises to give several activities for each crop. The figure shown here relates to the combination with the *lowest* marginal cost.

† Indicates that the crop is already in the optimal solution and therefore no price change is necessary to bring it into the plan.

‡ Indicates crops for which the marginal cost cannot be given. These crops are " in " the optimal plan as far as the computer is concerned although no acreage is allocated to them by the computer.

It might therefore appear that the substitution of L_2, L_3 or L_4 for the selected crop L_5 does not reduce the gross profits of the holding by any great amount, and that the grower might therefore grow all of these crops—partly to extend the harvesting period and perhaps to minimise the risk associated with price fluctuations which occur during the glasshouse lettuce season. But it must be emphasised that the excluded crops would need to be planted before Christmas and that, with the assumed manpower, this would necessitate reductions in the chrysanthemum acreage. Indeed, the marginal cost data for all crops are applicable only if we consider a very small area of undefined size; thus if a relatively large area is planted with lettuce in December, high value chrysanthemum crops may also be displaced and the marginal cost of the lettuce crop for a practicable area may be much higher than is indicated in Table IV (x).

Table IV (x)

Marginal Costs of Lettuce Crops* (£ per tenth of an acre)

Crop		Case 1	2	3	4	5	6	7	8	9	10	11	12	13	14
heated lettuces	L_1	10·0	23·9	‡	55·9	29·0	‡	68·3	60·8	‡	‡	59·7	54·7	‡	‡
	L_2	‡	12·4	80·4	†	6·9	5·0	†	2·2	5·0	5·0	1·2	†	†	6·9
	L_3	2·0	5·0	80·4	†	‡	5·0	‡	†	5·0	5·0	†	†	‡	6·9
	L_4	9·7	10·0	85·4	‡	8·2	10·0	‡	†	10·0	10·0	‡	1·2	33·4	36·7
	L_5	†	†	75·4	†	†	†	†	†	†	†	†	†	†	†
	L_6	29·0	50·0	0·9	30·5	40·3	177·6	45·0	72·2	20·0	135·5	48·2	42·8	23·0	173·5
	L_7	24·3	45·0	45·0	†	37·1	49·5	30·5	24·6	49·5	49·5	53·6	45·0	40·2	49·4
cold lettuces	cL_1	132·0	165·0	240·4	77·4	134·2	165·0	0	77·2	‡	165·0	†	‡	‡	165·0
	cL_2	†	†	‡	†	†	†	†	†	†	†	†	†	†	†

* See footnotes to Table IV (ix).

The heated lettuce crops not so far discussed (L_6 and L_7) have relatively high marginal costs in most cases. This is because if either of these crops were to enter a cropping plan then both L_5 and cL_2 would be displaced. Crop L_7, for example, could then be grown either as a single crop or in combination with another heated crop harvested earlier than L_5. Likewise, the marginal cost of the cold-grown crop (cL_1) is usually high, partly because it occupies the glasshouse for a longer period than cL_2 and cannot be coupled in rotation with any of the spring-harvested heated crops. Finally, the autumn lettuce crop L_1 does not appear in any of the optimum solutions. The market price would need to rise by more than 30 per cent. above the assumed price for a number of resource situations, and the crop seems particularly uneconomic when the labour force is small since it has to " compete " for labour at planting time against crops which yield much greater gross margins.

For chrysanthemum crops the consequences of faulty price predictions vary greatly according to the resource combinations in question (see Table IV (xi)). For example, it was assumed that the market value of mid-season pot-grown chrysanthemums (*mPX*) is £350 per tenth of an acre; thus for case 1 the value would need to rise by £259·9 or 74 per cent. whilst for case 13 the value would have to increase by only 16·4 or 5 per cent. for this crop to replace the pot-grown or lifted enterprise selected by the computer, assuming that the prices for the selected crops are accurately predicted. Although crop *mPX* occupies the heated houses for less time than the late pot-grown crop (*lPX*), its gross margin is considerably less (see Table II (v)) and it uses labour more economically only in the last two months of the year—when labour is not generally in great demand for other cropping work: thus the mid-season crop has a high marginal cost in comparison with crop *lPX* except when plenty of labour is available throughout the year. Similar reasoning explains the high marginal costs of the mid-season lifted crop (*mLX*) in comparison with the late lifted enterprise (*lLX*). In general, then, the choice lies between the late pot-grown crop and the late lifted crop in those situations in which the computer has selected one or the other. For case 1, for instance, the value of crop *lPX* would need to rise by only £24·9 per tenth of an acre for this to displace the lifted crop from the optimal solution. Again, though, the marketing periods for these two crops are similar and it can be supposed that if the value of one crop increases then the other crop will also rise in value: consequently it is likely that the crop selected by the computer will be the best choice even if prices are wrongly predicted.

TABLE IV (xi)

MARGINAL COSTS OF CHRYSANTHEMUM CROPS* (£ PER TENTH OF AN ACRE)

Crop \ Crop	1	2	3	4	5	6	7	8	9	10	11	12	13	14
mPX	259·9	247·2	89·0	222·6	226·6	93·9	231·2	111·6	94·3	89·0	252·9	136·1	16·4	29·0
lPX	24·9	6·0	†	28·4	5·4	†	53·5	†	†	†	53·0	†	†	†
mLX	207·1	222·5	112·2	159·0	205·5	107·2	149·8	105·3	107·8	113·7	171·9	129·1	42·0	57·5
lLX	†	†	12·2	†	†	†	24·1	†	†	13·8	22·8	†	2·2	6·4
DX	114·7	124·1	213·5	127·1	94·0	151·9	157·9	100·3	146·4	206·8	160·3	103·1	108·5	140·4
DDX	34·5	63·6	125·0	34·0	36·0	70·6	34·9	35·0	65·7	118·1	36·0	35·6	31·6	60·0
cDX	140·3	164·3	136·2	76·7	140·1	118·6	35·6	43·7	116·0	128·8	41·9	42·6	45·1	69·2
$DX_{(p)}$	†	†	†	†	†	†	†	†	†	†	†	†	†	†
$DDX_{(p)}$	†	27·6	91·4	†	†	37·1	†	†	31·9	84·3	†	†	†	27·7
$cDX_{(p)}$	103·3	118·3	90·2	44·2	94·9	72·6	†	†	70·0	82·8	†	†	†	23·2

* See footnotes to Table IV (ix).

