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New England Tablelands, New South Wales.

by

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Abstract

The economic impact of weeds on farms in the New England Region of New South Wales is estimated from data from a cross -sectional survey. Weeds can be classed as noxious or declared plants, plants that the farmers perceived as weeds, and trees -- which many farmers also perceived as weeds. Variables were defined for several levels of intensity of infestation for each of these three classes of weeds. The impact of each these variables, on property income and stocking, was estimated through Cobb-Douglas production functions. The presence of very-heavy infestations of non-noxious weeds, and heavy infestations of non-noxious weeds, were found to be associated with reductions in income. In total, the income of the representative property would be increased by 15 per cent, ceteris paribus, if these infestations were removed.

Key Words: Weeds, trees, income, stocking

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1 Introduction

Weeds are one of the leading problems in Australian agriculture. They are responsible for substantial losses of farm production and extensive damage to the environment. The Co-operative Research Centre for Weed Management Systems has estimated the economic cost of weeds to exceed $3 billion annually in terms of reduced productivity and the costs of weed control (Vere, Jones and Griffith, 1997).

The cost of weeds is an important part of every farm production system. Weeds impose costs on producers in two ways; through reductions in the quality and quantity of yields, and increases in input requirements for weed control. This cost may have economic consequences for the wider community if a large number of farmers are affected, leading to variations in supplies and prices of commodities. Farm level analyses, such as that undertaken in the present study, are necessary to establish the effects of weeds on production systems. The results will highlight the costs and benefits, in order to assist producers to make informed decisions about their weed control programs.

The study was undertaken in the New England Tablelands, centred around the city of Armidale. Major enterprises in the Tablelands are cattle and sheep (the area is known for its fine wool production), but there is very little commercial cropping. The major noxious weeds in the area include Blackberry and Sweet Briar, St. John's Wort, Nodding Thistle and a number of exotic grasses. Of increasing concern is the spread of Serrated Tussock and Nodding Thistle. There are also many plants, not declared noxious, that affect Tablelands producers. By far the largest problems are caused by various species of thistles, including black thistle and saffron thistle, of which the latter is noxious. Other plants, nominated by producers as problems, include rat's tail fescue and Bathurst Burr. Tree cover and tree regrowth is sometimes also cited as an impediment to achieving maximum production on properties.

The area covered by this study falls within the jurisdiction of the New England Tablelands Noxious Plants County Council (NETNPCC). This organisation is responsible for monitoring and control of noxious weeds on its constituent councils' land, and monitoring of noxious weed levels on privately owned property. The county district encompasses the shires of

Armidale City, Dumaresq, Guyra, Uralla and Walcha, a total area of 18 198 km^2, with headquarters located in Armidale (NETNPCC Annual Report, 1997).

A weed is any plant growing in a place where it is not desired (Combellack 1989). A noxious weed is one declared so because of its particular characteristics (if it is poisonous or fast growing). The presence of weeds on a property reduces overall productivity and the amount of land available for productive activities. This in turn reduces the income and carrying capacity of the farm. Control of weeds can increase the grazing potential of existing land and therefore, increase the income and carrying capacity of livestock enterprises.

The objective of this study is to estimate the impact of weeds on farm income and stocking rates on a sample of properties. In doing this, information on other factors such as the biophysical characteristics of the land, the weed history of the land, and levels of weed control will also be generated.

2 Literature Review

This section will provide a brief review of literature relevant to this study. First, comments from previous studies on the economic costs of weeds and benefits of weed control will be examined. Second, material related to the underlying economic theory and method of the analysis will be discussed.

Weeds are an important part of every farm production system, and there are numerous examples of research into their costs and control. Concern over weeds is also reflected in the many articles published in forums such as rural newspapers and magazines. A considerable amount of the research into weed infestation approaches the problem from a biological viewpoint, examining the physical effects of weeds and identifying the most effective control methods. In contrast, economic research into weed control appears to be very scarce (Pannell 1988). This apparent lack of economic research means that weed control may be based on incomplete information regarding the losses and costs arising from weeds, and the potential benefits from their control.

