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ON-FARM ECONOMICS OF LASER LANDFORMING FOR RICE FARMING IN THE MURRUMBIDGEE IRRIGATION AREA

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Abstract

Laser landforming is a technique for accurately modifying the microtopography of a farm landscape to improve the productivity of farm resources. Despite having been widely applied to flood-irrigated agriculture since its introduction to Australia in 1977, a comprehensive economic evaluation of the technique has not been undertaken.

The effects of laser landforming on productivity of farm resources including land, labour, equipment and irrigation water depend on a range of factors. These include the design of the job, the existing layout of a farm soil type, the effect of earthmoving operations on soil structure and fertility, and appropriate management changes being undertaken. The economics of a job will be affected also by a farmers' tax situation, eligibility for concessional credit, and length of planning horizon as well as by the cost of the job and forecast product prices and input costs. There may also be variable returns from successive increments of landforming development. The decision regarding whether, how and how much to laser-landform is therefore a complex one.

The primary aim of this project has been to examine the whole farm economic effect of application of this technique in a range of situations, and thereby to provide advisory officers with principles to guide them in advising farmers.

The whole farm impact of laser landforming was evaluated using a linear programming model of a representative rice farm for the Murrumbidgee Irrigation area. A spreadsheet model allowed quantification of the effect of the technique over the planning horizon of the investment and discounted cash flow analysis to be undertaken.

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1. INTRODUCTION

1.1 Background

Landforming[1] is a process aimed at modifying the microtopography of a farm landscape to improve productivity of resource use. Application of the technique may possibly also provide external benefits by reducing the rate at which water infiltrates to a rising or already shallow watertable (Tenison, 1990).

While landforming can have benefits for solely rainfed agriculture such as removing depressions in paddocks which lead to plant growth losses through poor surface drainage, landforming has primarily been applied in the context of flood-irrigated agricultural systems since the range of benefits there is much wider. As well as improving surface drainage, applied irrigation water flows more evenly across the target area. Landforming normally straightens contours and evens out the rate of fall across a paddock so that irrigation bays, the design of which are strongly constrained by surface contours, can be redeveloped to be closer to optimal sizes and shapes. If undertaken within a whole farm plan, the topography of the farm and water supply and surface drainage networks can be modified so that the area of the farm too elevated to be 'gravity-commanded' for irrigation is reduced. Surface run-off can also then be directed to flow to a single point on a farm for possible re-use. The arable area lost to supply and drainage channels can also be minimised by laser landforming according to a whole farm plan.

The application of laser technology to guide earthmoving operations is a relatively recent innovation[2]. The first use of this technology in Australia was near Shepparton in 1977 (Hall *et al*, 1983). Laser control greatly reduces the time taken to undertake a landforming job, considerably reducing costs. It also greatly increases the accuracy with which a bay surface is modified. It has become possible to grade the land surface consistently to within 6 millimetres of the required slope (Ewers, 1988).

Laser technology has thereby made landforming an attractive proposition for a much wider range of farmers, as well as encouraging farmers who had landformed previously to re-landform using the new technology to attain the greater benefits that the increased level of accuracy has made possible.

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[1] Confusion exists between the terms 'landforming' and 'grading'. Landforming is the process by which existing microtopography is changed by the mechanical shifting of soil to create a defined slope on an irrigation bay or eliminate excessive side slope on the bay. Gradingis the process of smoothing the land surface to achieve a uniform gradient. In practice most earthmoving jobs involve landforming and grading as part of the same operation (Patto, 1989). In this paper landforming is taken to encompass both processes.

[2] "By rapidly emitting pulses of laser light, the laser component of the equipment delivers a perfectly straight beam of light to a receiver mounted on the grader. It resembles an extremely accurate spirit level" (Ewers, 1988).

Considerable proportions of irrigated areas in NSW and Victoria have been landformed[3] since 1977. The proportions of the aggregate areas of rice farms landformed in the Murrumbidgee and Murray Valley zones of NSW in 1986/87 have been estimated at 29 percent and 12 percent respectively (Young, 1989). By 1988 a total of 37 percent of the average area irrigated in the Goulburn Murray Irrigation District of Victoria is estimated to have been landformed (Patto, 1989).

1.2 The Need for Economic Analysis

Despite the substantial application of this technology, questions remain regarding its value in improving farm profitability and ameliorating problems associated with rising watertables. Patto (1989) suggests research and extension personnel have lagged in generating and disseminating data to assist farmers to assess the claims and counter-claims made for the value of the technique.

Mistaken impressions of what landforming can achieve have led to serious mistakes in the past. For example, initially its rate of adoption was fastest in the Kerang region of Victoria with serious soil salinity problems (Hall *et al*, 1983). It was targeted at the poorest productivity, most highly salinised areas with the expectation of rehabilitating those areas by lowering watertables. It was eventually found, however, that the productivity increases on saline soils were insufficient to recover landforming costs (Tregowel Plains Sub-Regional Working Group, 1989).

The Irrigation Farm Working Group (1986) noted also the lack of technical information regarding the effects of landforming and concluded that "any investment in landforming would need the closest assessment to determine if it was justified on the basis of increased returns".

The few economic analyses of landforming that have been undertaken reached different conclusions. Two studies found that the technique generated negative returns even at a social rate of discount (Campaspe West Sub-Regional Working Group, 1989, and Tregowel Plains Sub-Regional Working Group, 1989). Analysis for the Berriquin Irrigation District concluded that landforming was a profitable investment (Tainsh, 1985). Two United States studies also indicated that the technique can provide attractive returns on the initial investment (Daubert and Ayer, 1982, and Edwardson *et al*, 1988).

Just as it is not possible to assert that purchasing a certain type of tractor is economic or uneconomic *per se*, it is not possible to make a ready judgement regarding landforming. The rate of return from a landforming investment will depend greatly upon the specific characteristics of the situation to which it is applied, on the quality of the design and implementation of the job and on the extent to which farm management practices change to realise the productivity gains afforded by the improved farm layout.

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[3] Since it is unlikely that any landforming in Australia is now undertaken without laser guidance, landforming will be taken to mean laser landforming for the remainder of this paper.

Advising a farmer whether to landform and on how to prioritise alternative landforming options (either at alternative sites or alternative job specifications for the same site) is greatly complicated not only by lack of research evidence regarding many of the effects of landforming but by the variety of these effects and by the magnitude of each effect varying according to the particular situation in which landforming is applied.

Recognising this, the primary emphasis of this study has been to establish some 'rules of thumb' to assist in assessing the extent to which landforming in a particular situation is likely to be economic for a farmer or not.

The Federal Government encourages landforming by allowing (subject to the facts of each case), under section 75D of the Income Tax Assessment Act, outright deduction of expenditure from taxable income in the year of expenditure. In Taxation Ruling IT 352 it was recognised that landforming measures in an irrigation area are generally undertaken to prevent or combat land degradation in the forms of salinity or drainage problems (Australian Tax Office, 1987). The New South Wales Government, through the Rural Assistance Authority, provides concessional credit under the Special Conservation Scheme to farmers undertaking landforming, subject to an assets test and the proposed works being evaluated as having "a beneficial impact on the land, the community and the environment at large" (NSW Rural Assistance Authority, 1990).

The study can assist in indicating the effect of these government concessions upon the on-farm economics of landforming.

A further question addressed in this study concerns whether it is economic to incur the additional cost of replacing topsoil ('topsoiling') to minimise the adverse effects of topsoil displacement or subsoil exposure during landforming. A number of studies have found topsoiling to be the only means of restoring yields on areas where this has occurred to the levels of undisturbed soil (see for example Pritchard *et al*, 1988).

1.3 Aims of This Study

The primary aim of the study is to evaluate the on-farm economics of landforming in a range of farm situations with a view to developing principles to guide advice to farmers regarding where, how and how much they should landform, and whether they should practice topsoiling.

A further aim is to assess the sensitivity of predicted economic outcomes to changes in a number of key parameters for which research evidence is lacking and/or the variability between paddocks and farms is known to be high. This is intended to guide researchers to obtain the types of information most needed to increase the accuracy of any economic evaluation of landforming and also to guide farm advisers regarding the characteristics of a landforming job they most need to obtain accurate information on in order to be able to provide the best advice possible.

Another aim is to evaluate the effect of government measures reducing the effective cost of undertaking and financing landforming on its economic value to a farmer.

It should be noted that in evaluating the economics of landforming for a farmer, only the benefits or costs for that farmer are considered. The benefits and costs for others resulting from landforming are not considered, nor are output prices, input costs and interest rates corrected where market imperfections or government intervention have resulted in their market values diverging significantly from their value to society. From the perspective of society, therefore, this study represents an economic analysis only at the individual farm level and does not indicate whether particular landforming jobs are in society's interest or not.

1.4 Focus of Study

To maximise the applicability of the analysis to a range of farmers in differing situations the approach of modelling a representative farm, for which various parameters could be adjusted, was utilised.

Nevertheless the range of situations in which landforming is applied (for instance, relating to crops grown, soil types, quality of existing layout and farmers' tax situations) and the range of choices a farmer has in planning a landforming job (for instance, relating to type of layout and target slope) has necessitated narrowing the range of farm situations and planning options to make analysis tractable and the findings not so general that they have limited applicability to real situations.

Selection of a particular location was required because of considerable geographical variation in factors likely to influence the economics of landforming such as climate, soil type, topography and land-use patterns. Moreover, institutional arrangements, such as relating to land tenure, water pricing and water allocation, also differ between irrigation schemes.

The location chosen for this study was the Murrumbidgee Irrigation Area (M.I.A.). The size of the representative farm was specified as 200 hectares with a corresponding irrigation water entitlement of 1360 megalitres per annum. The actual irrigation water availability on average was set at 110 percent of this volume, or 1496 megalitres, since in 70 years in every 100 a greater than 100 per cent allocation can be expected (Irrigation Farm Working Group, 1986).

The full area of the representative farm is assumed to be engaged in rotations of rice, wheat and annual pasture, the typical pattern of land-use for M.I.A. broadacre farms. None of the area of the farm is currently landformed. Flood irrigation is applied under the contour bay system which is necessary for ponded rice culture[4].

The representative farmer is assumed to consider landforming a means of improving the profitability of rice, wheat and annual pasture rotations rather than as an opportunity to diversify into other activities such as perennial pasture, alternative summer crops or vegetables.

Although increased potential for diversification *is* a major benefit of landforming, lack of alternative summer activities to rice offering comparable gross margins and unfamiliarity with management of alternative activities has meant to date that many farmers landform while retaining the contour bay layout.

The assumption that a contour bay layout is retained after landforming serves also to reduce the importance of one aspect of the complexity of the farmer decision-making process, that being the extent to which the slope of the land should be modified to optimise efficiency in the application and surface drainage of irrigation water. Inclusion of rice within rotations means that in general the relatively flat gradients within non-landformed contour bays remain financially appropriate. This is because rice, which thrives under waterlogged conditions and which usually provides a high proportion of the total gross margin for a rotation in which it is included, does not gain from the waterlogging reduction benefits of improved surface drainage via increasing bay slope. For rotations not including rice, however, these benefits are likely to be financially more significant. Hence the question of slope modification by landforming is more important in such cases.

As soil type significantly effects the impact of landforming on soil structure and fertility and consequently on plant growth, it is necessary to specify the soil type for each landforming job. The soils on the representative farm are assumed to be duplex (a sharp differentiation in the soil profile between topsoil and subsoil), with relatively shallow topsoil (less than 10 centimetres), and with a heavy clay subsoil.