On the basis of the input/output data used in this study it is evidently totally uneconomic to buy in cuttings for late struck chrysanthemum crops if they can be propagated on the holding (see Table IV (xi)). The reasons are simply that the propagating area assumed for each case is usually sufficient for any level of cropping permitted by the glasshouse area, and that the labour requirements for propagation are slight (see Table II (vi)) in relation to the financial benefits[1].

[1] For example, the gross margin for direct-planted chrysanthemums (*FX*) is £404 if cuttings are raised on the holding and only £190 if cuttings are bought in.

It would appear from Table IV (xi) that it is never profitable to buy in cuttings for the holdings studied here, for although the marginal cost of crop DX for case 1 is £114·7 this crop would never replace $DX_{(p)}$ in the solution because the two crops are assumed to be identical at the time of sale. However, if the cost of purchasing cuttings were to fall, say by £115 then this would make the crop DX the more profitable of the two since a cost reduction has the same effect as a price increase.

At least one of the direct-planted crops ($DX_{(p)}$) appears in each solution, and some solutions also include the delayed direct-planted enterprise, $DDX_{(p)}$. Where this latter crop does not appear in the solution its marginal cost is relatively low, mainly because it requires little labour in periods when demands on manpower are comparatively great (especially in the eighth "month"). In contrast, though, crop $DX_{(p)}$ has a higher market value which just compensates for its heavier use of labour. The cold-grown direct-planted crop, $cDX_{(p)}$, attracts a higher marginal cost in general because it occupies the glasshouses for a longer period and because, in comparison with $DX_{(p)}$, it is not markedly more economical in its labour requirements at critical times of the year.

In Chapter II it was noted that provision was made in the programming models for a number of three-crop rotations of mid-season or cold-grown tomatoes coupled with lettuce, or lettuce and chrysanthemums, with steam sterilisation at the very end of December. In many cases the lettuce and chrysanthemum enterprises are present in the optimum solutions, thus the marginal cost data for these rotations tends to equal the marginal cost of the tomato crop in the more favourable cases. For some resource situations, however, the marginal cost is very much higher, reflecting the inflexibility of tight cropping schedules.

Finally, in the cold houses the optimum cropping plans are dominated by a two-crop rotation of late lettuce (cL_2) followed by direct-planted chrysanthemums ($cDX_{(p)}$), although in some cases a second rotation of early lettuce (cL_1) followed by tomatoes (cT_3) is also present in the solution. Some of the solutions are, however, quite sensitive to price changes. For example, for case 6, the solution does not include a lettuce-tomato rotation. Here, though, it would only require increases in value of £30·0 and £36·1 respectively per tenth of an acre to bring these two crops (cL_1 and cT_3) into an optimal cropping plan (see Table IV (xii)). In a similar way, the full-term tomato enterprise (cT_1) would displace the alternative tomato crop from some solutions if seasonal price fluctuations differed slightly from those assumed in constructing the model.

TABLE IV (xii)

MARGINAL COSTS OF COLD HOUSE CROPS* (£ PER TENTH OF AN ACRE)

Crop	Case	1	2	3	4	5	6	7	8	9	10
Tomatoes	cT_1	25·3	34·2	157·4	44·3	29·2	130·0	75·0	62·7	158·8	149·1
	cT_3	†	†	‡	19·5	†	36·1	54·7	55·4	38·7	‡
Lettuce	cL_1	†	†	12·8	†	†	30·0	†	42·6	30·0	21·3
	cL_2	†	†	†	†	†	†	†	†	†	†
Chrysanthemums	$cmLX$	158·4	156·7	‡	155·7	176·8	‡	163·6	99·5	‡	‡
	cDX	37·0	46·0	46·0	32·5	45·1	46·0	35·6	43·7	46·0	46·0
	$cDX_{(p)}$	†	†	†	†	†	†	†	†	†	†

* See footnotes to Table IV (ix).

The chrysanthemum crop chosen as optimal given the assumed price data would, however, also be optimal for widely different price conditions. The direct-planted crop grown from bought-in cuttings (cDX) would only replace the crop grown from home-raised cuttings ($cDX_{(p)}$) if the price of cuttings were to fall by £37—£46 per tenth of an acre, since the market value of the two enterprises is always equal. And, the marginal cost of the lifted crop ($cmLX$) is so high for all resource situations that the market value of this crop would need to rise by 47—78 per cent. above the assumed value before this crop displaced the direct-planted enterprise from the solution: and this assumes that the latter crop does not also experience an increase in value.

In aggregate, it is not possible to be dogmatic about the effects of faulty price predictions on the optimality of computed solutions. In the first place the method of analysis used has been very simple, looking at a single enterprise in isolation from the remainder of the crops in the model. And, secondly, because the marketing seasons for several enterprises in a single model overlap or coincide then a faulty prediction of one price logically implies that the prices of other enterprises have also been wrongly predicted. More sophisticated methods of analysing the effects of price fluctuations on cropping plans are well known to programmers and in some circumstances may be more useful than the simple techniques used here; but as a practical proposition for growers it may be better to base cropping decisions on those enterprises which appear in optimal solutions under widely differing price situations and to complete cropping sequences by using simpler budgeting techniques, perhaps selecting minor crops in such a way as to minimise the possible risks arising from inability to predict the future.