Combellack (1989) provides a comprehensive assessment of the impact of weeds in a range of situations. The effects of weeds on human and animal welfare, on production of food and fibre and on the environment, are all discussed in some detail. Pasture weeds impose costs through reduction in the amount of pasture available for grazing, reducing stocking rates and therefore annual income. Weeds may also reduce the quality of production through deterioration

in the health of animals (from poisonings and injury) and contamination of the products (e.g. vegetable matter in wool and tainting of milk).

Combellack (1989) also reports estimates of the economic impacts in Australia of weeds in crops, pastures and public lands. Direct financial losses due to weeds in crops was estimated to be $1013.4 million (including cultivation, herbicides and their application). Indirect losses (resulting from yield losses and product contamination) totalled $855.6 million, giving a total economic loss of $1869 million. The total losses associated with pasture weeds, both direct and indirect, were valued at $971.1 million. In both cases, the indirect costs in terms of losses in productivity exceeded the direct costs of weed control. Evaluating the costs of weeds on public land is very difficult, as the services it provides are not valued.

Papers that assess the various methods of control include Pannell (1990) and King (1991). The former presents a model of yield response to herbicide application under conditions of herbicide resistance. The optimal herbicide rate is determined, and illustrated using empirical examples. Pannell (1990) also discusses the issue of farmers using other (usually less) than officially recommended herbicide rates. King (1991) examines the relative economic costs and benefits associated with various methods of weed control. Chemical control is found to be a more cost-effective control measure than mechanical control (slashing and ploughing) or pasture improvement, but concludes that combinations of the three methods may prove even more effective. King (1991) also notes that there may be unknown environmental effects from a long-term program of chemical control.

The research conducted by King is typical of the majority of research into weeds, with the focus only on the one species. Another species-specific paper is Vere, Auld and Malcolm (1993), which uses discounted cash flow analysis to assess the economic impact of Serrated Tussock on pasture production. However, multiple weed species are more likely to be present, and their effects on yields are unlikely to be predictable from estimates of the effects of single species acting individually.

Pannell (1988) suggests that one of the reasons behind the lack of research into the economic effects of weeds is the complexity of the problem. The presence of multiple weed species is the rule rather than the exception, and this increases the information requirements for an analysis, and this makes data collection time consuming and expensive. Complicating the problem further is the fact that certain plants are considered weeds at one stage of growth, but can be used as fodder at other stages, usually when young (Combellack, 1989).

There appear to be a greater number of economic studies at the regional, or policy, level than at the farm level, although they also tend to have the narrow focus described above. These studies often examine the rationale behind government involvement in weed control. Government intervention is justified on the grounds of market failure, usually because of the existence of externalities. In the case of weeds, an individual farmer who imposes external costs (e.g. herbicide drift) tends to invest more in weed control than is socially optimal. But a farmer who produces external benefits, by preventing weed spread onto neighboring land, is likely to under-invest in control (Pannell 1988). Thus governments intervene to achieve a socially optimal outcome.

Government intervention is also justified on grounds of economies of scale, differences between private and public attitudes to risk and the public good nature of information. It is also argued that most biological control agents are able to spread well beyond the boundaries of the properties where they are introduced, and so they are also considered public goods (Tisdell, Auld and Menz 1984).

However, Pannell (1988) argues that policy–level research tends to have longer lags of adoption than farm-level research. This is due to the observation that farmers are forced by economic realities to be receptive to economically rational advice, but those in politics are prevented from being so by the electorate and the media.

Vere et al. (1997) present a review of the methods of production systems modelling, and how they have been applied to weeds research. Budgeting methods, including gross margin, partial budgeting and whole–farm budgeting, are some of the more simple techniques used in evaluating the economic impacts of weeds on farm systems. These methods are usually static in nature and the problems analysed in the short-run. However, many researchers have adopted an optimisation approach, using linear or non-linear programming. These models can be developed further by incorporating risk into the analysis, to more realistically represent farmer decision-making.

The paper then goes on to detail an integrated modelling system for evaluating the impacts of weeds and weed technology. The system incorporates both production and marketing sectors of the industry, in order to accurately assess the total impact of weeds. Farm-level models are necessary to highlight the costs of weeds and estimate the benefits of weed control. Aggregation of farm responses is used to estimate the supply response of the industry to improved weed control. This is used to derive estimates of the overall industry benefits of

reducing the effects of weeds. Empirical examples are also presented to demonstrate the practical application of the modelling system.