Poor structure and fertility of the subsoil means that topsoil removal from a part of the area landformed is likely to significantly diminish plant growth in the affected area unless remedial action is taken (Pritchard and Mason, 1982). By assuming homogeneity of soil type across the representative farm, a further aspect of complexity in the landforming decision process is removed, that of prioritising landforming jobs associated with different soil types. Most M.I.A. rice farms do in fact comprise a variety of soil

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[4] This is essentially a system of terraced irrigation bays within a paddock, the banks of the bays following the prevailing contours. The area within a bay slopes only slightly toward the bank, enabling relatively even depth of ponding across the bay. The border check system, in which the banks of each irrigation bay run perpendicular to prevailing contours and irrigation is applied by flushing bays from the top rather than by ponding, is generally superior for pastures, cereals and crops other than rice. These activities, unlike rice, generally benefit from the shorter period of transient waterlogging following irrigation resulting from using the border check system.

types.

The potential benefit of improved surface drainage from landforming will be fully realised only if the increased volume of drainage water (due to lower losses from evaporation and deep percolation[5]) can be drained from the farm rather than pond in low-lying sections of the farm. It is assumed that the representative farm has access to a district drainage system and that its on-farm drainage system is adequate. Hence the full surface drainage benefits of landforming should be realised. Note that this may not be the case in Irrigation Districts in which many farms do not have the potential for adequate off-farm drainage.

A question not addressed in this study is the effect of watertable depth and soil salinity levels on the on-farm economics of landforming. It is assumed that the depth of the watertable underlying the representative farm, and soil salinity levels, can be maintained during the planning horizon at levels which would not reduce the benefits of landforming.

The study as designed can indicate the area of the representative farm it is in a farmer's economic interest to eventually landform. The study does not address the question of the optimal staging of that development over time. This question may be an important one for farmers with limited access to capital to finance the works or where the process of landforming is likely to cause disruption to farm programs and consequent cash flow problems. The latter consideration is likely to be more significant the more rapidly landforming of a farm proceeds.

The foregoing assumptions allow simplification of the decision regarding landforming development to a question of how much, if any, of the representative farm it is economic to landform.

1.5 Study Design

Consideration of only the benefits and costs occurring within the area landformed will result in inaccurate evaluation of the landforming job. This is because among the resources utilised more efficiently on landformed layouts are those with a fixed supply except in the long term. Depending on the time of year and the farm activity mix, the opportunity costs of these resources, including land, permanent labour and allocated irrigation water, may be considerably greater than the prices paid for them. Without whole farm analysis, the prices paid for these resources are the most commonly used proxy for their opportunity costs. This is most clearly deficient in the case of unpaid family labour.

Only from a whole farm perspective can the actual benefits of increased efficiency in

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[5] Deep percolation represents infiltration of water through a soil profile to below the crop or pasture rootzone.

the use of these resources be seen in terms of enabling a change to a mix of farm activities more profitable in aggregate than previously possible.

Of the studies undertaken to date of the on-farm economics of landforming, Tainsh (1985) has approached nearest to a whole farm analysis. Although a whole farm perspective was adopted and the effect of landforming on whole farm irrigation water use taken into account, increased labour efficiency following landforming was not considered. Moreover the specific form of a rotation of rice, wheat and annual pasture chosen to apply before landforming was implicitly assumed to remain the most profitable following landforming.

For this study a linear programming model of a M.I.A. broadacre farm (Jones, 1991) was adapted to allow systematic analysis of the whole farm effects of landforming. The areas of the representive farm landformed and non-landformed were specified separately as constraints, and crop and pasture activities were also differentiated with regard to whether or not they were associated with landformed layouts. This model is described in more detail in Section 4.2.

The effect of landforming various proportions of the representative farm was examined, in 40 hectare increments from nil area landformed up to the full 200 hectares of the farm. The approach allowed examination of variation in the economic value of landforming jobs according to the area of the farm already committed to be landformed. Limitation of the availability of irrigation water through the volumetric allocation system was in particular thought likely to contribute to diminishing returns once the area of the farm landformed reaches a certain level. This is because it is generally profitable to irrigate a paddock more intensively after landforming. Hence, if water supply is fixed, landforming is likely to increase the degree to which water becomes a limiting resource.

A linear programming solution was determined for the representative farm at each stage of landforming development, including the stage of nil area being landformed. For the evaluation of any particular increment of landforming development, the activity levels shown in the linear programming solutions associated with that increment being undertaken and not being undertaken were inserted into a spreadsheet model. This model was designed to predict post-tax cash flows eventuating under both scenarios over the planning horizon of the investment.

The difference in cash flow in each year attributable to that increment of landforming development was also calculated in the spreadsheet model and the series of annual differences subjected to discounted cash flow analysis to determine the economic value to the farmer of undertaking that increment. The economic value of topsoiling on areas from which topsoil was substantially displaced during the landforming process was similarly calculated.

Note that the models used are deterministic. Where a parameter is likely to vary during the planning horizon, the value of the parameter used in the model is defined as the average of the expected values of the parameter.

1.5 Outline of Paper

The remainder of the paper is organised as follows. In Section 2 the benefits of landforming are briefly described and the method of incorporating them in the analysis is outlined. In Section 3 the costs and problems associated with landforming are briefly described and the method of incorporating them in the analysis outlined. In Section 4 the specification of the linear programming and spreadsheet models and the assumptions underlying the on-farm economic analysis are discussed. In Section 5 the results of analysis using the base set of assumptions are presented. The sensitivity of results to a range of alternative assumptions are reported in Section 6. The findings of Sections of 5 and 6 are discussed more fully in Section 7 and conclusions are drawn.

2. ACCOUNTING FOR THE BENEFITS OF LANDFORMING

The benefits of landforming for rice farming can be categorised as follows:

(a) Increased crop yields and pasture production;
(b) Cost savings from better shapes and sizes of irrigation bays;
(c) Reduced labour requirements for supervision of individual irrigations;
(d) Increased efficiency of irrigation water use; and
(e) Reduced problems associated with field operations after wet periods.

The procedures by which these benefits were accounted for in the analysis are detailed below.

2.1 Increased Crop Yields and Pasture Production

Landforming contributes to improved crop yields and pasture by:

(a) Increasing the evenness of water application across an irrigation bay, thereby improving seedling establishment and uniformity of plant growth and maturity;

(b) Increasing uniformity of ponding depth for rice, thereby improving weed control and providing better protection against cold stress at the time of panicle initiation;

(c) Reducing the time taken to irrigate and drain an irrigation bay, thereby reducing problems of transient waterlogging and scalding and enabling scheduling of irrigations more closely to plant needs;

(d) Increasing the productive area of a paddock by reducing area lost to banks and water supply channels;

(e) Increasing the productive area of a paddock by allowing the full area to be commanded by gravity for irrigation (there may have been problems with high spots of a paddock); and

(f) Overcoming surface drainage problems in low-lying areas of irrigation bays which can result in prolonged ponding, particularly during abnormally wet years, and severely hamper plant growth in those areas.

The yield and pasture production estimates shown in Table A1 for layouts landformed and non-landformed incorporate considerations (a), (b), (c) and (d). These yield estimates were provided by Departmental advisory agronomists and presume normal seasonal conditions and reasonable management. They can be considered achievable yield levels for a reasonable manager, and do not account for problems such as ponding, or deterioration of soil structure and fertility following landforming.

Note that the post-landforming yields shown in Table A1 assumed that management of irrigation, crops and pastures is adapted following landforming to capitalise on the benefits of the new layout. This may necessitate increased allocation of management time, irrigation water and other inputs such as fertilisers to areas once they are landformed; hence, there are likely to be costs involved in achieving increased yields other than the initial outlay on landforming.

The representative farm was assumed to be fully gravity-commanded for irrigation. Hence consideration (e) was not relevant for this analysis.

Consideration (f) was incorporated into the analysis as follows. The proportion of a non-landformed paddock assumed prone to prolonged ponding in abnormally wet seasons was 5 percent. The expected frequency of an abnormally wet season was assumed to be one year in three. The yield levels for pond-prone areas in abnormally wet years were as provided by Departmental advisory officers. These yield levels are expressed in Table A2 as proportions of the respective non-landformed achievable yield levels shown in Table A1. Of course yield levels for rice are unaffected as it is normally grown in ponded conditions.

2.2 Cost Savings from Better Shapes and Sizes of Irrigation Bays

Contour bays by their nature are bounded by banks following the contours of a paddock. Although there is likely to have been some modification to the natural contours of a paddock in the absence of laser landforming (for instance non-laser landforming may have been undertaken previously) the contour banks are most unlikely to follow lines or smooth curves or to run roughly parallel to each other, both of which provide for efficiency of field operations by machinery (hereafter referred to as field efficiency[6]). Landforming can modify contours so that these deficiencies are at least minimised.

Irregularity in the rate of altitude fall across a paddock causes contour banks to be irregularly spaced. This is because they are generally placed so that the altitude fall from the base of one bank to the next is reasonably constant. This causes considerable variation in the areas of irrigation bays within paddocks which, particularly in the case of overly small bays, again reduces field efficiency. Landforming is able to modify the rate of altitude fall across a paddock in order to minimise this problem.

These two deficiencies of non-landformed layouts reduce field efficiency by increasing the extent of overlapping passes during a single operation and the need for sharp cornering.

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[6] In this study field efficiency is defined as the relative efficiency of a paddock layout in terms of the productivity of field machinery operations. It relates here to hectares treated per hour of machinery use.

Landforming can therefore appreciably reduce the variable costs of an activity. Reductions in overlapping and in sharp cornering generate savings in repairs, maintenance, and fuel for tractors, headers and implements. Reduced overlapping leads also to savings in seed and fertiliser utilisation (except where these are applied aerially).

Utilisation of pesticides and herbicides was assumed to be unaffected by increased field efficiency of a layout, on the basis that farmers normally are careful to avoid overlapping applications of these chemicals.

Provision for the effect upon variable costs of increases in field efficiency from landforming was as follows. Work rates (hours per hectare) of tractors with implements and for headers were estimated for a landformed contour bay layout of 'good' field efficiency[7]. It was assumed that landforming of any area would create a layout with this level of field efficiency. Application rates (kilograms per hectare) for seed and fertiliser for a landformed layout of 'good' field efficiency were similarly estimated[8].

The increase in field efficiency from landforming depends then on the field efficiency of the layout prior to landforming. A number of representative cases were examined in this study, each differing in the field efficiency increases attained after landforming. The field machinery work rates (for jobs other than harvesting) and seed and fertiliser application rates for the layout prior to landforming were calculated by assuming they would exceed respective rates for the landformed layout by the same proportion that the field efficiency of the prior layout is increased by landforming. For harvesting the same procedure was followed, but with an adjustment recognising the lower crop yields on the prior layout.

This procedure for calculating field machinery work rates and seed and fertiliser application rates could then be incorporated in calculating the variable costs of a crop or pasture on a layout with any level of field efficiency prior to landforming.

Labour requirements for cultivation and harvesting were not considered in calculating variable costs at varying field efficiency levels, since where family labour is used its opportunity cost cannot be determined in isolation of the whole farm situation.

The cultivation and harvest labour requirements of rotation activities for non-landformed layouts were instead incorporated in labour input coefficients within the

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[7] Note that work rates differ according to job (eg. sowing, scarifying, harvesting etc), while field efficiency as defined here is a generalised average measure for all jobs. It is assumed, however, that work rate savings from landforming for all jobs are inversely proportional to field efficiency increases if the workload remains constant (i.e. a 25 percent increase in field efficiency causes a 20 percent reduction in work rates). If the workload changes (eg. after landforming the size of the crop to be harvested increases) the work rate is adjusted accordingly.