CHAPTER V

MODIFICATIONS FOR FUTURE APPLICATION

The management problems confronting growers differ greatly from one holding to another and we must be careful to recognise that no single model can adequately represent the situations of all growers. The basic model and the assumptions underlying it may have general relevance, but for the planning of cropping on any specific holding the model used in this study may require extensive modification. In this final chapter, then, some of the factors and problems which are likely to arise in real applications of linear programming are discussed.

1. Formulation of Resource Constraints

The results obtained from programming models vary according to the assumptions made about the availability and type of resources on the holding. For example, in each of the models analysed in the earlier chapters it has been assumed that a specific quantity of regular manpower is available: the possibility of supplementing the labour force with casual labour has not been explored, although in practice there is no difficulty in incorporating this feature into management models (see Appendix III below). At the present time, however, many growers are unable to hire what can properly be called casual labour. Most supplementary labour is in fact part-time regular labour, and the grower may have to guarantee employment, at least throughout the summer if not through the whole year, if he is to be certain of supplementing his regular labour force at times when extra manpower really is needed.

Conclusions reached as to the optimum cropping solutions for holdings staffed only by regular labour are still relevant if the " casual " labour is employed on a part-time basis over the whole year. And, even where part-time workers can be hired only for the summer months, Figures 15 to 28 give an indication of the number of part-time workers needed and the months in which they would be required if, say, the grower were to employ four regular men plus part-timers to operate a holding with a cropping plan which would require five regular men.

No distinctions have been made between daywork and overtime in this study and, whilst the cost to the grower of the former is fixed, the cost of the latter varies in proportion to the amount of overtime actually worked. Strictly speaking, some of our solutions are sub-optimal since we have found that the marginal value of labour in some months (see Chapter IV) is less than the marginal cost of overtime (i.e. the amount that the grower is required to pay). Again, this problem can be overcome in the construction of models by utilising the method presented in Appendix III. Some difficulty in programming does arise though if both overtime and casual labour are available to supplement the daywork inputs of the regular labour force. Since casual labour is usually cheaper than overtime the computer will always select the former rather than the latter, though such a solution is unlikely to be acceptable in practice.

As a second simplification, our basic model assumed that the glasshouses are either unheated or are fitted with heating systems capable of producing a 30°F. temperature lift suitable for growing early tomatoes. This is appropriate for the construction of hypothetical models of holdings, but in practice such clear-cut distinctions between heated and unheated houses are seldom encountered. The heating systems of many heated houses are certainly not good enough for successful growing of early tomatoes yet the cropping potential of these houses is certainly higher than that of unheated glass. And, additionally, " space heaters " are being increasingly used in hitherto unheated glass to increase their cropping potential. In the construction of models for actual holdings, therefore, it may be necessary to devise separate sets of input/output data for crops according to the temperature regimes of the houses available. Restrictions can then be placed on the total areas of " high ", " moderate " and " low " temperature crops.

2. Other Crops and Production Methods

During construction of the basic programming model it was decided that several techniques of production for tomatoes, lettuces and chrysanthemums should be excluded from the analysis and reasons for these omissions were given in Chapter II (Section 2, *d*). The results of the computations given in figures 1 to 14 do suggest, however, that a number of alternative production methods might usefully be considered in any further investigations.

For example in many of the optimal solutions late-struck chrysanthemums ($DX_{(p)}$) follow a cold lettuce crop (cL_2) cleared in May, and parts of the houses are therefore empty until the chrysanthemums are planted in August. This may be a useful policy to adopt in practice since it permits the internal painting of houses from time to time, but the majority of growers would probably attempt to plant the chrysanthemum crop earlier, with wider spacings and to take more blooms per plant. Since fewer cuttings are required production costs are considerably reduced, particularly if cuttings are normally bought-in. But, at the same time the labour profile of this crop is modified due to the earlier date of planting.

Another chrysanthemum enterprise also might justify inclusion in future models. Rooted cuttings may be planted in mid-June with three cuttings per 9 in. whalehide pot, and with pots standing outdoors. Stopped in mid-late July and housed in late September, each plant should yield three blooms, as with the standard pot-culture method. This production technique appears to combine some of the advantages of both the direct-planted and pot-grown enterprises since the glasshouses would be free for tomatoes until September and the labour requirements would be lower than for pot-grown crops in the early summer when work on the tomato crop is at its peak.

The use of soil-blocks for reducing the length of time lettuce crops occupy the cropping houses is not an uncommon practice and could also be considered here. This production method allows an extra lettuce crop to be " squeezed in " in some cases, but the technique may only be of importance when the glasshouse area is more of a limiting factor on production than is labour. At the same time, the area required for propagating and holding the crop until it is planted out is much increased, and our results indicate that propagation space is a limiting factor at those times of the year when the technique might be considered useful on other criteria.

One fact of some significance which emerges from the study is that the optimal solutions prescribe fairly early pulling-out of tomato crops—in time for chrysanthemums or autumn lettuce —even though the houses are not required immediately for other crops or for soil sterilisation (see Figures 4, 7, 8, 11 and 12). Although this practice probably commends itself to relatively few growers it nevertheless deserves serious consideration, for higher returns to labour may be obtained by applying labour to other crops rather than by carrying on the tomato crop to its last fruit. Secondly, in cases 7 and 11 it was found that part of the heated area is not used at all during the summer because of the shortage of labour. These features raise the question of whether or not some crops can be grown with lower labour inputs than are assumed in this study. If labour inputs are reduced then gross margins are likely to fall due to lower crop yields, but at the same time it might be possible to crop larger areas and thus gain an overall increase in gross profits for the holding. As yet, little information is available about the relative merits of " ranching " crops as opposed to intensive methods of production but future developments might justify the introduction of these alternative methods into programming models.