The analysis of weeds problems in this dissertation bears conceptual similarities to the analysis of land degradation conducted by Walpole, Sinden and Yapp (1996). It involved an assessment of the impact of land quality on agricultural output, using land degradation (as opposed to levels of weed infestation) as a measure of land quality. Cobb-Douglas production functions were estimated, from which the empirical models were derived. The models were then used to calculate the opportunity costs of different types of land degradation.

Vere et al. (1997) emphasises the need for greater utilisation of farm-level models. The paper maintains that research of this nature is necessary to establish the effects of weeds in production systems, and the output and revenue changes from improved weed control. The research undertaken in this dissertation is farm-level analysis, and so should be a relevant and useful contribution to the small but growing volume of literature on weed economics

3 Method and Data Collection

3.1 Method of Analysis

This study is based at the farm level and uses property data to determine the effects of various categories of weed infestation and tree cover on production. In particular, the study attempts to determine the effects of weeds on income. A *production function* shows the relationships between resources and their product, and relationships between the resources themselves (Cramer and Jensen 1994). The effects of land, labour and capital on output have traditionally been analysed using a production function of the form

$$Y = f(a, l, k) \tag{3.1}$$

where Y represents output, a quantity of land, l quantity of labour and k quantity of capital. To incorporate the effects of weeds on production, a specific extra variable is used for land quality. The resulting production function would be

$$Y = f(a, l, k, q) \tag{3.2}$$

where q is the measure of land quality (or weed levels).

Model 3.2 combines inputs which will have a positive impact on production (a, l and k) and one which may have a negative influence (q). The relationship should display diminishing

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marginal returns to each traditional unit of input (*a*, *l* and *k*), so a linear form would be inappropriate. In this situation a log-linear form such as the Cobb-Douglas may be more applicable (Walpole et al. 1996). A Cobb-Douglas production function is easy to use and is a 'relatively efficient' user of degrees of freedom (Heady and Dillon, 1969). It assumes constant elasticities and marginal products. It is suited to this analysis in that the coefficients of the variables in the function are the production elasticities of the respective inputs. This allows the effects of each input (including the weed variables) to be isolated and analysed.

The models to be estimated will represent a farm production system. They will be typical Cobb-Douglas production functions, with production dependent on land, labour and capital. They will also include a second land variable, *land quality*, which will be a measure of the levels of weed infestation. These equations will be estimated by regression analysis. After the functions have been estimated, they will be tested for statistical significance using the t-ratios of the variables and the adjusted coefficient of determination (R^2). The functions will also be tested for multi-collinearity, to ensure there is no bias in the estimation or the conclusions drawn.

There will be 36 individual production functions estimated in total. They will be a combination of the two measures of production (annual income and stocking rate), six aggregate weed variables and 12 disaggregate weed variables (see Table 1). Once the significant models have been determined, the actual effects of the various weed categories (if any) will be calculated. The degree of difference between the impact of each category will also be tested.

3.2   Data Collection

This study focuses on a local problem, for which no secondary data are available. A survey was therefore the most appropriate and effective method of data collection. After consultation with the New England Tablelands Noxious Plants County Council and field visits with six farmers, the survey questionnaire was constructed. A brief description of important variables is given in Table 1. The questions attempt to obtain information on the parameters included in the model, so information on income, stocking, land area, machinery and labour was requested, along with information on levels of weed infestation and tree cover. Tree cover was included when it was raised by several producers as a potential problem, especially regrowth in areas of cleared land.

The questionnaire also covered other variables to help explain the influence of weeds and clarify management techniques. These variables include physical aspects of the farm (such as soil type), weed history, and how long it has been managed by the respondent. The survey also asked for the respondents' opinion on issues related to weeds, for example, what had caused increases

or decreases in the weed densities on the property, what was the most effective method of controlling weeds, limitations on weed control programs and, whether controlling weeds had directly increased production.