[8] Application rate saving rates were also assumed to be inversely proportional to rates of field efficiency increase.

linear programming model and reflected the field efficiency level of the non-landformed layout being considered. The cultivation and harvest labour requirements per hectare for a particular rotation undertaken on a particular layout were calculated as the sum of total tractor time per hectare, factored upward on the assumption that tractor running time averages 80 per cent of the time taken for an operation (other time is taken in preparation, minor repairs, rests, etc), and of total header running time per hectare, factored upward on the assumption that header running time averages 70 per cent of the time taken to harvest.

The benefits from landforming of reduced cultivation and harvest labour requirements per hectare of rotation activities are thereby reflected in the linear programming solution by reduced costs associated with paid casual labour at seasonal peaks of activity when the permanent labour supply is most likely to be constraining and by a shift to a more profitable activity mix.

A further benefit of increased field efficiency and consequent reduced field machinery running time after landforming accrues in relation to field machinery disposal value. By reducing the running time of field machinery below that which would otherwise occur given a certain farm activity mix, the disposal value of items at a given age is likely to be increased. Note, however, that after landforming the farm activity mix is likely to change. It is possible that a rotation more intensive in field machinery utilisation may be selected. In that case total running time of field machinery may be higher than previously despite increased field efficiency.

The total running times of tractors and of headers, with and without a particular increment of landforming, were calculated within the spreadsheet model for each year during the planning horizon. It was assumed that the farm tractor and header were purchased in the year of landforming and were traded-in and replaced at five year intervals during the planning horizon (and that they would have been purchased and traded-in and replaced at these times regardless of whether landforming was undertaken). The net effect of a landforming increment on trade-in values in those years for those items was calculated and incorporated into the discounted cash flow analysis.

2.3 Reduced Labour Requirements for Supervision of Individual Irrigations

The time taken in supervising individual irrigations is likely to be reduced after landforming for reasons including the following:

(a) Greater regularity of irrigation bay shape is likely to increase ease of access to and inspection of the full area of a bay;

(b) The time necessary to irrigate a paddock is reduced due to faster surface drainage from each bay; and

(c) The removal of high spots within bays means that lower volumes of water need to be run into bays to achieve a depth that covers these spots.

Improvement to the on-farm water supply network concurrently with landforming, with the aim of increasing the potential flow rate to bays, may offset the above effects to some extent. This is because the volume of water oversupplied to a paddock due to a given lateness of shutting-off of inflow will then be higher, thus perhaps warranting more intensive supervision.

The irrigation labour requirement per hectare of rotation activities for landformed and non-landformed layouts were also incorporated into the labour input coefficients of the linear programming model. Note that, unlike for cultivation and harvest labour, irrigation labour requirements for rotations on non-landformed layouts were assumed not to vary according to the prior layout.

Time savings [illegible] irrigation supervision can have 'social' benefits as well as farm productivity benefits, particularly when the need for supervision is reduced during times normally favoured for leisure (or sleep in the case of overnight irrigation). These social benefits have not been considered in this analysis.

2.4 Increased Efficiency of Irrigation Water Use

Irrigation water is used more efficiently after landforming as a result of its faster application to and drainage from irrigation bays, and due to elimination of pond-prone areas, each of which reduces losses of irrigation water as evaporation and deep percolation. In addition the levelling of high spots reduces the volume of water needed to cover an entire irrigation bay and thereby reduces the likelihood of excess water leaving the farm as drainage. Annual irrigation water use per hectare for rotation activities on landformed and non-landformed layouts were incorporated as input coefficients in the linear programming model. As for irrigation labour, note that irrigation water requirements for rotations on non-landformed layouts were assumed not to vary according to the condition of the layout.

The estimates of rates of irrigation water use reflected the assumption that irrigation efficiency (expressed in terms of the proportion of applied water utilised by plants) would increase by 25 per cent after landforming. However, annual irrigation water use may increase after landforming despite increased irrigation efficiency since the frequency of irrigations is likely to increase due to reduced problems with transient waterlogging and scalding following irrigations (except in the case of rice where bays remain ponded for most of the growing season).

2.5 Reduced Problems Associated with Field Operations After Wet Periods

Rainfall shortly before field operations for which timeliness is critical often causes problems for farmers. Farmers' strategies in response to this risk vary. They can try to undertake the operation earlier than is optimal, reducing the chance of rainfall interfering. Otherwise, if it rains, they can delay the operation until the paddock is dry enough. In either case yield or quality losses may eventuate due to reduced timeliness.

Alternatively farmers may undertake a field operation despite excessive wetness of a paddock, perhaps utilising ameliorative measures such as putting tracks on the tractor wheels. This strategy also has costs: soil structure may deteriorate from being worked or traversed while too wet; there may be increased likelihood of machinery breakdown in the heavy conditions; there may be a need for additional cultivation prior to the following crop or pasture to overcome wheel rutting; or the cost of purchasing tracks or paying a contractor who has them.

Another option is to proceed as soon as possible on areas of a paddock which dry out fastest, leaving the remaining areas out of production. Finally, farmers may decide not to proceed at all, leaving a paddock fallow, for example, instead of sowing to wheat; the paddock may later be sown instead to rice. Each of the latter two options also involves foregone income. By increasing the rate of drainage from a paddock and removing low-lying areas prone to ponding, landforming can reduce these problems.

The major problems of timeliness of field operations for rice farmers are associated with harvesting of rice and sowing of wheat. Significant problems with sowing of rice also occur, although the expected release of short season (i.e. early maturing) rice varieties in coming seasons is likely to greatly reduce this problem (Clampett, pers. comm.). However, only anecdotal evidence exists for the benefits of landforming in reducing these problems. A description of the approach taken in accounting for these benefits follows.

Following discussions with district advisory agronomists, rice harvests were assumed on average to be significantly disrupted by rain in one of every five harvests. For non-landformed layouts it was assumed that it would take twice as long as normal to harvest in these rain-disrupted years and that preparation for the following crop would require the equivalent of an additional two passes of a disc plough and one pass of a landplane over the entire paddock. A landformed layout was assumed to take 1.25 times as long as normal to harvest in rain-disrupted years, and preparation for the following crop to require the equivalent of an additional pass of a disc plough over the entire paddock and one pass of a landplane over half the paddock. All these costs were attributed to the harvest.

The weighted average annual harvest costs for rice on landformed and non-landformed layouts were calculated and incorporated in the variable costs of rice activities.

Wheat sowing on non-landformed layouts was assumed on average to be affected by rain one year in every five. In rain-affected years it was assumed that 20 percent of a non-landformed area cannot be sown due to continuing saturation of low-lying areas and their peripheries as well as lack of access to other parts of the paddock. With 'normal' yield (i.e. the yield shown in Table A1 adjusted for yield losses from ponding) assumed achieved on the 80 percent of the area able to be sown, the average yield for the full area in a rain-affected year is 80 percent of 'normal'. When averaged with the remaining four wheat sowings in five which are unaffected by rain, the result is an average annual wheat yield on non-landformed layouts of 96 percent of 'normal'.

Absence of low-lying areas in landformed paddocks was assumed to preclude problems with sowing of wheat after rain. Hence the yields of wheat used for landformed layouts were unchanged from the 'normal' levels.

3. ACCOUNTING FOR THE COSTS ASSOCIATED WITH LANDFORMING

The costs associated with landforming can be categorised as follows:

(a) Costs of the landforming job;
(b) Increased input levels following landforming;
(c) Temporarily low crop yields and pasture production following landforming, and costs of remedial measures;
(d) Foregone income due to disruption of farm program;
(e) Costs of building-up livestock numbers to take advantage of increased pasture production;
(f) Costs of periodic repolishing of the paddock; and
(g) Replacement or renovation of farm structures.

3.1 The Costs of the Landforming Job

The costs of the landforming job include those preparatory to the main earthmoving operation. These costs include those of surveying the paddock, levelling banks, ploughing and laying out grids. These costs were estimated to total $65 per hectare and were assumed to remain constant in real terms during the planning horizon.

Landforming itself was assumed to be undertaken by an experienced contractor. Earthmoving costs of landforming were distinguished for three jobs differing in volumes of earth required to be moved to attain 'plane of best fit'. For a job requiring 200 m^3/ha of earth to be moved, the assumed contract rate was $260/ha. For jobs requiring 350 m^3/ha and 500 m^3/ha of earth to be moved, the assumed contract rates were $420/ha and $600/ha respectively. These rates are based on contract rates current during 1990.

3.2 Increased Input Levels Following Landforming

As noted in Section 2.1, attainment of achievable yield increases following landforming can necessitate increased application of certain inputs. Changes in input levels after landforming, particularly of fertilisers and irrigation water, were accounted for in calculation of variable costs of crop and pasture activities undertaken on landformed layouts.

The effect of increased frequency of irrigations after landforming on labour utilisation was accounted for in labour utilisation coefficients within the linear programming model.

3.3 Temporarily Low Crop Yields and Pasture Production Following Landforming, and Costs of Remedial Measures

3.3.1 Crop and pasture management problems following landforming

Management problems with crops and pastures may arise in the first few years following landforming due to unfamiliarity with enduring characteristics of the new layout (such as with volumes of irrigation water required and the time necessary to irrigate and drain) and difficulties with temporary features of the new layout.

The latter source of management problems is likely to be largely related to greater than usual unevenness of soil fertility and moisture availability across a paddock. This is attributable to substantial redistribution of topsoil and subsoil during landforming. These problems are difficult to rectify by fertiliser and irrigation management. Consequently for some years following landforming, crop or pasture growth and maturity is likely to be uneven across the area landformed.

Yield and quality losses may occur due to grain in sections of a paddock being under or over-mature when most of the paddock is ready for harvest, or due to 'blown' crops where fertility of sections of a paddock has been raised by addition of topsoil (ie. 'fill areas').

The extent of these management problems is likely to be positively related to the volume of earth moved during landforming operations.

3.3.2 Effect of heavy machinery operations on soil structure

Landforming requires many passes of heavy machinery over the one area to attain the desired accuracy. This causes damage to soil structure (Mount, 1985). The extent of damage to soil structure from this cause will be related to frequency of heavy machinery traffic across the area being landformed which will be largely dependent upon the volume of earth to be moved.

3.3.3 Accounting for the joint effects of the problems described in Sections 3.3.1 and 3.3.2

The effects upon yields of heavy machinery operations damaging soil structure and of crops and pasture management problems following landforming were jointly accounted for in the analysis as follows.

In Section 3.1 three landforming jobs involving different volumes of earth displacement were specified. The crop yield and pasture production levels in the first year following landforming were assumed to be negatively related to the volume of earth moved during the job. The first year levels shown in Table A3 are defined as proportions of the achievable levels for a landformed layout.

Crop yields and pasture production levels were assumed to increase linearly from this base to 100 percent of potential levels in the third year following landforming.

Note that these yield response assumptions do not apply for 'heavy cut' (defined in Section 3.3.4) portions of the area landformed.

3.3.4 Effect of topsoil removal and subsoil exposure

Scientific studies and reports from farmers who have landformed indicate that crop yields and pasture production can be considerably reduced in areas from which topsoil has been displaced during landforming. This is because much of soil fertility is concentrated in the topsoil and because poor subsoil structure impedes plant growth and seedling establishment. The effect of exposed subsoils on plant growth appears to be due to the inability of high clay content subsoils to readily supply water to plants (Kelly, Blaikie, Mason and Martin, 1989). Particularly vulnerable to these problems are duplex soils with shallow topsoil which are assumed to occur across the representative farm (Pritchard *et al*, 1988).