For the present study it was assumed that partial soil sterilisation by steam or chemical methods must be carried out annually in all houses carrying a crop of tomatoes; and in most optimal solutions steam sterilisation is suggested by the computer. For a variety of reasons, neither the assumption nor the result will satisfy some growers. Some glasshouse managers use steam and chemical methods in alternate years, and it is relatively easy to force this sequence to programming models. On the other hand, problems may be encountered in programming for situations in which the grower is satisfied with soil sterilisation only every other year or at even longer intervals (see Appendix II). Finally, the assumption that soil sterilisation is only necessary when tomatoes are included in the rotation is not strictly true since both lettuces and chrysanthemums also benefit from steam sterilisation in the lettuce—tomatoes—chrysanthemums rotation. In fact, some growers are now using the technique of " sheet steaming "[1] specifically for direct-planted chrysanthemums and lettuce crops. One of the objectives is to reduce the incidence of weeds in the growing crop since their removal by hand is a time-consuming operation. On holdings where weeds are particularly troublesome under glass there is therefore a case for including an enterprise for direct-planted chrysanthemums in which sheet steaming is used as a partial or total substitute for hand weeding. And, for tomatoes, there is also the possibility of dispensing with soil sterilisation altogether by grafting commercial varieties onto disease-resistant rootstocks.

[1] With this technique, low-pressure steam is fed underneath a tarpaulin weighted to the ground at the edges, and the steam penetrates the top few inches of soil. Labour requirements are much lower than for other steam sterilisation methods.

3. Linear Programming for Glasshouse Planning: Some Final Remarks

It has not been our intention to produce a complete or comprehensive set of models or analyses likely to cover all eventualities, and we have therefore refrained from considering a vast range of crops which find a place in the cropping programmes of many individual growers. Our main concern has been the elucidation of the role that can be played by an increasingly important technique of analysis, and to provide a basic framework for advisers and growers within which more detailed and more specific management decisions can be made.

Comments throughout the discussion have hinted at the problems associated with the construction and analytical interpretation of linear programming models. Notwithstanding these, the technique is a powerful tool for planning broad strategy, and in some cases even for guiding the practical manager through a maze of detailed decision making. It is, indeed, difficult to envisage alternative tools of analysis being able to supplant linear programming techniques if models are to represent with some degree of realism the possibilities and problems of the real world.

Nevertheless, it is salutary to examine some of the advantages and disadvantages of linear programming in comparison with other forward planning techniques. The most important single advantage of linear programming is that it enables the adviser to consider, almost simultaneously, all of the alternative feasible enterprises and all of the restrictions to which the cropping pattern of the holding is subject. In contrast, less sophisticated techniques, which utilise essentially identical data, rely to some extent on a hit-and-miss approach which examines the possibilities of substituting one crop for another and is rarely able to assess the effects of substituting one or more crops for several others at one and the same time. Thus the optimum deployment of resources can only be identified with certainty by linear programming methods. Furthermore, modifications to the standard method of computing linear programming solutions are available which enable the adviser to study changes in optimum solutions resulting from changes in prices, costs and other characteristics.

In practice, however, it is not always easy to recognise and quantify all of the factors which are likely to restrict cropping on a holding. And, whereas other techniques permit modifications to be made to the data and the restrictions during computation, linear programming requires that the whole problems must be formulated correctly and completely before computation begins. Indeed, many of the failures of linear programming to provide solutions which can be put into effect are due not to short-comings inherent in the technique itself but can be ascribed to a failure in identifying the problem to be solved with a sufficient degree of precision.

On the other hand, linear programming does have some inherent disadvantages which cannot be altogether ignored. One of the basic assumptions of the method is that all inputs and output are perfectly divisible: the essence of this assumption is that an optimal solution might prescribe the growing of 0·27 acres of tomatoes or the utilisation of 38·7 man-hours of labour in a specific week. In this example, the grower might not have a glasshouse with an area of 0·27 acres, and the execution of the solution would require the grower to mix the cropping in some of his houses. However, it is not always practicable to do this since different crops require different environmental conditions and because problems of maintaining hygiene standards might be encountered. The majority of growers would therefore wish to modify linear programming solutions to ensure that the optimal cropping plans are consistent with the sizes and numbers of glasshouses on their holdings. On holdings with a relatively large number of glasshouses there will be less need for modification and optimal solutions may simply require rounding for the crops to fit the houses, whilst on other holdings partial budgeting methods may be required to fulfil this objective.[1]

Another fundamental assumption that linear programming makes about the real world is that input/output ratios are constant for each activity in the model whatever the level of output: thus the gross margin for a crop and its requirements of labour and other resources are assumed to be ten times greater for one acre than for one tenth of an acre. This assumption is not always consistent with observed behaviour in the real world, and if it is established that the relevant ratios alter as the level of output increases then modifications of the linear programming model are required if this feature is to be adequately handled by the computer.

[1] On a rather technical plane, it is possible to re-process linear programming solutions using techniques of " integer programming " to produce cropping plans which fit the available sizes and numbers of houses exactly. Computer library programmes are available for this purpose, but hitherto only small models have been solved in this way.

The importance of these shortcomings of the conventional model varies from one situation to another, and their effects can usually be mitigated by modifying the way in which the model is constructed and possibly by resorting to alternative techniques of computation which are related to the basic linear programming routine. In spite of its defects, though, the conventional method of linear programming can be justified in most instances, for although it may embody faulty assumptions the importance of these can often be judged from a detailed analysis of the computed solution.

For holdings on which cropping plans appear to be reasonably efficient in an economic sense, periodic reviews of cropping patterns can be accomplished satisfactorily by using traditional budgeting methods of analysis. Even in these cases, however, linear programming may amply repay its cost in terms of increased profitability, judging from experience of use of the technique in other agricultural situations: often it is found that relatively minor changes in cropping can yield substantial increases in gross profits. And, for holdings on which the pattern of cropping clearly seems to be maladjusted to economic circumstances, the cost of using linear programming can be expected to be trivial in relation to the financial benefits, given a reasonable standard of crop husbandry.