Producers were not selected randomly, but selected to keep some factors similar, while allowing variation in others. The areas included in the survey had no cropping, similar soil types and were within 80 km of Armidale. The properties were selected to try and obtain a variation in property area, weed levels and management techniques. The New England Tablelands Noxious Plants County Council provided a list of local producers, from which 34 were approached by phone and asked whether they would participate in the survey. Thirty producers agreed to participate and the surveys were then distributed to them over April and May 1998. During July, 80% of the producers were personally interviewed, with the questionnaire. This ensured there was no confusion over the information required, and the data provided was in an appropriate form for use in the study. The remaining 20% returned their completed surveys by mail.

4 Results: Description of the sample

All farms in the survey were located in the Central District of the New England Tablelands Noxious Plants County Council. Cattle and sheep are the dominant sources of income, with goat and horse enterprises on a small number of farms as well. There was no commercial cropping on the land included in the survey. A summary of the statistics for the broad characteristics of properties is presented in Table 2.

There was a great variation in the size of the properties in the survey (AREA), ranging from a minimum of 481 ha to 7500 ha, with an average of 1732 hectares. Producers were asked to classify their land as either improved (with introduced species of pasture) or native pasture (NATIVE). Some farmers had sown their whole property to improved pasture (IMP), while others had not introduced any improved pasture species at all, reflected in minimum of zero and maximum of 100%. On average, 52% of each property was improved pasture, while native pasture covered the remaining 48% of the property.

The number of years a property has been owned or managed by the family of a respondent (OWN) ranged from four to 147 years. The average was a relatively long 45 years, although this average was influenced by several responses greater than 90 years. Seventy five percent of responses fell between 15 and 50 years. The average sale value of properties (VALUE) was $1.7 million, with 65% falling between $1 million and $3 million. Of course, this figure

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depends heavily on the size of the property, so this wide range of values corresponds with the range in land area.

For the 30 properties, the average total income for the last year (1997) was $306 900, and the average stocking was 9564 DSE. The value of machinery, as a replacement cost, varied from $15 000 to $254 000, and averaged $118 480. The final variable in Table 1 is total labour (family labour plus hired labour) and the range of values again reflects the large variation between the properties. The average amount of labour used last year was 369 days, but ranged up to 2450 days.

The next set of variables, in Table 3, is directly concerned with weed management. The first item in the table is the percentage of the property completely free of weeds or trees (CLEAN). On average, producers said that almost 60% of their property was clear of weeds. The minimum of zero indicates that some farmers believed their entire property has weeds or tree cover of some kind. The maximum of 99.6% implies that not one producer believed their property was totally unaffected by weeds or tree cover.

The area covered by producers' weed control program (CNTRL) averaged 633.8 ha, or 42.7% of the property (AREAC). Some farmers' programs to control weeds covered their entire property, reflected by a maximum of 100% for AREAC, but others have a very small control program (implied by a minimum of 0.9%). Of the area covered by the weed program, an average of 41.0% is controlled by grazing (GCNTRL) and an average of 67.1% is controlled using herbicides (HCNTRL). Most producers use a combination of both forms of control, and some also employ mechanical control methods such as slashing or chipping. However, a few producers use either grazing or herbicides exclusively, reflected by maximums of 100%, and others don't use grazing at all, shown by the minimum of zero. When asked to rank the most effective form of weed control, 90% of farmers chose herbicides, or a combination of herbicides and grazing. Only two ranked grazing as the most effective form. However, it must be remembered that grazing cannot be used to control some weeds in the Tablelands area.

Time spent controlling weeds (WTIME) presents some interesting results. Out of all producers surveyed, the average time spent on weed control was 37 days, with a minimum of five and a maximum of 200 days. This is of course, heavily influenced by the size of the property and the labour available. Many producers maintained that the largest constraints on their weed control program was time and money – they didn't have enough time to spend more on weeds, and didn't have the money to employ someone else to do it for them. However, the amount of time spent

controlling weeds is positively correlated with both income and stocking, so there could be benefits to producers if they increased WTIME.

The final value in Table 3 concerns the respondent's estimate of the potential increase in production as a result of weed control (PRODINC). The average is 5.7%, but this value could be misleading because 40% of producers claim there was no increase in production due to weed control. The distribution of estimates is as follows.

No increase	40%
5% - 10% increase	40%
+15% increase	20%
	100%

Only six claimed increases of 15% or greater, the remainder estimated a five to 10% increase in production.