Yields of crops grown on exposed subsoil of this soil type in south-eastern Australia have been shown to be 50 percent or less than those from undisturbed soil, even a number of seasons after the initial exposure (Pritchard and Mason, 1982) and Hume (pers. comm.).

Replacement of 75 mm of topsoil on such areas has been shown to restore dry matter production of irrigated maize to the level of an undisturbed soil, while amelioration of exposed subsoil with ploughing, gypsum and fertilisers was found to restore production to only 71 percent of that of an undisturbed soil (Pritchard, 1988). Similar responses were found for irrigated perennial pasture (Kelly, 1989).

Soil nutrition deficiencies in exposed subsoil ('heavy cut') areas have been found also to lower rice yields. Application of 400 kg/ha single superphosphate plus trace elements was found to increase rice grain yields on such areas by over 60 percent (Heenan, 1982). Soil structure in heavy cut areas of rice farms may recover more quickly and thoroughly than elsewhere because, by growing (and establishing, if aerially sown) under ponded conditions, soil structure problems are partly circumvented for rice; moreover the successful growth of rice (if adequate nutrition is supplied) contributes a substantial mass of organic matter to the soil which may enable yields for rice and other crops and pastures to recover completely to the levels on undisturbed soils after a number of seasons (Lewin, pers. comm.).

The effects of heavy cut on yields following landforming were accounted for as follows. Heavy cut areas were defined as those from which greater than 80 mm depth of topsoil is removed during landforming. With single superphosphate and urea applied to heavy cut areas at the rate of 200 kg/ha and 326 kg/ha respectively to reduce problems of soil fertility and structure, crop yields and pasture production in the first year following landforming were assumed to be only 40 percent of achievable levels for landformed layouts. Thereafter these levels were assumed to increase linearly until 100 percent of achievable levels are attained in the seventh year following landforming.

With topsoil instead replaced on heavy cut areas to a depth of 80 mm, crop yields and pasture production in these areas were assumed to follow the same pattern as described in Section 3.3.3 for areas not heavy cut.

The cost used in this analysis for undertaking topsoiling in this manner was $1000 per hectare of land requiring topsoiling. This includes the cost of removing an extra 80 mm of soil depth from heavy cut areas to provide room for the topsoil.

3.4 Foregone Income Due to Disruption of Farm Program

The time necessary to complete a landforming job can mean that crops or pasture that would otherwise generate income from that land cannot be grown. Normally, however, a farmer would be expected to schedule landforming to minimise the extent of foregone income; for instance, while a paddock is in the fallow phase of a rotation or during late summer and early autumn when annual pasture is contributing minimal feed for livestock.

In this study the representative farmer is assumed to schedule landforming developments to avoid significantly foregoing income.

3.5 Cost of Building-Up Livestock Numbers to Take Advantage of Increased Pasture Production

Unless the completion of an increment of landforming leads to a change in the farm plan so that reduced areas are planted to annual pasture than is the case without that increment undertaken, the pasture productivity-increasing effect of landforming will ultimately increase the livestock carrying capacity of the farm. To take advantage of this, however, involves increased investment by a farmer in livestock, whether the increase in livestock numbers is attained through breeding or by purchasing-in.

Livestock numbers with an increment of landforming undertaken were assumed to increase following landforming pro rata to the annual increase in total farm pasture production after landforming. With pasture production per hectare following landforming increasing gradually to achievable levels for the reasons described in Section 3.3, the achievable livestock carrying capacity of the farm (the level given in the linear programming solution) cannot be realised immediately. The annual cost of livestock purchases to build-up numbers was accordingly incorporated in the analysis.

Note that low levels of pasture production immediately following landforming (due to soil structure/fertility problems) may mean that the livestock carrying capacity of a farm is in fact *reduced* initially, particularly if a substantial proportion of the farm is landformed in rapid succession and if topsoiling is not undertaken. For ease of analysis the representative farmer was assumed in such a case to reduce livestock numbers to the new carrying capacity by selling livestock at the time of landforming. The income from this sale was included in the analysis.

3.6 Cost of Periodic 'Repolishing' of the Landformed Area

Maintenance ('repolishing') of a landformed area is required periodically to retain the accuracy of levelness and slope of the original job. If repolishing is undertaken frequently enough the benefits of the landformed layout should continue indefinitely.

The cost of repolishing used in the analysis was $60 per hectare. This cost was assumed to remain constant in real terms during the planning horizon. The cost was assumed to be first incurred in the third year following landforming and thereafter every 5 years during the planning horizon.

3.7 Replacement or Renovation of Farm Structures

In some cases replacement or renovation of farm structures may be required in order to attain the levels of benefits assumed in this study. For example, water supply channels and drains may need to be improved, new fence lines erected or new farm roads constructed.

Despite advice to farmers that they landform as part of a planned whole farm redevelopment, many farmers continue to landform within the existing paddock layout of their farms.

The levels of benefits from landformed used in this study are assumed to be consistent with landforming within existing paddocks. Hence refencing is not required. Existing farm water supply channels and drains and access to paddocks are assumed to be adequate for those levels of benefits to be achieved. The base assumption therefore is that farm structure costs associated with landforming are zero. Sensitivity analysis was undertaken to ascertain the effect of increased total landforming costs (due possibly to costs of replacing or renovating farm structures) on the on-farm economics of landforming.

4. MODEL SPECIFICATION AND ASSUMPTIONS

4.1 Decision Rule for Evaluating Landforming

The technique of benefit-cost analysis was used in this study to evaluate private investment decisions of a farmer regarding whether or not to undertake particular landforming jobs.

Discounted cash flow procedures were applied for this purpose due to the extended duration of benefits from landforming and the need to reflect the 'time value of money' whereby a given sum of money has greater value if earned or spent sooner rather than later (Bernard and Nix, 1981). Under these procedures the stream of annual benefits and costs of landforming over the relevant planning horizon are reduced to a single value called the net present value (NPV) of the investment.

According to the decision rule of benefit-cost analysis, an investment should be undertaken if its NPV exceeds zero. Given a choice of investments and a capital constraint, investments should be undertaken in descending order of their benefit-cost ratios (i.e. present value of benefits divided by present value of costs) until the capital budget is exhausted (Dasgupta and Pearce, 1978).

4.2 Linear Programming Model of a Representative M.I.A. Rice Farm

In the linear programming model of the representative farm, land is differentiated on the basis of whether it is landformed or still non-laser landformed. The full area of the farm is assumed to be laid out for irrigation. Land not irrigated can be used for dryland (unirrigated) pasture. For environmental reasons the area planted to rice is currently restricted to 71 hectares per farm by the Department of Water Resources in conjunction with the Rice Industry Co-ordination Committee.

Other constraints apply regarding restrictions on some crops, annual water allocation, monthly channel supply capacities and labour. Following Ryan (1969), the representative farm's permanent labour supply (ie. 'operator's labour') is assumed to consist of the owner-operator and one permanent employee. The supply and utilisation of operator's labour is specified on a monthly basis. Further labour can be obtained via a hire casual labour activity if required. In addition to the above restrictions, constraints also apply to crop selling pools, pasture supply pools and crop-pasture rotation ties.

Crop activities are specified in rotational form. This approach has been adopted because of its simplicity and flexibility. In the MIA not only is there a wide range of agricultural activities that can be produced, but there are a wide range of rotational choices which involve the same crops. For instance, typical rice-wheat-pasture rotations can have up to three years rice, which may be followed by up to two years of wheat, and/or up to four years of irrigated winter pasture.

Separate rotations have been specified for landformed and non-landformed areas. The rotations are the same but the yields and other technical coefficients differ. Irrigated pasture follows a cropping sequence via the pasture-rotation tie constraints. This means that a crop rotation will be followed by either 2, 3 or 4 years irrigated annual pasture phase. There is also a facility for dryland annual pasture to be grown on non-irrigated areas. Pasture is supplied on a seasonal basis in units of livestock months (LSMs), with unused production in spring being able to be transferred to summer with 30 percent efficiency. Hay can be made from irrigated annual pasture in spring and fed out in either summer or autumn. Livestock demands are represented by a number of sheep activities which include merino self- replacing, prime lamb production (both first and second cross) and wethers. These draw their feed requirements (LSMs) from a seasonal feed pool. However, only merino self-replacing and wethers can utilise dryland pasture. Crop selling activities apply to rice and wheat. Irrigation water is obtained by a water purchase activity.

The objective function of the linear programming model is maximisation of total farm gross margin.

The constraints are specified in the model as follows:

(i) *Land constraints*

$$\sum_{j=1}^{n} x_{ij} \leq L_i$$

where x is the level of the j^{th} activity for the i^{th} constraint, and L is the maximum land available relating to the i^{th} constraint. Land constraints apply to non-landformed contour bay, landformed contour bay, dryland and rice areas.

(ii) *Water constraints*

Annual allocation and water use:

$$\sum_{j=1}^{n} x_{ij} \leq A_i$$

Monthly channel capacities:

$$\sum_{j=1}^{n} x_{ij} \leq MC_i$$

where A is the total annual water allocation, and MC is the i^{th} month channel constraint.

(iii) *Crop and pasture pools*

Crop:

$$CS_{ij} \leq \sum_{j=1}^{n} r_{ij}$$

where CS is the crop selling activity for the i^{th} crop pool, and r is the j^{th} rotation activity which contributes crop yields to the selling pool.

Pasture:

$$\sum_{j=1}^{r} d_{ij} \leq \sum_{j=1}^{n} z_{ij}$$

where d is the seasonal pasture requirement of the j^{th} livestock activity, and z is the seasonal supply of pasture from the j^{th} pasture activity.

(iv) Pasture/rotation tie constraints

$$pr_{ij}=ps_{ij}$$

where pr is the pasture phase requirement of the j^{th} rotation and ps is the supply of pasture to the tie from the j^{th} pasture phase.

(v) *Labour pool*

$$\sum_{j=1}^{n} a_{ij} \leq q_{i} + v_{i}$$

where a is the monthly labour requirement by the j^{th} activity, q is the supply of operator's labour (hours) and v is the supply of hired casual labour (hours).

(vi) *Operator's labour*

$$q_{i} \leq OL_{i}$$

where OL represents total operator's labour.

4.3 Calculation of Net Present Value of an Increment of Landforming

The net present value to a farmer of undertaking an increment of landforming was calculated using the following equation:

$$NPVL_{kslmc} = \sum_{t=0}^{h} \frac{1}{(1+R_m)^t} \cdot [(1-T_m)[(GVP_{tksl} - GVP_{t(k-1)sl}) - (TVC_{tksl} - TVC_{t(k-1)sl}) - LC_{sl} - M_t + E_{tslc}] + TI_{tksl} - F_{tksl}] \tag{1}$$

where

k = the increment of landforming being evaluated; k = 1, ..., 5 and relates to the five possible 40 hectare increments of landforming on a 200 hectare farm. For example, k = 4 refers to the fourth increment which would increase the area landformed from 120 hectares to 160 hectares;

s = the soil amelioration practice implemented during or following landforming; s = 1 if topsoiling is undertaken and s = 2 if only fertilisers are applied;

l = the category of layout on the farm prior to landforming;
l = 1 low cost layout to landform to plane of best fit;
l = 2 medium cost layout to landform to plant of best fit;
l = 3 high cost layout to landform to plane of best fit.

m = the marginal income tax rate category of the farmer;
m = 1 marginal tax rate = 0.00
m = 2 marginal tax rate = 0.10
m = 3 marginal tax rate = 0.15
m = 4 marginal tax rate = 0.20
m = 5 marginal tax rate = 0.25

c = farmer credit category; c = 1 if farmer is eligible for concessional credit and c = 2 if the farmer is ineligible;

t = the number of years following landforming; t = 0, ... h;

h = the length of the planning horizon following landforming;

$NPVL_{kslmc}$ = the net present value of the k^{th} increment of landforming, with soil amelioration practice s applied, prior layout category l, marginal tax rate category m, farmer credit category c;

R_m = the real post-tax discount rate relating to marginal income tax rate category m.