APPENDIX I

THE PROGRAMMING MATRIX*

RESTRICTIONS *(with units of measurement)* \ *ACTIVITIES*	*Number of Equations*	*Resource Supply levels*	*ENTERPRISES FOR HEATED HOUSES*							*ENTERPRISES FOR UNHEATED HOUSES*	
			Tomatoes + Sterilisation (Groups (a) and (b) (See note (1) and Appendix II)	*Lettuce and Chrysanthemums*	*3-Crop Rotations (See note (2))*	*Use of Heated Cropping Area for Propagation (See note (4))*	*Land Transfer (See note (1) and Appendix II)*	*Tomatoes + Sterilisation Group (c) (See note (1) and Appendix II)*	*Duplicate lettuce and Chrysanthemums (See note (1) and Appendix II)*	*Tomatoes + Sterilisation*	*Lettuce and Chrysanthemums*
Number of Activities		1	44	19	10	10	1	32	5	12	5
Labour Supply (Man days)	13	(3) >0	$\geqslant 0$	$\geqslant 0$	$\geqslant 0$	0	0	$\geqslant 0$	$\geqslant 0$	$\geqslant 0$	$\geqslant 0$
Heated Cropping Area (units of one tenth of an acre)	18	(3) >0	1, 0, or Dummy —(see note (1) and Appendix II)	1 or 0	1	1 1 1 (Unit Matrix) 1	1	0	0	0	0
Permission Equations (units of one tenth of an acre)	7	0	0	0	0	0	-1	1 or 0	1 or 0	0	0
Unheated Cropping Area (units of one tenth of an acre)	10	(3) $\geqslant 0$	0	0	0	0	0	0	0	1, 0, or Dummy—(see note (1) and Appendix II)	1 or 0
Propagation Area (unit of one three hundredth of an acre)	10	30	$\geqslant 0$ or <0 (see note (2))	0	$\geqslant 0$	—30 —30 (Scalar matrix)—30	0	$\geqslant 0$ or <0 (see note (2))	$\geqslant 0$	$\geqslant 0$	$\geqslant 0$
Early Tomato Restriction (units of one tenth of an acre)	1	(3) >0	1 or 0	0	0	0	0	1 or 0	0	0	0
3-crop Rotation Restriction (units of one tenth of an acre)	1	2	0	0	1	0	0	0	0	0	0
Profit Equation (£'00s)	1	0	>0	>0	>0	0	0	>0	>0	>0	>0

*The symbol $\geqslant 0$ means that some elements in the sub-matrix are greater than zero and that others are equal to zero; a single figure in a sub-matrix is common to all elements in that sub-matrix.

In Chapter 2 detailed tables are presented listing the input/output requirements of all of the enterprises considered in the analysis. These data need to be linked together into a system of equations of the type formulated at the end of Chapter II.

A *schematic* representation of the equation system is given above, showing the order of magnitude and other characteristics of the elements of the programming matrix, largely for the benefit of future programmers who may wish to refer to the basic framework of the model: and it is into this framework that the actual input/output coefficients are inserted.

Notes.

(1) The classification of tomato enterprises into groups (*a*), (*b*) and (*c*), the need for " Dummy " input/output coefficients in a number of equations, as well as the use of " permission equations " and duplicated activities for lettuce and chrysanthemums are all described in *Appendix II* below.

(2) For some activities there are negative input/output coefficients in the " propagation space " equations. This is because " dummy " coefficients have been used in the " glasshouse space " equations for these enterprises to indicate periods of the year when other crops must not use the vacant glasshouse area. The space can, however, be used for propagation purposes. If, for example, there is a short time-lag between pulling out the tomato crop and sterilisation, and the land is not available for long enough to grow another crop then it can be used for propagation if required. It must be noted, though, that where there is a time-lag between sterilisation and the planting of a following tomato crop the use of the vacant land for propagation has not been permitted because of the risk of re-infecting the sterilised soil.

(3) The supply levels of these resources are varied according to the resource combinations under examination (*see Chapter* 2).

(4) At the outset, it was thought that at certain times of the year the propagation area assumed to be available might constrain the solution. In practice, however, part of the cropping house area could be used temporarily for propagation purposes. Ten activities are therefore formulated which allow this to be done at the critical times of the year; and in effect, these vectors permit the computer to reduce the area of a crop such as lettuce and use the glasshouse space thus freed for propagation if this allows higher profits to be attained.

APPENDIX II

Construction of a Model to Optimise the Timing of Soil Sterilisation

The method of construction of the programming matrix was partly dictated by the twin requirements (i) that all land use for growing tomatoes must also be sterilised and (ii) that the timing of sterilisation should be optimised within the model and not be prejudged by the programmer.

To illustrate the problem arising from these two conditions suppose that there are four time periods within a year and that two-tenths of an acre are available for cropping. Suppose further that there are two tomato crops, one designated T_1 and requiring land during the first period only, and another, T_2, requiring land in the first two periods. A chrysanthemum enterprise, X_1, requires land in the second, third and fourth periods; and two sterilisation activities use land in the third and fourth periods respectively.

It might be supposed that the relevant part of the model can be composed in matrix form as

$$\begin{bmatrix} 1 & 1 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 1 & 0 & 1 \\ 1 & 1 & 0 & -1 & -1 \end{bmatrix} \cdot \begin{bmatrix} T_1 \\ T_2 \\ X_1 \\ S_1 \\ S_2 \end{bmatrix} \leqslant \begin{bmatrix} 2 \\ 2 \\ 2 \\ 2 \\ 0 \end{bmatrix} \qquad (1)$$

where the last inequality,

$$T_1 + T_2 - S_1 - S_2 \leqslant O,$$

ensures that the total acreage of tomatoes is equal to the sterilised acreage.