The basic statistics for the variables for levels of infestation by type of weed are summarised in Table 4. The first part of the table concerns the aggregate variables WNOX, WOTH, TREE, PNW, POW, PT, X1, X2 and X3. The disaggregate variables are split into three categories, noxious weeds (W1, W2, W3 and W4), non-noxious weeds (O1, O2, O3 and O4) and tree cover (T1, T2, T3 and T4). Tree cover was included in the study as a "weed" because some farmers consider tree regrowth a problem (see Section 3).

Again, there is a large difference in the areas and percentages for both the aggregate and disaggregate variables. Some farmers reported that certain categories of weeds don't exist on their properties, so these categories have a minimum of zero. However, the maxima for some of the variables are substantial, as high as 2732 ha. The maxima for the percentage figures 50%, 88% and 57% for noxious plants (PNW), non-noxious plants (POW) and trees (PT) respectively are also high. The minimum value for X3 (percentage of the property affected by any problem plant) of 0.4 per cent shows that no farmer considered their property completely free of either noxious or non-noxious weeds, or trees. This reinforces the conclusion drawn above from figures for the area of the property totally clear of weeds (CLEAN).

5 Results: estimation of the models

Since Cobb-Douglas production functions were to be estimated, the log of each variable was calculated. The functions incorporate combinations of the two measures of production (annual income and stocking level) and the six aggregate and twelve disaggregate measures of weed infestation. The coefficients of the explanatory variables were tested for significance using

t-ratios. A model was deemed useful if the weed variable was negative and statistically significant, that is, its t-value was above an absolute value of 1.3, using a level of significance of 10% and 25 degrees of freedom, (Newbold and Bos 1994). The equations as a whole were tested for significance using the adjusted coefficient of determination (R^2). The figures in brackets are the t-ratios.

5.1   For Aggregate Weed Variables

The initial task was to examine the effect of weeds as a whole, but only one of the models with aggregate weed variables proved useful. This model contained the dependent variable stocking (DSE), area, machinery and labour, and variable X3, that is, area of land affected by all three categories of weeds, as a percentage of total area. Although only this one is significant (model 5.2), its counterpart for income is also reported (model 5.1).

5.1 $LYT = 4.185 + 1.057 LAREA + 0.055 LMACH - 0.032 LLAB + 0.044 LX3$ $R^2 = 0.56$
$\quad\quad\quad\quad\quad\quad (5.2) \quad\quad\quad\quad (0.2) \quad\quad\quad\quad (0.4) \quad\quad\quad (0.4)$

5.2 $LDSE = -2.046 + 0.880 LAREA + 0.360 LMACH + 0.061 LLAB - 0.090 LX3$ $R^2 = 0.81$
$\quad\quad\quad\quad\quad\quad\quad (8.0) \quad\quad\quad\quad (2.8) \quad\quad\quad\quad (1.5) \quad\quad\quad (1.6)$

The income model (5.1) does not have a significant weed infestation variable (the t-ratio is below 1.3), and so is not useful for further analysis. Therefore, no aggregate weed variable

significantly affects income. However, the stocking or DSE model does have a significant X3 variable, and it also has a higher R^2 value. Model 5.2 also conforms to theoretical expectations in terms of the signs and significance of all the variables. The inputs (LAREA, LMACH and LLAB) have positive coefficients, meaning that each extra unit of the input increases the dependent variable (DSE).

These coefficients are the elasticity's of the inputs with respect to stocking, and show the percentage change in DSE resulting from a 1% change in that particular variable, holding all other variables constant. Thus, X3 in equation 5.2 has a negative elasticity of 0.090, implying that an increase of 1% in the area of the property affected by weeds and trees reduces stocking by 0.090 %.

5.2   For Disaggregate Weed Variables

Eight of the 24 disaggregate models appear to be useful. The equations with significant weed variables come from both the income and stocking sets, and each weed category is represented. The full series of significant functions is as follows.