T_m = a farmer's marginal income tax rate if in category m;

GVP_{tksl} = gross value of farm production in the t^th^ year following landforming, with the k^th^ increment undertaken, soil amelioration practice s applied, prior layout category l. (Note that $GVP_{t(k-1)sl}$ refers to this measure for the (k-1)^th^ increment undertaken;

TVC_{tksl} = total variable costs for the farm in the t^th^ year following landforming, with the k^th^ increment undertaken, soil amelioration practice s applied, prior layout category l;

LC_{sl} = the cost of undertaking a 40 hectare increment of landforming with soil amelioration practice s applied, prior layout category l;

M_t = the cost of periodic repolishing in the t^th^ year following landforming;

E_{tslc} = subsidy equivalent of concessional credit provided to finance landforming, in the t^th^ year following landforming for farmer credit category c;

TI_{tksl} = increase in field machinery trade-in value in the t^th^ year following landforming, with the k^th^ increment undertaken, soil amelioration practice s applied, prior layout category l;

F_{tksl} = the cost of (revenue from) increasing (reducing) flock or herd size in the t^th^ year following landforming, with the k^th^ increment of landforming undertaken, soil amelioration practice s applied, prior layout category l;

The rationale underlying specification of equation (1) has largely been covered in Sections 2 and 3. Further details relating to interpretation of equation (1) follow.

4.3.1 Prior layout categories

The positive correlation of landforming cost with the volume of earth moved during landforming was discussed in Section 3.1. As a general rule, the increase in field efficiency of a layout after landforming and the proportion of an area heavy cut during landforming are both also positively correlated with the volume of earth that must be moved to achieve a *given* standard of landformed layout (Darnley-Naylor, pers. comm.). The former correlation may be explained by considering that the volume of earth that must be moved to raise the field efficiency of a prior layout with 'low' field efficiency to a *given* level is likely to be greater than that required to raise the field efficiency of with 'low' field efficiency to a *given* level is likely to be greater than that required to raise the field efficiency of a prior layout with higher field efficiency to that same given level.

These relationships were used in defining typical features associated with undertaking landforming on layouts requiring low, medium and high costs of earthmoving to attain plane of best fit. Those features are detailed in Table 1. This simplifying approach was adopted in view of the great variability in characteristics of layouts prior to landforming.

Note that the field efficiency increases of 17.6, 25.0 and 66.7 per cent shown in Table 1 correspond with reductions in field machinery work rates (assuming no changes in workload) of 15, 20 and 40 per cent respectively.

Table 1: Features of the Three Prior Layout Categories

Prior Layout Category (cost to landform)	Earthmoving Cost ($/ha)	Increase in Field Efficiency Following Landforming (%)	Proportion of Landformed Area Heavy Cut (%)
Low cost (l=1)	260	17.6	5
Medium cost (l=2)	420	25.0	15
High cost (l=3)	600	66.7	30

4.3.2 Marginal income tax rates of farmers

The majority of farmers pay income tax under the income averaging provisions of the Income Tax Assessment Act (Douglas *et al*, 1990). Approximately 75 per cent of farmers using these provisions in 1989/90 had a marginal tax rate of below 25 per cent (Douglas, pers. comm.).

The representative farmer was assumed to utilise these averaging provisions. This assists in incorporating tax effects in the analysis as the marginal tax rate does not vary between income brackets as is the case under the standard provisions.

4.3.3 Income tax effects on the on-farm economics of landforming

A farmer's marginal rate of income tax will affect the on-farm economics of landforming in the following ways:

(a) The marginal tax rate determines the share of any increase (or decrease) in annual profit attributable to landforming that actually accrues to (is incurred by) a farmer;

(b) As deduction of expenditure on landforming from taxable income in the year of expenditure is generally permitted (see Section 1.2), the post-tax cost of a landforming job will be lower the higher is a farmer's marginal tax rate;

(c) Interest receipts are taxable. Hence the higher is a farmer's marginal tax rate, the lower will be the opportunity cost of the capital invested in landforming (assuming the alternative use of the capital would have been to earn interest income).

Note that increased income resulting from increases in trade-in values of field machinery attributable to landforming are not taxable if a farmer makes an election under Section 59 (2A) of the Income Tax Assessment Act. It is assumed that field machinery is not sold at a price higher than the original cost adjusted for inflation. Otherwise a farmer would be liable for capital gains tax.

Purchases (sales) of livestock to increase (decrease) flock or herd size after landforming do not affect income tax liability of the representative farmer since it is assumed that the trading profit from the transactions are zero; that is, that the disposal value of livestock is equal to the acquisition cost.

Note that the income tax effect (ie. payment of tax liabilities or receipt of tax refunds) of a transaction is assumed to occur in the year following the transaction.

4.3.4 Eligibility for concessional credit

Eligibility for concessional credit from the Special Conservation Scheme administered by the NSW Rural Assistance Authority provides farmers with finance to undertake landforming at a considerably lower interest rate than available from commercial sources. Access to this source of credit can reduce the financing cost of landforming significantly.

Loans under the Special Conservation Scheme are available at an interest rate of 8 per cent per annum. The size of loan is limited to 90 per cent of the reasonable cost of the works. The maximum term of a loan is 15 years. To be eligible for a loan, criteria including the following must be met:

- the proposed works must have a beneficial impact on the land, the community and the environment at large;

- the farming enterprise must provide the majority of total income of the applicants; and

- the applicant must be in working occupation of the farm and have net assets not exceeding $800,000 in value (NSW Rural Assistance Authority 1990).

Landforming is likely to satisfy the first criterion if the development is carefully planned and executed. Satisfaction of the remaining criteria depends on the situation, although most M.I.A. rice farms are likely to comply (Darnley-Naylor, pers. comm.).

4.3.5 The length of planning horizon

The benefits of landforming can continue indefinitely as periodic repolishing usually prevents deterioration of a landformed layout. A relatively long planning horizon for analysis is therefore appropriate in most situations, particularly in view of the relatively high cost of the initial landforming investment. Shorter planning horizons may be appropriate if there is a risk that the benefits of landforming may become obsolete in the future (Daubert and Ayer, 1982). This could be due to the land going out of agricultural production (for example due to soil salinisation), the relative advantage of landformed layouts declining in the future due to alternative irrigation methods becoming available, or due to activities requiring alternative layouts becoming more profitable than activities on landformed layouts.

The planning horizon was assumed to be 30 years, but the sensitivity of results to shorter planning horizons was also examined.

4.3.6 Gross value of farm production

The gross value of farm production for each year during the planning horizon was calculated using the following formula:

$$GVP_{tksl} = \sum_{b=1}^{4} \sum_{e=1}^{7} CA_{keb} \cdot CY_{teb} \cdot CP_{bt} + \sum_{d=1}^{5} LN_{tksld} \cdot LGM_{dt} \qquad (2)$$

where

b = crop activity type;

b = 1 rice sod sown;
b = 2 rice aerially sown;
b = 3 wheat sod sown;
b = 4 wheat combine sown.

d = livestock activity type;

$d = 1$ merino self-replacing flock;
$d = 2$ merino ewe x dorset ram flock;
$d = 3$ merino ewe x border leicester ram flock;
$d = 4$ first cross ewe x dorset ram flock;
$d = 5$ merino wethers.

e = layout soil condition category;

$e = 1$ non-landformed layout;
$e = 2$ landformed layout, small area heavy cut ($l = 1$), soil amelioration by topsoiling ($s = 1$);
$e = 3$ landformed layout, small area heavy cut ($l = 1$), soil amelioration by fertiliser ($s = 2$);
$e = 4$ landformed layout, medium area heavy cut ($l = 2$), soil amelioration by topsoiling ($s = 1$);
$e = 5$ landformed layout, medium area heavy cut ($l = 2$), soil amelioration by fertiliser ($s = 2$);
$e = 6$ landformed layout, large area heavy cut ($l = 3$), soil amelioration by topsoiling ($s = 1$);
$e = 7$ landformed layout, large area heavy cut ($l = 3$), soil amelioration by fertiliser ($s = 2$);

GVP_{tksl} = gross value of farm production in year t, with the k^{th} increment of landforming completed, prior layout category l, and soil amelioration practice s applied after landforming;

CA_{keb} = area of crop type b grown on layout soil condition category e with the k^{th} increment of landforming completed;

CY_{teb} = yield of crop type b grown on layout soil condition category e, t years following landforming;

CP_{bt} = farm-gate price received for crop type b, t years following landforming;

LN_{tksld} = number of livestock run within livestock activity d, t years following landforming, with the k^{th} increment of landforming completed, prior layout category l and soil amelioration practice s applied after landforming;

LGM_{dt} = gross margin per head for livestock activity d, t years following landforming.

Values for CP_{bt} and LGM_{dt} represented average levels for the six year period 1985-90 (NSW Agriculture & Fisheries, 1985-90). These prices and gross margins were assumed to remain constant in real terms during the planning horizon.

Values for CA_{keb} were calculated from the areas of rotations given in the solution of the corresponding specification of the linear programming model. Values for LN_{tksld} were also based on the solution of the linear programming model, but factored downward in the early years after landforming following the procedure discussed in Section 3.5.

Note that e can take only two values for the representative farm; one value for non-landformed areas (e=1) and another value for landformed areas (within the range e=2 to e=7). This is because the study design requires that the prior layout category and the soil amelioration practice applied following landforming, both remain constant for all increments of landforming.

4.3.7 Total variable cost for farm

Total variable cost for a farm was calculated using the following equation:

$$TVC_{tksl} = \sum_{f=1}^{6} \sum_{g=1}^{4} AVC_{tfg} \cdot AA_{tkfg} + CL_{tkl} \cdot W_t + H_{tksl} \cdot HC_t \qquad (3)$$

where

f = crop or pasture activity;

f = 1 rice sod sown (irrigated)
f = 2 rice aerially sown (irrigated)
f = 3 wheat sod sown (irrigated)
f = 4 wheat combine sown (irrigated)
f = 5 annual pasture (irrigated)
f = 6 annual pasture (non-irrigated)

g = layout variable cost category;

g = 1 non-landformed layout with high field efficiency (l = 1);
g = 2 non-landformed layout with medium field efficiency (l = 2);
g = 3 non-landformed layout with low field efficiency (l = 3);
g = 4 landformed layout.

TVC_{tksl} = total variable cost for a farm t years following landforming, with the k^{th} increment of landforming undertaken and with prior layout category l;

AVC_{tfg} = variable cost per hectare of activity f undertaken on layout variable cost category g, t years following landforming;

AA_{tkfg} = area of activity f undertaken on layout variable cost category g, t years following landforming and with the k^{th} increment of landforming undertaken;

CL_{tkl} = number of hours of casual labour utilised in the t^{th} year following landforming, with the k^{th} increment of landforming undertaken and prior layout category l;

W_t = hourly rate paid for casual labour in the t^{th} year following landforming;

H_{tksl} = number of bales of hay made in the t^{th} year following landforming, with the k^{th} increment of landforming undertaken and prior layout category l;

HC_t = contractor rate for hay-making ($ per bale) in the t^{th} year following landforming.