It is clear that there is a feasible solution comprising $T_1=1$, $T_2=1$, $X_1=1$, $S_1=1$ and $S_2=1$.

Alternatively, the same data may be used in another way to achieve the same result. Let each tomato activity be combined with each sterilisation activity in turn, to form a set of composite input/output vectors. For example, let

$$\begin{aligned} T_1+S_1&=K_1 \\ T_1+S_2&=K_2 \\ T_2+S_1&=K_3 \\ \text{and } T_2+S_2&=K_4 \end{aligned}$$

The system of constraints may now be re-written:

$$\begin{bmatrix} 1 & 1 & 1 & 1 & 0 \\ 0 & 0 & 1 & 1 & 1 \\ 1 & 0 & 1 & 0 & 1 \\ 0 & 1 & 0 & 1 & 1 \end{bmatrix} \cdot \begin{bmatrix} K_1 \\ K_2 \\ K_3 \\ K_4 \\ X_1 \end{bmatrix} \leqslant \begin{bmatrix} 2 \\ 2 \\ 2 \\ 2 \end{bmatrix} \qquad (2)$$

and a feasible solution would be $K_1=1$, $K_4=1$, and $X_1=1$ which is equivalent to $T_1=1$, $T_2=1$, $X_1=1$, $S_1=1$, and $S_2=1$ as before.

Both formulations of the illustrative model are, however, totally unworkable given the first of the initial conditions for, diagrammatically, both computed solutions suggest that each of the one-tenth acre blocks of land should be utilised through the year as follows:

1st Block ⟶	TOMATOES T_2	STERIL S_1		STERIL S_2
2nd Block ⟶	TOMATOES T_1	CHRYSANTHEMUMS X_1		
Time period ⟶	1	2	3	4

Thus, the computed solution includes two-tenths of an acre of tomatoes and the same acreage of sterilised soil, but half the soil is sterilised twice and the other half is not sterilised at all. In brief, neither formulation of the model ensures that *every block of land* occupied by tomatoes is also sterilised.

The problem can, conceptually at least, be resolved by summing the input-output vectors of all feasible combinations of crops to form complete rotations before programming, but, given a relatively large number of activities together with the possibility of two or three year rotations, this procedure is not practicable. Instead, it was decided to aggregate the input/output data of each tomato vector with each sterilisation vector in turn to form all feasible composite activities. The joint vectors may then be classified into the three following groups:

(*a*) vectors for which the sterilisation *immediately* precedes or follows the tomato crop,

(*b*) vectors for which the time lapse between sterilisation and either planting or pulling-out of tomatoes is insufficient to grow another crop on the vacant land, and

(*c*) vectors for which the land is vacant between sterilisation and either planting or pulling-out of tomatoes for a sufficiently long period to grow another crop, e.g. of lettuces or chrysanthemums.

Programming difficulties are only encountered when there is a time interval between the requirement of land for the tomato crop and the requirement of the *same land* for sterilisation, as with vectors in groups (*b*) and (*c*). For vectors in group (*b*) it is by definition impossible to use the vacant land in practice, and for programming purposes it is therefore valid to assume that the vacant land is " required " by the crop. Thus, by inserting " dummy " coefficients in the appropriate equations for the glasshouse area these vectors become similar to those classified in group (*a*). Referring back to the matrix representation of the illustrative example (2), this may now be rewritten:

$$\begin{bmatrix} 1 & 1 & 1 & 1 & 0 \\ (1) & (1) & 1 & 1 & 1 \\ 1 & (1) & 1 & (1) & 1 \\ 0 & 1 & 0 & 1 & 1 \end{bmatrix} \cdot \begin{bmatrix} K_1 \\ K_2 \\ K_3 \\ K_4 \\ X_1 \end{bmatrix} \leqslant \begin{bmatrix} 2 \\ 2 \\ 2 \\ 2 \end{bmatrix} \qquad (3)$$

in which the bracketed coefficients are dummy land requirements. All solutions to the model are now feasible in practice and conform with the initial pre-requisites.

For vectors classified into group (*c*) a more complicated treatment is demanded. Firstly, the vectors are treated in exactly the same way as those in group (*b*). This treatment corresponds to situations in which an additional crop is *not* fitted into the rotation between the tomato crop and soil sterilisation. Secondly, the activities need to be duplicated in the matrix in such a way that feasible rotations of tomatoes plus sterilisation, together with any activity which can use the vacant land, can be generated during computation. To fulfil this objective it was necessary to compile a sub-matrix linked to the main matrix, since it was found uneconomic in terms of computational effort to formulate all feasible rotations prior to programming. Thus, a separate section of the overall input/output matrix contains a duplicated vector for each tomato/sterilisation activity in group (*c*) together with duplicated vectors for all of the lettuce and chrysanthemum activities which can be incorporated in crop rotations with these. In this section of the matrix requirements of activities for glasshouse space are ignored and are replaced by a series of " permission equations ", determining the crops which can be combined with each specific tomato/sterilisation vector; and the land for all crops is generated by a " land transfer " activity. The general form of the equation system, indicated in Appendix I, is elaborated below:

	Resource Supply Levels	*Main body of matrix containing all enterprises*	*Land Transfer Activity*	*Duplicated group* (c) *tomato/sterilisation vectors*	*Duplicated lettuce and chrysanthemum vectors*
Heated Glasshouse Area Equations 1	>0	Coefficients are zero or unity	1	All coefficients are zero	All coefficients are zero
2	>0		1		
18	>0		1		
Permission Equations 1	0	All coefficients are zero	−1	1 1 0 0	0 0 1 0
2	0		−1	1 1 1 1	0 0 0 0
3	0		−1	1 0 1 1 etc	0 1 0 0 etc
4	0		−1	0 0 1 1	1 0 0 1
7	0		−1		