5.3 $LYT = 3.356 + 1.058LAREA + 0.194LMACH - 0.073LLAB - 0.161LO1$ $R^2=0.58$
                (5.3)   (0.6)   (0.2)   (1.3)

5.4 $LYT = 3.950 + 1.091LAREA + 0.042LMACH + 0.012LLAB - 0.160LO2$ $R^2=0.64$
                (5.9)   (0.2)   (0.2)   (2.4)

5.5 $LYT = 2.802 + 1.230LAREA + 0.056LMACH + 0.010LLAB - 0.140LT2$ $R^2=0.63$
                (6.2)   (0.3)   (0.2)   (2.4)

5.6 $LYT = 2.899 + 1.152LAREA + 0.105LMACH - 0.015LLAB - 0.089LT3$ $R^2=0.61$
                (5.8)   (0.6)   (0.2)   (1.8)

5.7 $LDSE = -0.504 + 0.824LAREA + 0.292LMACH + 0.048LLAB - 0.054LW4$ $R^2=0.82$
                (7.5)   (2.8)   (1.5)   (1.6)

5.8 $LDSE = -0.260 + 0.882LAREA + 0.219LMACH + 0.067LLAB - 0.087LO2$ $R^2=0.83$
                (8.4)   (2.1)   (1.7)   (2.3)

5.9 $LDSE = -0.894 + 0.961LAREA + 0.225LMACH + 0.067LLAB - 0.078LT2$ $R^2=0.83$
                (8.6)   (2.2)   (1.7)   (2.4)

5.10 $LDSE = -0.891 + 0.926LAREA + 0.252LMACH + 0.054LLAB - 0.058LT3$ $R^2=0.82$
                                 (8.4)   (2.4)   (1.4)   (2.1)

Overall, these models match the expectations regarding coefficients. The signs for the input variables are positive (with the exception of models 5.3 and 5.6, which have negative but insignificant labour coefficients) and the signs for the weed variables are all negative. As noted above, these coefficients represent the elasticity of each variable with respect to the dependant variable (either income or stocking).

The R^2 values are uniformly high across all models, with the stocking models having higher average R^2 values than the income models. The stocking models are also stronger models in terms of the number of significant variables. In all four income models, both labour and machinery are insignificant, implying that these variables contribute little to explaining the changes in income. In contrast, in the stocking models, all variables are significant, suggesting that all four variables have an important influence on stocking levels of the farms in the sample.

The problem of multicollinearity was also examined using correlations. According to Griffiths, Hill and Judge (1993) a correlation coefficient greater than 0.8 indicates a potentially harmful collinear relationship. In the significant models the highest level of correlation was 0.78, between income and area (see Appendix 3), therefore multicollinearity is not a problem.

5.3   Differences in the Effects of Weed and Tree Variables

The effects of the weed variables on production are given by the elasticities, so the next step was to determine if there was any statistical difference between the effects of the different weed variables. That is, does one category of weeds have a greater impact on income or stocking than the other categories? This was accomplished by testing the degree of difference between the elasticities of the weed variables. Since the models are linear-log Cobb-Douglas production functions, the elasticity of each variable is simply the parameter estimated in the model.

The elasticities were compared using standard hypothesis tests following Newbold and Bos (1994). At a significance level of 0.05, and with 25 degrees of freedom, a critical value of 1.708 was used to test the null hypothesis that the elasticity of one weed category was equal to the elasticity of another weed category. This was done for the income models above, and then for the stocking models. As a group, there is no statistical difference between the different categories of weed infestation in terms of their impacts on income.

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Hypothesis tests were also undertaken for the four stocking models (5.6 to 5.10). Again, in each case the absolute value of the test statistic was less than the critical value, and so the null hypothesis could not be rejected. There was, therefore, no statistical difference between the elasticities of each disaggregate category of weed infestation. No individual category has a greater effect on stocking than any other category.

5.4   Effects of Changes in Weed and Tree Area on Income

The changes in income are determined for the significant weed and tree variables for the representative property. An estimate of the effects of each level of weed infestation on income can be determined from the models, using the average areas for each infestation and their elasticities. The results were as follows.