Values for AVC_{tfg} were obtained from McKenzie (1989), McKenzie (1990a) and McKenzie (1990b). These values relate to crops to be harvested, and annual pastures grown, during 1990. Note that variable costs of livestock activities are accounted for in the variable LGM_{dt} of equation (2).

Values for AA_{tkfg} were derived from the solution of the corresponding specification of the linear programming model. Note that the yields specified in the linear programming model for landformed areas were the achievable yields; that is, the yields eventually realised after problems associated with soil structure, soil fertility and management following landforming have been overcome. It was assumed that values of AA_{tkfg} would remain constant during the planning horizon, despite crop and pasture yields on landformed areas in the initial years following landforming still increasing toward achievable levels.

The values of CL_{tkl} were also obtained from the solution of the corresponding specification of the linear programming model. The values of H_{tksl} were based on the solution of the linear programming model. However, in the early years following landforming these values were factored downward pro rata to the reduction in whole farm pasture production attributable to the temporary deleterious effects of landforming on soil structure and fertility.

The values of W_t and HC_t were obtained from McKenzie (1990a).

4.3.8 Cost of landforming (including soil amelioration measures)

The values of LC_{sl} were calculated by the procedures discussed in Sections 3.3.3 and 3.3.4. Note that the study design requires that all landforming development is completed in period 0 ($t = 0$).

4.3.9 Cost of repolishing landformed areas

The cost of repolishing was given in Section 3.6. In the years in which repolishing is undertaken the value of M_t is at this level and in other years M_t equals zero.

4.3.10 Real post-tax discount rates

The nominal rate of interest paid on savings used for calculation of discount rates was the average of rates offered for fixed bank deposits each month over the period 1980/81 to 1989/90, for sums less than $50,000 and for terms of less than 12 months (Reserve Bank of Australia, various). The average rate was calculated to be 12.44 percent per annum.

Nominal interest rates were adjusted for income tax as follows. The net present value of returns from one dollar invested as a fixed deposit in the current period was calculated, based on the assumption that the corresponding income tax liability for interest income falls one year later (see Section 4.3.3). The tax liability in the following year equals the product of interest income in the current year and the marginal income tax rate. Its present value was calculated using the nominal pre-tax interest rate. The nominal post-tax interest rate was then calculated by dividing the net present value of the investment return (i.e. the current interest return minus the present value of the tax liability) by the one dollar invested.

Real post-tax interest rates could then be calculated using the following equation (Donnet, 1982):

$$R_m = \frac{w_m - I}{1 + I} \qquad (4)$$

where w_m is the nominal post-tax interest rate for savings for marginal income tax rate category m, and I is the annual inflation rate. The annual inflation rate used was 8.7 percent which is the average of annual percentage increases in the Australian Consumer Price Index over the period 1980 to 1989 inclusive (ABARE, 1990).

The resulting real post-tax interest rates (for savings) by marginal tax rate category are shown in Table A4. The rates range from 3.5 percent p.a. where the marginal tax rate is zero to 0.9 percent where the marginal tax rate is 25 percent.

These rates were assumed to represent the real opportunity cost of capital for farmers in the different marginal tax rate categories and were accordingly used in the study as real discount rates.

4.3.11 Subsidy equivalent of concessional credit

In the context of discounted cash flow analysis, in which the discount rate represents the opportunity cost of capital (in this case to a farmer), the benefit from being provided credit at a concessional rate of interest arises from incurring a lower cost for use of capital than its opportunity cost.

The margin by which the opportunity cost of capital (for a farmer) exceeds the cost actually incurred for the use of that capital can be considered the equivalent of a cash subsidy paid periodically during the term of the concessional loan.

The calculation of the subsidy equivalent (pre-tax) of concessional credit provided under the Special Conservation Scheme (S.C.S.) was as follows. Farmers eligible for S.C.S. credit were assumed to be provided the maximum amount possible (90 percent of the cost of landforming) for the maximum possible term (15 years). The loan was assumed to be repaid in amortised annual instalments. Instalments were assumed to be paid at the end of each year. The outstanding principal during each year was calculated accordingly. The pre-tax subsidy equivalent of concessional credit in any year was calculated by the following equation:

$$E_{tslc}=P_{tslc}(y-u) \tag{5}$$

where P_{tslc} is the outstanding principal on a S.C.S. loan during the t^{th} year following landforming, with soil amelioration practice s undertaken, prior layout category l and farmer credit category c; y is the pre-tax opportunity cost of capital (ie. the nominal pre-tax rate of interest received for savings); and u is the interest rate payable for S.C.S. credit.

4.4 Calculation of Net Present Value of Topsoiling

The net present value of undertaking topsoiling during an increment of landforming was calculated using the following equation:

$$NPVT_{klmc}=\sum_{t=0}^{h}\frac{1}{(1+R_m)^{t}}\cdot(CFIT_{tklm}-CFIF_{tklm}) \tag{6}$$

with prior layout category l, marginal tax rate category m, farmer credit category c;

$CFIT_{tklm}$ = post-tax cash flow increase attributable to undertaking the k^{th} increment of landforming *with topsoiling* (s = 1) in the t^{th} year following landforming, with prior layout category l, marginal tax rate category m;

$CFIF_{tklm}$ = post-tax cash flow increase attributable to undertaking the k^{th} increment of landforming *without topsoiling* (s = 2), in the t^{th} year following landforming, with prior layout category l, marginal tax rate category m;

and $CFIT_{tklm}$ and $CFIF_{tklm}$ equal:

$$(1-T_m)\ [(GVP_{tksl}-GVP_{t(k-1)sl})-(TVC_{tksl}-TVC_{t(k-1)sl}-LC_{tsl}-M_t+E_{tslc}]+TI_{tksl}-F_{tksl} \qquad (7)$$

for s = 1 and s = 2 respectively. Note that the right-hand side of equation (7) is a term within equation (1). Note also that underlying this equation specification is the assumption that a farmer undertakes all increments of landforming using the same soil amelioration practice.

4.5 Treatment of the Risk Involved in Investing in Landforming

The methods used in this study for evaluating the economics of landforming are deterministic. It is assumed that a farmer has perfect foresight for not only the physical effects of landforming but for the values of all the parameters discussed in previous sections. To the extent that this certainty is not possible, there are risks involved in investing in landforming.

Farmers consequently are likely to be interested not only in the economics of landforming assuming 'best guess' values of these parameters, but also in the sensitivity of the economic outcome to variation in these values. This risk was accounted for in this study by testing for the sensitivity of net present value of landforming and of topsoiling to variation in key parameters, rather than by incorporating a risk premium in the discount rate or by modelling the parameters as stochastic variables.

5.0 RESULTS

Unless otherwise specified, the following results assume that the representative farmer is eligible for concessional credit, and has a marginal income tax rate of 15 percent and a planning horizon of 30 years.

5.1 Landforming (Without Topsoiling)

The net present value (NPV) of each increment of landforming without topsoiling for each prior layout category is shown in Table A5.

The NPV of landforming without topsoiling is positive for all increments for all prior layout categories. This indicates that, under the assumptions made, landforming (without topsoiling) of the full area of the representative farm represents an economic investment for the farmer.

For each prior layout category, however, the NPV of landforming without topsoiling is shown to vary between increments. For the prior layout categories associated with low and medium cost of landforming, there is relatively minor variation between the NPV of the first four increments. However, in the case of the prior layout category associated with high cost of landforming, there are successive substantial declines in NPV from the first to the fourth increment. For all prior layout categories, the NPV of the fifth increment is much lower than for the fourth. This is because, in all cases, availability of irrigation water (limited by volumetric allocation) has become a binding constraint. In each case insufficient water is available to adequately irrigate the whole 200 hectares of the representative farm once fully landformed.

Economic comparison of landforming jobs associated with different prior layout categories is complicated by differences in the magnitude of investment involved. This problem can be avoided by comparing projects on the basis of their benefit-cost ratios (Dasgupta and Pearce, 1978). For this purpose the benefit-cost ratios corresponding with the NPVs of Table A5 are shown in Table A6.

It is seen that for the prior layout category associated with low cost of landforming, the benefit-cost ratio of landforming without topsoiling is considerably higher than for corresponding increments undertaken within the prior layout categories associated with medium and high costs of landforming; whereas the benefit-cost ratio for the medium cost category is only slightly higher than for the high cost category for all corresponding increments.

For the first increment undertaken the benefit-cost ratios for the prior layout categories associated with low, medium and high costs of landforming respectively are 5.68, 3.97 and 3.96; whereas for the last increment landformed they are 2.59, 1.73 and 1.60 respectively.

5.2 Topsoiling

The NPV of undertaking topsoiling for each increment of landforming and for each prior layout category is shown in Table A7.

Note that topsoiling has been assumed to improve the yields of rice, wheat and annual pasture similarly (ie. on a percentage yield increase basis). The financial value of equi-proportionate yield increases for these activities depends on their output values (which in the case of annual pasture is the value of livestock production). The NPV of topsoiling will therefore depend upon the marginal effect of the associated landforming increment on landformed area planted to each of rice, wheat and annual pasture. Given the assumptions made regarding output values, the value of equi-proportionate yield increases is significantly greater for rice than for wheat or annual pasture. Hence the NPV of topsoiling associated with a landforming increment will be higher the greater the whole farm effect of the increment in terms of increasing landformed area planted to rice.

This explains the variability of NPV of topsoiling observed within Table A7. Note that for each of the prior layout categories, NPV of topsoiling is highest when associated with the fourth increment of landforming.

The NPV of topsoiling, given the assumptions made, is seen to be positive for all increments of landforming and for all prior layout categories.

Benefit-cost ratios for topsoiling are shown in Table A8. It is seen that, for each landforming increment, the benefit-cost ratio for topsoiling is highest for the prior layout category associated with low cost of landforming, followed in order by the medium and high cost categories. This ranking indicates the relative economic value to a farmer of topsoiling in the different circumstances.

Note that the benefit-cost ratios for topsoiling are in all cases considerably lower than the benefit-cost ratios of the landforming increments with which they are associated (see Table A6).

6.0 SENSITIVITY OF RESULTS TO UNDERLYING ASSUMPTIONS

6.1 Financial Assumptions

Unless otherwise specified, the following sensitivity analysis assumes that the representative farmer is eligible for concessional credit, and has a marginal income tax rate of 15 percent and a planning horizon of 30 years.

6.1.1 Marginal income tax rate

(a) Landforming without topsoiling

The NPV of the first increment of landforming without topsoiling for each of the prior layout categories is shown in Table A9 for marginal income tax rates of 0, 10, 15, 20 and 25 percent. It is seen that for all prior layout categories the NPV increases with the marginal income tax rate. Note that the spread of values is greater for the prior layout categories associated with medium and high cost of landforming (where in each case the NPV for a 0 percent tax rate is 78 percent of that for a 25 percent tax rate) than for the low cost category (where the corresponding proportion is 85 percent).

(b) Topsoiling

The corresponding NPVs for topsoiling are shown in Table A10. It is seen that for the prior layout category associated with low cost of landforming, the NPV of topsoiling decreases with increases in the marginal tax rate. The reverse is true for the high cost category. In the case of the medium cost category, the NPV is higher for the 10 percent tax rate than for the 0 percent rate, but is successively lower for the 15 , 20 and 25 percent rates. Whereas the spread of NPVs for the low and medium cost categories is relatively small, it is substantial in the case of the high cost category.