Before it can allow any of the activities in the sub-section of the matrix to enter the programming basis the computer must first include an appropriate amount (say one tenth of an acre) of the " land transfer " vector (which reduces the amount of glasshouse space available to other activities in the main body of the matrix throughout the year), whose negative coefficients, in effect, increase the resource supply in each of the permission equations from zero to one tenth of an acre. Thus one tenth of an acre of the first of the tomato/sterilisation activities shown in the above table could then be included in the solution and this would again reduce the resource supply in each of the first three permission equations to zero. Therefore neither of the second and third duplicated lettuce and chrysanthemum activities could be included in the solution in association with one tenth of an acre of this tomato/sterilisation enterprise as this would violate the resource restriction of the first and/or third permission equation. On the other hand, the one tenth of an acre resource supply generated by the land transfer vector in the fourth to seventh permission equations is not required by the tomato/sterilisation activity in question and up to one tenth of an acre of the first and/or fourth lettuce and chrysanthemum vectors could be grown in rotation with it. The whole system of permission equations is devised in such a way that computed rotations are also feasible in practice.

The methodology developed above is entirely satisfactory for situations in which soil sterilisation is to be carried out before all tomato crops, but the same procedure may not be efficient if it is assumed that soil sterilisation is only required in alternate years or at even longer intervals.

If the grower prefers to sterilise half of the tomato acreage each year then the same technique of matrix construction is permissible, for the only modification required is that the coefficients of the sterilisation vectors must be halved. If on the other hand a pre-judgment is made that all of the tomato acreage must be sterilised in one year and none of it in the following year, or steam sterilisation and chemical sterilisation in alternate years, then further complications arise, particularly if the tomato acreage is allowed to vary temporarily. In these cases it appears imperative that the model and the matrix must formally represent all of the possibilities which can occur during a two-year time span. Thus the number of equations in the system is doubled and the number of column vectors is also greatly enlarged, producing a matrix which becomes time-consuming in terms of the computational burden involved and more difficult to interpret analytically.

APPENDIX III

LABOUR AS A VARIABLE COST

In each of our applications it is assumed that the labour force comprises a fixed element in the costs of glasshouse operation and that the amount of time available in terms of man-days is also predetermined.

Conceptually, there are no difficulties involved in relaxing these assumptions and assuming that, for example, a basic minimum amount of regular man power is available and that this can be supplemented by casual labour if this is found to be profitable during computation. In the equation system tabulated below it is assumed that casual labour can be hired on a monthly basis at a cost of £1·5 per man-day, and constraints on the monthly maximum amount of casual labour are also

		Supply Level P_0	*Crop Vectors* P_1 P_2 P_3 *etc.*	*Casual Labour Vectors* P_{10} P_{11} P_{12} *etc.*		
	C_j		Positive coefficients	−1·5	−1·5	−1·5
Labour Supply in:	May	145	Positive or zero coefficients	−1	0	0
	June	145		0	−1	0
	July	145		0	0	−1
Max. casual Labour in:	May	50	Zero coefficients	1	0	0
	June	75		0	1	0
	July	75		0	0	1

included, possibly reflecting a grower's subjective ability or desire to use casual manpower. Alternatively, these constraints can be omitted, reflecting a situation in which the supply of casual labour is perfectly elastic, in which case the computer will specify the hiring of casual labour so long as its marginal value product exceeds its specified marginal cost or until other constraints in the equation system limit the need for additional labour. Similar formulations are, of course, relevant if the quantities of other fixed resources can be treated wholly or partly as variable items.

Overtime (as opposed to day work) can thus be treated as a variable cost and the computer allowed to select the most profitable level of overtime working in precisely the same way as for casual labour. Some difficulties are encountered, however, if one assumes that a basic amount of regular labour can be supplemented by both overtime and casual labour, since casual wage rates are normally considerably lower than overtime rates and the computer will therefore always select casual labour in preference to overtime. This is not, of course, in keeping with observed practice since the regular staff of a glasshouse holding is normally required to work some overtime even if casual labour is also being employed.

The difficulty can be resolved by first determining the optimum solution when overtime working is allowed up to the level at which casual labour would be hired in practice, but when the hiring of casual labour is not permitted. Should all the available overtime be used up in say June this quantity of labour is added to the original basic regular labour supply for June and the programme re-run, this time allowing casual labour to be hired in June instead of overtime. By repeating this procedure and allowing casual labour to be hired in each month for which the available overtime was fully committed in previous runs of the programme the optimum solution would be reached. Clearly, however, the computational burden would be heavy and a more practicable approach might be to specify the relative proportions of overtime and casual labour which would be hired at a given period of the year and use an average cost for both forms of extra labour.

APPENDIX IV

LIST OF ACTIVITIES IN THE MATRIX

Throughout the study a symbolic shorthand has been used to identify the precise enterprises, whilst in the matrix used for computation all single and composite activities are identified by a number (from 1 to 138). The following table for the sake of completeness simply lists the order in which enterprises appear in the matrix and identifies exactly the extent to which the input requirements of enterprises (e.g. tomatoes plus sterilisation) have been aggregated into joint activities and rotations.