Model	Weed Variable	Change in Income ($)	% Change in income
5.3	LO1- very heavy non-noxious weeds	+ 17 290	5.6
5.4	LO2 – heavy non-noxious weeds	+ 28 202	9.2
5.5	LT2 – heavy tree cover	+ 29 802	9.7
5.6	LT3 – medium tree cover	+ 26 053	8.5

These results show that the total eradication of these categories of weeds would have a major impact on income. Eradication of very heavy infestations of non-noxious weeds (model 5.3) would have the least effect. This is because it does not affect a very large area of the sample properties, averaging only 3.6ha . Its eradication would increase income by $17 290, or 5.6%. Interestingly, the lower infestation level LO2 has a larger effect on income than does LO1, perhaps because LO2 covers a larger average area (17.6 ha). The category with the largest impact on income is heavy tree cover (LT2, model 5.5). Total removal of LT2 would increase average income by $29 802. However, the total eradication of weeds is an almost impossible task, farmers have neither the time nor the money to do so, and removal of all trees is usually not desirable.

Consider now the total loss in income (or the increase in income from eradication) for a representative property for the two categories of non-noxious weeds. This loss can be estimated directly using the average area of LO1 and LO2 and the results derived above.

Loss of income = cost of LO1 + cost of LO2

= 17 290 + 28 202

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$$= \$45\ 492$$

Thus, the loss in income for the representative property with an area of 1732 ha is \$45 492 per year, or 14.8% of annual income. Again, the total eradication of all these weeds is an almost impossible task from a technical viewpoint, and may not be entirely profitable from an economic viewpoint.

6 Discussion and Conclusions

The weeds variables were tested first, as aggregates, to see if the area of weeds as a whole affected income or stocking. Only one of these aggregate weed variables proved significant, and then only in relation to stocking. Thus weeds in the aggregate appear to have no influence on income. But effects on income and stocking could be discerned when the areas of weeds were disaggreggated by weeds groups (noxious and non-noxious) and by levels of infestation (light to very heavy). Even after this disaggregation, noxious weeds did not have a significant effect on income, only stocking –- whereas non-noxious weeds did. This implies that non-noxious weeds have a greater impact on production in the New England Tablelands than do noxious weeds. Variations in the areas of very heavy and heavy infestations of non-noxious weeds, and in heavy to medium tree cover, did influence income and stocking.

The major limitation of the study is the simplicity of the model used in the analysis. It does not account for other factors that may affect production, such as rainfall, drought and attitude to risk. In regard to the variables included in the analysis, many had high standard deviations, especially the weed variables. This indicates a large variation in the data across the properties. Thus conclusions drawn for average figures may seem unrelated to the actual farms in the survey.

Another limitation is the nature of the measurements of weed and tree levels. Each farmer was asked to classify his land according to the four levels of infestation. Thus these measures of weeds and tree cover were not entirely objective. Related to this is the difficulty in valuing extra pasture production. Since pasture is an intermediate product with no market price, its value has to be calculated from livestock production (Pannell 1988). This may not reflect the true value of the increased pasture production. Also, when estimating production, capital should include sheds, improvements to land etc. Machinery (as used in this study) is not a full measure of capital.

This study is based at the farm level, so the main benefits from the research accrue to local farmers. The study could be expanded and conducted in other areas, perhaps involving a greater number of properties and incorporating more variables. This would allow identification of the impacts of weeds at a regional level. A larger scale study may also be able to identify the effects on production, and the importance, of individual weed species.

There may also be value in further investigation of the impacts of trees on farm production. Several farmers raised the issue of tree re-growth as a negative impact during the initial stages of the study, prompting the inclusion of tree cover in the analysis. However, trees are widely recognised for their positive contributions to preventing soil erosion and providing cover and protection for pasture and livestock. Research into the economic optimum level of tree cover would be of great interest and value to local producers.

Government intervention is only justifiable when there is market failure. Weeds impose external costs when they spread beyond the boundaries of farms, or when farmers are producing external costs (or benefits) with their weed control programs. If this occurs, the sum of the quantities of private weed control will not be equal to the socially–optimal level of weed control. Further research may identify the existence of externalities, and therefore justify government involvement in control programs to prevent the spread or re-invasion of weeds.