6.1.2 Real post-tax discount rate

(a) Landforming without topsoiling

The sensitivity of NPV of landforming without topsoiling to variation in assumed real post-tax discount rates was tested by increasing the assumed nominal pre-tax rate of interest on savings by 20 percent (with no change to the assumed inflation rate). As explained in Section 4.3.10, real post-tax discount rates have been calculated as a function of the nominal pre-tax rate of interest on savings, the inflation rate and the marginal rate of tax applicable for the representative farmer.

When a marginal income tax rate of 15 percent is assumed, the effect of the above assumption change is to increase the real post-tax discount rate from 1.95 percent per annum to 3.98 percent per annum (an increase of 104 percent).

The percentage change in the NPV of landforming without topsoiling attributable to this assumption change is shown in Table A11 for the first increment of landforming for each prior layout category. It is seen that this assumption change reduces NPV by around 30 percent in each case, with the percentage reduction slightly greater the higher the landforming cost associated with a prior layout category.

(b) Topsoiling

The corresponding percentage changes in NPV of topsoiling are also shown in Table A11. It is seen that the percentage reduction in NPV of topsoiling attributable to this assumption change is greater the landforming cost associated with a prior layout category. For the prior layout category associated with a high cost of landforming, the percentage reduction in NPV is 101 percent.

6.1.3 Eligibility for concessional credit

(a) Landforming without topsoiling

The percentage change in the NPV of landforming without topsoiling attributable to the representative farmer being ruled ineligible for Special Conservation Scheme credit (rather than eligible as assumed previously) is shown in Table A12 for the first increment of landforming for each prior layout category. It is seen that ineligibility for concessional credit reduces NPV by a very small percentage in each case.

(b) Topsoiling

The corresponding percentage changes in NPV of topsoiling are also shown in Table A12. It is seen that ineligibility for concessional credit reduces NPV by substantial percentages in each case. The greatest percentage reduction (137 percent) is for the prior layout category associated with high cost of landforming; this reduction results in a negative NPV for topsoiling.

6.1.4 Income tax deductibility of full cost of landforming in year of expenditure

(a) Landforming without topsoiling

The percentage change in the NPV of landforming without topsoiling attributable to termination of this concession or the representative farmer being ruled ineligible for this concession (rather than eligible as previously assumed) is shown in Table A13 for the first increment of landforming for each prior layout category.

It is seen that ineligibility for, or termination of, this concession reduces NPV by 3 percent in the case of the prior layout category associated with low cost of landforming, and by 5 percent for the medium and high cost categories.

Note that these effects relate to a farmer with a 15 percent marginal tax rate. For a farmer with a 0 percent marginal tax rate there would obviously be nil effect due to ineligibility for, or termination of, this concession.

(b) Topsoiling

The corresponding percentage changes in the NPV of topsoiling are also shown in Table A13 (again assuming a 15 percent marginal income tax rate).

It is seen that percentage reductions in NPV are much more substantial than in the case of landforming without topsoiling, and that the percentage reductions in NPV of topsoiling are much greater for the prior layout category associated with high cost of landforming than for the low and medium cost categories.

6.1.5 Length of planning horizon

(a) Landforming without topsoiling

The percentage change in the NPV of landforming without topsoiling attributable to reducing the planning horizon from 30 years to 15 years is shown in Table A14 for the first increment of landforming for each prior layout category.

It is seen that this shortening of the planning horizon reduces NPV by more than 50 percent in each case; the reduction is greater the higher the landforming cost associated with a prior layout category.

(b) Topsoiling

Following from the assumptions made in Section 3.3.4 regarding the soil amelioration effects of topsoiling, the benefits of topsoiling are fully realised within 7 years following landforming. Hence shortening the planning horizon to 15 years has no effect on the NPV of topsoiling, as can be seen in Table A14.

6.1.6 Crop prices and livestock gross margins

(a) Landforming without topsoiling

The percentage change in the NPV of landforming without topsoiling attributable to reducing crop prices and livestock gross margins by 20 percent from those originally assumed is shown in Table A15 for the first increment of landforming for each prior layout category.

It is seen that NPV is reduced by more than 20 percent in each case, with the greatest reduction being for the prior layout category associated with a high cost of landforming (31 percent).

(b) Topsoiling

Corresponding percentage changes in the NPV of topsoiling are also shown in Table A15.

It is seen that the percentage reductions in NPV of topsoiling are considerably greater than for landforming without topsoiling. The percentage reduction in NPV of topsoiling is higher the greater the landforming cost associated with a prior layout category (99 percent reduction for the high cost category).

6.1.7 Landforming and topsoiling costs

(a) Landforming without topsoiling

The percentage change in the NPV of landforming without topsoiling attributable to increasing assumed earthmoving costs of landforming by 20 percent is shown in Table A16 for the first increment of landforming for each prior layout category.

It is seen that the NPV of landforming without topsoiling is quite insensitive to earthmoving costs of landforming, 20 percent increases in earthmoving costs reducing NPV by no more than 5.3 percent in any case.

(b) Topsoiling

Corresponding percentages changes in the NPV of topsoiling are also shown in Table A16.

It is seen that percentage reductions in NPV of topsoiling are much greater than for landforming without topsoiling, and are greater the higher the landforming cost associated with a prior layout category (339 percent reduction for the high cost category).

6.2 Technical Assumptions

6.2.1 Increase in achievable yields following landforming

(a) Landforming without topsoiling

The percentage change in the NPV of landforming without topsoiling attributable to reducing achievable yield increases following landforming (see Table A1) by 50 percent is shown in Table A17 for the first increment of landforming for each prior layout category.

It is seen that reductions in NPV of landforming without topsoiling are substantial in each case, ranging from 47 percent for the prior layout category associated with high cost of landforming to 69 percent for the medium cost category.

(b) Topsoiling

Corresponding percentage changes in the NPV of topsoiling are also shown in Table A17.

It is seen that NPV is reduced by approximately 20 percent for the prior layout categories associated with low and medium cost of landforming, but by 169 percent for the high cost category.

6.2.2 Yield effects of decline in soil structure and fertility following landforming

6.2.2.1 Yield levels in the year following landforming and length of delay until achievable yields are attained.

(a) Landforming without topsoiling

The effect of reducing yield levels in the year following landforming by 10 percentage points and delaying attainment of achievable yields by a further year (for all landformed areas, i.e. topsoiled heavy cut, non-topsoiled heavy cut, and remaining landformed areas, are shown in Table A18.

It is seen that NPV of landforming without topsoiling is reduced by around 10 percent for each prior layout category.

(b) Topsoiling

Corresponding percentage changes in the NPV of topsoiling are also shown in Table A18.

It is seen that these changes to assumptions have a very substantial positive effect on the NPV of topsoiling. NPV of topsoiling is increased by 196, 164 and 843 percent for the prior layout categories associated with low, medium and high cost of landforming respectively.

6.2.2.2 Proportion of area heavy cut during landforming

(a) Landforming without topsoiling

The percentage change in the NPV of landforming without topsoiling attributable to the proportion of the area heavy cut during landforming being 5 percentage points greater than previously assumed is shown in Table A19 for the first increment of landforming for each prior layout category.

It is seen that the reductions in NPV of landforming without topsoiling are quite small, less than 5 percent in each case.

(b) Topsoiling

Corresponding percentage changes in the NPV of topsoiling are also shown in Table A19.

The NPV of topsoiling is shown to increase substantially in each case, by 100 percent, 33 percent and 17 percent for the prior layout categories associated with low, medium and high costs of landforming respectively.

6.2.3 Rate of field efficiency increase following landforming

(a) Landforming without topsoiling

The percentage change in the NPV of landforming without topsoiling attributable to reducing rates of field efficiency increase following landforming by 20 percent is shown in Table A20 for the first increment of landforming for each prior layout category.

Percentage reductions in NPV of landforming without topsoiling are greater the higher the landforming cost associated with a prior layout category, ranging from a reduction of 4 percent for the low cost category to a reduction of 15 percent for the high cost category.

(b) Topsoiling

The NPV of topsoiling is unaffected by changes in assumptions regarding field efficiency increases following landforming.

7.0 DISCUSSION AND CONCLUSIONS

The emphasis of this study was not to determine whether landforming and topsoiling are likely to be economic in general for rice farmers. It was recognised prior to the study being undertaken that a confident answer to this question would be an unlikely outcome due to the lack of research evidence regarding a number of effects of landforming and topsoiling. The sensitivity analysis undertaken during this study has confirmed the sensitivity of on-farm economics of landforming and topsoiling to assumptions made regarding values of a number of technical parameters for which research evidence is lacking; in the process sensitivity to assumptions regarding a number of uncertain 'financial' parameters has also been shown.

The emphasis was rather on identifying those variables for which accurate specification is critical for realistic ex ante on-farm economic evaluation of particular landforming and topsoiling jobs.

This study has contributed to a solution of this problem by more comprehensively accounting for the benefits and costs of landforming than has been the case in previous studies. This has been achieved by utilising 'best guess' estimates from researchers, advisory officers or farmers where research evidence concerning a parameter was unavailable, and by using a linear programming model of a representative M.I.A. rice farm which allowed quantification of the whole farm effects of landforming in particular situations. The flexibility of the computer-based models developed allowed comprehensive sensitivity analysis to be undertaken with relative ease.

The more important conclusions to be drawn from the study *regarding landforming (without topsoiling)* are:

(a) The net present value of landforming a particular section of a farm is influenced by how much of the farm is committed to be landformed or has previously been landformed. In particular, net present value of landforming falls sharply once sufficient area of a farm has been landformed such that availability of irrigation water (limited by entitlement) is inadequate to fully irrigate additional areas landformed. Note, however, that this problem can be reduced if availability of irrigation water is augmented by means such as on-farm storage and drainage recirculation, groundwater pumping or purchase of additional water entitlement.

(b) If the design objective of landforming is to attain plane of best fit within irrigation bays, the lower the volume of earth required to be moved the greater will be the return to investment in landforming (as measured by benefit-cost ratio).

Note that this conclusion follows from assumptions made that the cost of landforming and the extent of damage to soil during landforming increase as the volume of earth required to be moved (to attain plane of best fit) increases. The greater increases in field efficiency assumed for landforming jobs requiring greater volumes of earth to be moved are evidently not large enough to outweigh the effects of the former assumptions.

Note also that a number of the other effects of landforming were assumed uniform regardless of the volume of earth required to be moved. These effects included increases in achievable yield, increase in irrigation efficiency and saving of labour in supervising irrigations. In certain situations it is possible that these effects may be greater the more earth required to be moved, thereby reducing the relative economic disadvantage of jobs requiring greater volumes of earth displacement.

(c) The results indicate that landforming is an investment with considerable economic potential for rice farms in the Murrumbidgee Irrigation Area. Even though the net present value of landforming has been shown to vary considerably according to the situation in which it is applied and with variation in values assumed for a number of critical parameters, the finding that benefit-cost ratios comfortably exceed the breakeven level of one in all situations analysed using the base set of assumptions indicates that this technology warrants serious consideration by this group of farmers. It should be noted that the base set of assumptions is quite conservative in terms of making landforming 'look good'.

(d) The net present value of landforming is greater the higher the marginal income tax rate assumed to apply to a farmer during the planning horizon of the investment. The negative effect of a higher income tax rate on the proportion of increased profits retained by a farmer is evidently more than compensated by higher income tax rates reducing the post-tax opportunity cost of capital and thereby the applicable discount rate. Higher income tax rates also increase the value to farmers of eligibility for full tax deductibility of landforming costs in the year of expenditure.