Vector	*Enterprises*
1	eT_1+stS_2 (or stS_3)
2	eT_1+stS_4
3	eT_1+stS_5
4	eT_1+chS_2 (or chS_3)
5	eT_2+stS_5
6	eT_3+stS_5
7	eT_4+stS_5
8	mT_1+stS_2
9	mT_1+stS_4
10	mT_1+stS_5
11	mT_1+stS_7
12	mT_1+stS_8
13	mT_1+chS_2 (or chS_3)
14	mT_1+chS_4
15	mT_1+chS_5
16	mT_2+stS_5
17	mT_2+stS_6 (or stS_7)
18	mT_2+stS_8
19	mT_2+chS_5
20	mT_3+stS_5
21	mT_3+stS_6 (or stS_7)
22	mT_3+stS_8
23	mT_3+chS_5
24	mT_4+stS_5
25	mT_4+stS_6 (or stS_7)
26	mT_4+stS_8
27	mT_4+chS_5
28	cT_1+stS_1
29	cT_1+stS_2
30	cT_1+stS_4
31	cT_1+stS_7
32	cT_1+stS_9
33	cT_1+stS_{10}
34	cT_1+chS_1
35	cT_1+chS_5
36	cT_1+chS_6
37	cT_2+stS_9
38	cT_2+stS_{10}
39	cT_2+chS_5
40	cT_2+chS_6
41	cT_3+stS_9
42	cT_3+stS_{10}
43	cT_3+chS_5
44	cT_3+chS_6
45	L_1
46	L_2
47	L_3
48	L_4
49	L_5
50	L_6
51	L_7
52	cL_1
53	cL_2
54	mPX
55	lPX
56	mLX
57	lLX
58	DX
59	DDX
60	cDX
61	$cDX_{(p)}$
62	$DX_{(p)}$
63	$DDX_{(p)}$
64	$mT_2+L_1+L_5+stS$
65	$mT_3+lPX+L_5+stS$
66	$mT_3+lLX+L_5+stS$
67	mT_4+DX+L_5+stS
68	$mT_4+DDX+L_5+stS$
69	$mT_4+DX_{(p)}+L_5+stS$
70	$mT_4+DDX_{(p)}+L_5+stS$
71	$cT_2+L_1+cL_1+stS$
72	$cT_3+lPX+cL_1+stS$
73	$cT_3+lLX+cL_1+stS$
74 to 83	Allowing heated growing houses to supplement the propagation area.
84	Land Transfer Vector
85	eT_3+stS_3
86	eT_3+st_4
87	eT_3+chS_3
88	mT_3+stS_3
89	$mT_3+stS_3+L_4$
90	$mT_3+stS_3+L_5$
91	mT_3+stS_4
92	$mT_3+stS_4+L_4$
93	$mT_3+st_4+L_5$

Vector	Enterprises
94	mT_3+chS_3
95	mT_3+chS_4
96	cT_1+stS_5
97	cT_1+chS_2
98	cT_1+chS_4
99	cT_2+stS_5
100	cT_2+stS_6
101	cT_3+stS_3
102	$cT_3+stS_3+L_4$
103	$cT_3+stS_3+L_5$
104	$cT_3+stS_3+cL_1$
105	cT_3+stS_4
106	$cT_3+stS_4+L_4$
107	$cT_3+stS_4+L_5$
108	$cT_3+stS_4+cL_1$
109	cT_3+stS_5
110	cT_3+stS_5+lPX
111	cT_3+stS_5+lLX
112	cT_3+stS_6
113	cT_3+stS_6+lPX
114	cT_3+stS_6+lLX
115	cT_3+chS_3
116	cT_3+chS_4

Vector	Enterprises
117	L_1
118	L_6
119	L_7
120	mPX
121	mLX
122	cT_1+stS_1
123	cT_1+stS_2 (or stS_3)
124	cT_1+stS_4
125	cT_1+chS_1
126	cT_1+chS_2 (or chS_3)
127	cT_1+chS_4
128	cT_1+chS_5
129	cT_1+chS_6
130	cT_3+stS_4
131	cT_3+chS_4
132	cT_3+chS_5
133	cT_3+chS_6
134	cL_1
135	cL_2
136	$cmLX$
137	cDX
138	$cDX_{(p)}$

RESOURCE COMBINATIONS

Case	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Men per acre	3	4	5	3	4	5	3	4	5	6	3	4	5	6
H:C ratio	0·25:0·75			0·50:0·50			0·75:0·25				1·0:0			

ENTERPRISE NOTATION

Tomatoes

eT=early tomatoes planted early February
mT=mid-season tomatoes planted mid March
cT=cold-grown tomatoes planted May.

Subscripts:

$_1$ full crop cleared in October
$_2$ crop cleared for Autumn lettuce
$_3$ crop cleared for pot-grown or lifted chrysanthemums
$_4$ crop cleared for direct-planted chrysanthemums.

Lettuce

L=heated lettuce

Subscripts:

$_1$ planted October cut December
$_2$ planted early November cut late February
$_3$ planted late November cut early March
$_4$ planted late December cut mid March
$_5$ planted early January cut late March
$_6$ planted late January cut early April
$_7$ planted early February cut mid April.

cL=cold-grown lettuce

Subscripts:

$_1$ planted early January cut mid April
$_2$ planted mid March cut early May.

Chrysanthemums

PX=pot grown chrysanthemums houses in late September
LX=lifted chrysanthemums housed in late September

cDX=cold-grown direct-planted. Planted in May at 10 in. × 10 in.
DX=directed-planted. Planted in August at 5 in. × 5 in.
DDX=delayed direct-planted. Plants held outdoors from June to August then houses at 12 in. × 12 in.

Prefixes

m=mid-season varieties
l=late varieties
cm=cold-grown mid-season varieties

The subscript (p) refers to crops grown from cuttings produced on the holding.

Soil Sterilisation

stS=steam sterilisation

Subscripts:

$_1$ sterilised in fortnight 22
$_2$,, ,, ,, 23
$_3$,, ,, ,, 24
$_4$,, ,, ,, 25
$_5$,, ,, ,, 1 (or 2)
$_6$,, ,, ,, 3
$_7$,, ,, ,, 4
$_8$,, ,, ,, 5
$_9$,, ,, ,, 6
$_{10}$,, ,, ,, 8 (or 7)

chS=chemical sterilisation

Subscripts:

$_1$ sterilised in fortnights 22—26
$_2$,, ,, ,, 23—1
$_3$,, ,, ,, 24—2
$_4$,, ,, ,, 25—3
$_5$,, ,, ,, 1—5
$_6$,, ,, ,, 4—8