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Table 1: Description of variables used in analysis

VARIABLE	DESCRIPTION
INCOME	Annual income for last year ($)
DSE	Stocking rate of property (DSE[a])
AREA	Total area of property (ha)
MACHINERY	Replacement value of machinery ($)
LABOUR	Total labour (family + hired) employed on farm (days)
AGGREGATE WEED VARIABLES	
PNW	Area of noxious weeds as a percentage of total area
POW	Area of non-noxious weeds as a percentage of total area
PT	Area of tree cover as a percentage of total area
X1	PNW (%)
X2	PNW + POW (%)
X3	PNW + POW + PT (%)
DISAGGREGATE WEED VARIABLES	
W1 to W4	Area of noxious weeds in four categories of infestation - very heavy (W1), heavy (W2), medium (W3) and light (W4)
O1 to O4	Area of non-noxious weeds in four categories of infestation - very heavy (O1), heavy (O2), medium (O3) and light (O4)
T1 to T4	Area of tree cover in four categories of infestation - very heavy (T1), heavy (T2), medium (T3) and light (T4)

[a] amount of feed required to maintain a 48 kg wether for a period of 12 months (Makeham and Malcolm, 1993)

Table 2: Mean, standard deviation and range for property variables

NAME	VARIABLE	N	MEAN	ST. DEV	MINIMUM	MAXIMUM
AREA	Total area of the property (ha)	30	1732	1569	481	7500
IMP	% property with improved pasture	30	52	37.5	0	100
NATIVE	% property with native pasture	30	48	36.7	0	100
OWN	Years property owned or managed by family	30	45	34.8	4	147
VALUE	Sale value of the property ($m)	30	1.7	1.3	0.5	6.4
YT	Total income per property ($)	30	306 900	359 640	13 790	1 771 900
DSE	Total DSE per property	30	9564	8309	1764	30 140
MACH	Total value of machinery ($)	30	118 480	62 782	15 000	254 000
LABT	Total labour (days)	30	369	532	0	2450

Table 3 Mean, standard deviation and range for the weed management variables

NAME	VARIABLE	N	MEAN	ST. DEV	MIN	MAX
CLEAN	% property free of weeds	30	58.4	34.8	0	99.6
CNTRL	Area covered by weed control program (ha)	30	633.8	727.4	7	3100
AREAC	CNTRL as % of total area	30	42.7	37.9	0.9	100
GCNTRL	Area controlled by grazing (% of CNTRL)	30	41.0	39.0	0	100
HCNTRL	Area controlled by herbicides (% of CNTRL)	30	67.1	34.9	1.1	100
WTIME	Time spent controlling weeds (days)	30	37	43.5	5	200
PRODINC	Increase in production due to weed control (%)	30	5.7	6.2	0	20

Table 4: Mean, standard deviation and range for specific weed variables

Aggregate variables

NAME	VARIABLE	N	MEAN	ST. DEV	MINIMUM	MAXIMUM
WNOX	Area of noxious weeds (ha)	30	198.6	245.3	0.0	1000
WOTH	Area of non-noxious weeds (ha)	30	392.9	651.5	0.0	2732
TREE	Area of tree cover (ha)	30	217.2	366.4	0.0	1416
PNW	Area of noxious weeds (% of total)	30	12.6	14.3	0.0	50.0
POW	Area of non-noxious weeds (% of total)	30	19.5	22.6	0.0	88.8
PT	Area of tree cover (% of total)	30	9.5	14.5	0.0	56.5
X1	PNW	30	12.6	14.3	0.0	50.0
X2	PNW + POW	30	32.1	32.1	0.4	100
X3	PNW + POW + PT	30	41.6	34.8	0.4	100

Noxious weeds: by class of infestation

W1	Very heavy (ha)	30	4.9	18.9	0	101
W2	Heavy (ha)	30	9.1	30.1	0	162
W3	Medium (ha)	30	64.3	191.3	0	1000
W4	Light (ha)	30	120.4	185.7	0	669

Non-noxious weeds: by class of infestation

O1	Very heavy (ha)	30	3.6	18.5	0	101
O2	Heavy (ha)	30	17.6	46.6	0	161
O3	Medium (ha)	30	142.3	399.2	0	2000
O4	Light (ha)	30	229.4	545.8	0	2732

Tree cover: by class of infestation

T1	Very heavy (ha)	30	47.1	138.9	0	607
T2	Heavy (ha)	30	58.8	190.5	0	1000
T3	Medium (ha)	30	70.8	163.4	0	663
T4	Light (ha)	30	40.5	107.9	0	500