(e) Eligibility for concessional credit under the Special Conservation Scheme and for full income tax deductibility of landforming costs in the year of expenditure were each shown to have only a minor positive effect on net present value of landforming.

(f) Sensitivity analysis undertaken for remaining parameters indicates that the net present value of landforming is most sensitive to assumptions regarding length of planning horizon, size of discount rate, levels of crop prices and livestock gross margins and increases in achievable yield levels following landforming; to a lesser extent it is sensitive to assumptions regarding the yield effects of decline in soil structure and fertility following landforming; interestingly, sensitivity to cost of landforming is relatively low.

The more important conclusions to be drawn *regarding topsoiling* are:

(a) The net present value of topsoiling depends on the mix of activities to be undertaken on the landformed area associated with the topsoiling. This is because the value to a rice farmer of topsoiling depends on the extent to which it improves yields of rice, wheat and annual pasture following landforming and on the values of output from these activities. In this study, wherein the yield effects of topsoiling (in proportionate terms) were assumed uniform for all activities and all landforming development was assumed to be undertaken simultaneously, it was shown that the net present value of topsoiling is higher the greater the whole farm effect of the associated increment of landforming in terms of increasing the landformed area planted to rice (since rice is the activity with the highest assumed output value).

(b) The net present value of topsoiling was shown to be positive in all situations analysed using the base assumptions. The return from investing in topsoiling (as indicated by benefit-cost ratios) was lower the greater the volume of earth displacement required to attain plane of best fit during associated landforming. However, net present value of topsoiling was found to be considerably sensitive to assumptions made regarding a number of parameters, becoming negative under a number of the assumption changes examined.

Consequently considerable caution should be exercised in drawing conclusions from this study regarding the economic value of topsoiling to farmers and its relative value in different situations.

(c) The net present value of topsoiling was found to be most sensitive to the following parameters:

- marginal income tax rate of farmer;
- discount rate
- eligibility for concessional credit;
- eligibility for full income tax deductibility of topsoiling costs (included in landforming costs) in the year of expenditure;
- levels of crop prices and livestock gross margins during the planning horizon;
- cost of undertaking topsoiling;
- increases in achievable yields of activities following landforming;
- deleterious yield effects of decline in soil structure and fertility following landforming (and the effect of topsoiling in reducing these effects); and
- proportion of a landformed area which is heavy cut.

In most cases the net present value of topsoiling associated with landforming jobs requiring high volumes of earth displacement was shown to be considerably more sensitive to variation in these variables than was the case for topsoiling associated with landforming jobs requiring lower volumes of earth displacement. This can be attributed to the underlying assumption that both the heavy cut proportion of a landformed area and the deleterious yield effects of decline in soil structure and fertility following landforming (without topsoiling) increase as the volume of earth required to be moved during landforming increases.

Further technical research regarding the final three parameters listed above is essential to improve accuracy of any economic assessment of topsoiling.

Of course even with accurate specification of technical parameters, the problem of uncertainty regarding financial parameters remains. This problem is perhaps more intractable since specification of financial parameters such as output prices necessitates prediction over a relatively lengthy planning horizon. This problem is less serious for topsoiling than for landforming since the benefits and costs of topsoiling are likely to occur over a substantially shorter time horizon.

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APPENDIX

Table A1: Assumed Achievable Crop Yield and Pasture Production Levels for Landformed and Non-Landformed Layouts

Crop or Pasture		Yield Unit	Achievable yield	
			Non-Landformed Layout	Landformed Layout
Rice sod sown		t/ha	8.00	9.00
Rice aerial sown		t/ha	8.50	9.00
Wheat sod sown		t/ha	1.75	2.50
Wheat combine sown		t/ha	3.25	4.00
Annual pasture	- autumn	(LSM[a]/ha)	15.00	35.90
	- winter	(LSM[a]/ha)	78.00	85.00
	- spring	(LSM[a]/ha)	90.40	122.40

[a] Livestock months

Table A2: Assumed Yield Levels for Pond-Prone Areas of Non-Landformed Layouts in Abnormally Wet Years

Crop or Pasture		Yield as Proportion of Non-Landformed Achievable Level
Rice sod sown		1.00
Rice aerially sown		1.00
Wheat sod sown		0.50
Wheat combine sown		0.50
Annual pasture	- autumn	0.80
	- winter	0.50
	- spring	0.80

Table A3: Crop Yield and Pasture Production Levels in the Year Following Landforming: Topsoiled Areas and Areas Not Heavy Cut

Volume of Earth Moved (m^3/ha)	Proportion of Achievable Yield Attained in First Year %
200	95
350	85
500	70

Table A4: Real Post-Tax Interest Rates for Savings by Marginal Tax Rate Category

Marginal Rate of Income Tax %	Real Post-Tax Interest Rate (% p.a.)
0	3.48
10	2.46
15	1.95
20	1.44
25	0.93

Table A5: Net Present Value of Landforming Without Topsoiling

Category of Prior Layout (cost to landform)	NPV of k^{th} Landforming Increment ($)				
	Landforming Increment				
	1	2	3	4	5
Low cost	67,313	69,094	65,455	63,319	23,772
Medium cost	60,284	63,562	59,966	56,234	14,975
High cost	85,760	82,627	76,254	69,716	15,980

Table A6: Benefit-Cost Ratios for Landforming Without Topsoiling

Category of Prior Layout (cost to landform)	B/C Ratio for k^{th} Landforming Increment				
	Landforming Increment				
	1	2	3	4	5
Low cost	5.68	5.73	5.58	5.42	2.59
Medium cost	3.97	4.10	3.95	3.76	1.73
High cost	3.96	3.90	3.75	3.55	1.60

Table A7: Net Present Value of Topsoiling

Category of Prior Layout (cost to landform)	NPV of Topsoiling the k^th Landforming Increment ($)				
	Landforming Increment				
	1	2	3	4	5
Low cost	905	799	1,041	1,195	445
Medium cost	2,148	1,794	2,402	2,776	644
High cost	559	1,291	2,850	4,277	54

Table A8: Benefit-Cost Ratios for Topsoiling

Category of Prior Layout (cost to landform)	B/C Ratio for Topsoiling the k^th Landforming Increment				
	Landforming Increment				
	1	2	3	4	5
Low cost	1.41	1.37	1.48	1.55	1.20
Medium cost	1.33	1.28	1.37	1.43	1.10
High cost	1.05	1.10	1.23	1.34	1.00

Table A9: Marginal Income Tax Rate and Net Present Value of Landforming Without Topsoiling

Category of Prior Layout (cost to landform)	NPV of First Landforming Increment ($)				
	Marginal Income Tax Rate (%)				
	0	10	15	20	25
Low cost	60,773	65,162	67,313	69,398	71,385
Medium cost	51,253	57,287	60,284	63,232	66,094
High cost	72,952	81,520	85,760	89,915	93,934

Table A10: Marginal Income Tax Rate and Net Present Value of Topsoiling

Category of Prior Layout (cost to landform)	NPV of First Landforming Increment ($)				
	Marginal Income Tax Rate (%)				
	0	10	15	20	25
Low cost	928	916	905	890	870
Medium cost	2,135	2,154	2,148	2,132	2,104
High cost	43	401	559	701	826

Table A11: Effect of Increasing Nominal Pre-Tax Interest Rate for Savings by 20 Percent (No Change in Assumed Inflation Rate)

Category of Prior Layout (cost to landform)	% Change in NPV associated with first increment of landforming[b]	
	Landforming without topsoiling	Topsoiling
Low cost	(28.3)	(14.1)
Medium cost	(33.6)	(17.0
High cost	(33.9)	(100.7)

Table A12: Effect of Ineligibility for Concessional Credit on Net Present Value of Landforming and of Topsoiling

Category of Prior Layout (cost to landform)	% Change in NPV associated with first increment of landforming[b]	
	Landforming without topsoiling	Topsoiling
Low cost	(1.3)	(14.1)
Medium cost	(2.1)	(17.9)
High cost	(2.1)	(137.4)

[b] brackets denote negative values

Table A13: Effect of Ineligibility for Income Tax Deductibility of Landforming Expenditure on Net Present Value of Landforming and of Topsoiling

Category of Prior Layout (cost to landform)	% Change in NPV associated with first increment of landforming[b]	
	Landforming without topsoiling	Topsoiling
Low cost	(2.9)	(32.5)
Medium cost	(4.9)	(41.1)
High cost	(4.8)	(316.1)

Table A14: Effect of Reduction of Length of Planning Horizon to 15 Years on Net Present Value of Landforming and of Topsoiling

Category of Prior Layout (cost to landform)	% Change in NPV associated with first increment of landforming[b]	
	Landforming without topsoiling	Topsoiling
Low cost	(52.9)	0.0
Medium cost	(53.7)	0.0
High cost	(64.6)	0.0

[b] brackets denote negative values

Table A15: Effect on Net Present Value of Landforming Without Topsoiling and of Topsoiling of Reducing Crop Prices and Livestock Gross Margins by 20 Percent

Category of Prior Layout (cost to landform)	% Change in NPV associated with first increment of landforming[b]	
	Landforming without topsoiling	Topsoiling
Low cost	(23.8)	(58.1)
Medium cost	(23.4)	(70.7)
High cost	(30.8)	(99.1)

Table A16: Effect on Net Present Value of Landforming and of Topsoiling of Increasing Earthmoving Costs of Landforming and Topsoiling by 20 Percent

Category of Prior Layout (cost to landform)	% Change in NPV associated with first increment of landforming[b]	
	Landforming without topsoiling	Topsoiling
Low cost	(3.1)	(34.9)
Medium cost	(5.3)	(44.1)
High cost	(5.2)	(338.9)

[b] brackets denote negative values

Table A17: Effect on Net Present Value of Landforming and of Topsoiling of Reducing Achievable Yield Increases Following Landforming by 50 Percent

Category of Prior Layout (cost to landform)	% Change in NPV associated with first increment of landforming[b]	
	Landforming without topsoiling	Topsoiling
Low cost	(62.7)	(18.9)
Medium cost	(69.1)	(22.0)
High cost	(47.4)	(169.1)

Table A18: Effect on Net Present Value of Landforming and of Topsoiling of Reducing Yields in Year Following Landforming by 10 Percentage Points and Delaying Attainment of Achievable Yields by a Further Year

Category of Prior Layout (cost to landform)	% Change in NPV associated with first increment of landforming[b]	
	Landforming without topsoiling	Topsoiling
Low cost	(9.2)	196.2
Medium cost	(13.8)	163.7
High cost	(10.8)	843.3

[b] brackets denote negative values

Table A19: Effect on Net Present Value of Landforming and of Topsoiling of Increasing the Proportions of Areas Heavy Cut During Landforming by 5 Percentage Points

Category of Prior Layout (cost to landform)	% Change in NPV associated with first increment of landforming[b]	
	Landforming without topsoiling	Topsoiling
Low cost	(4.0)	100.0
Medium cost	(4.2)	33.3
High cost	(2.2)	16.7

Table A20: Effect on Net Present Value of Landforming and of Topsoiling of Reducing Rates of Field Efficiency Increase Following Landforming by 20 Percent

Category of Prior Layout (cost to landform)	% Change in NPV associated with first increment of landforming[b]	
	Landforming without topsoiling	Topsoiling
Low cost	(3.5)	0.0
Medium cost	(7.4)	0.0
High cost	(15.3)	0.0

[b] brackets denote negative values