Fertiliser Association
Shaping profitable and sustainable farming

Cadmium balance model decision support tool

User Guide Version 2.0.1

The CadBal model was initially developed for New Zealand agricultural systems in 1996 by A.H.C.Roberts and R.D.Longhurst (AgResearch). This early model (Version 1.03) was upgraded in 2005.

A review of the model was undertaken by AgResearch and Manaaki Whenua (Landcare Research) in 2018. Following significant investment by the Cadmium Management Group on New Zealand specific research including assessment of the relationships between plant uptake and soil characteristics, the Fertiliser Association of New Zealand commissioned AgResearch, with assistance from Manaaki Whenua (Landcare Research), to undertake a full redevelopment of the model. Link

The Cadmium Balance Model has been developed with the best available science and New Zealand specific data, but large uncertainties remain[1]. The model results are sensitive to selection of soil pH, organic matter and drainage, and these inputs should be selected carefully, based on robust supporting information.

Background

CadBal is a mass-balance model that estimates cadmium (Cd) accumulation or depletion in agricultural soils over time. It is based on the initial total soil Cd concentration for a Land Management Unit (LMU), along with a series of Cd inputs and losses summarised in Figure 1.

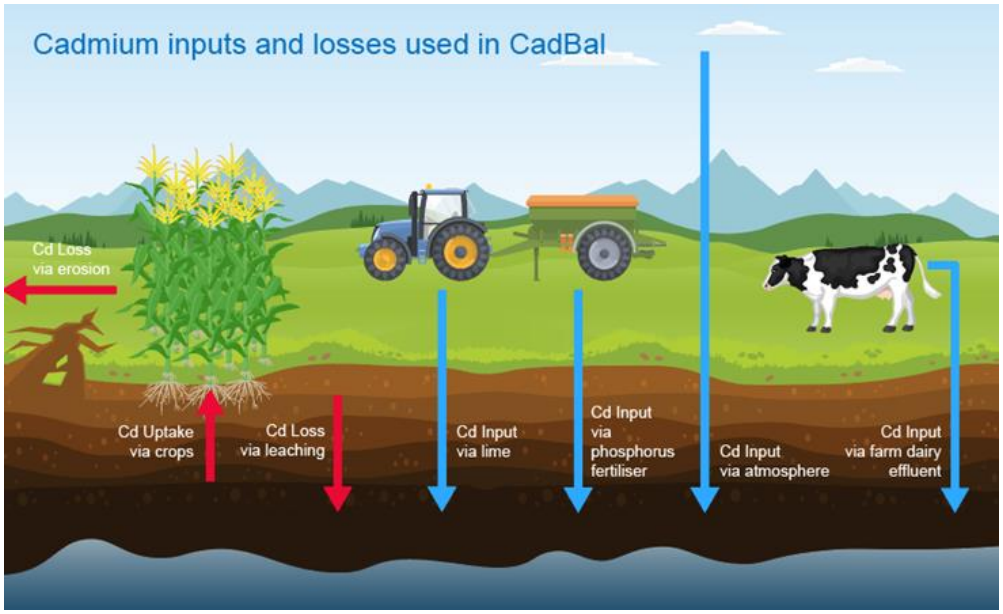

Figure 1: Summary of the main cadmium (Cd) inputs and Cd losses used in the CadBal model.

[1] **Disclaimer:** Every effort has been made to ensure this tool is consistent with current science. However, scientific research and development can involve extrapolation and interpretation of uncertain data and can produce uncertain results. Neither the Fertiliser Association of New Zealand or any organisation or person involved in development of this tool, shall be responsible for any error or omissions or for any use of or reliance on this tool unless specifically agreed otherwise in writing. To the extent permitted by law, the Fertiliser Association of New Zealand excludes all liability in relation to this tool, whether under contract, tort (including negligence), equity, legislation or otherwise unless specifically agreed otherwise in writing.

This online tool allows users to predict Cd accumulation in soils over time for different land management scenarios. It can be used to ensure Cd does not accumulate in soils to concentrations that will pose a risk to agricultural production systems in New Zealand. The tool should be used alongside OVERSEER® and the Tiered Fertiliser Management System (TFMS) for decision making. This guide summarises the different input parameters required to be entered by a user to operate the CadBal model. Detailed information and the data supporting the different input parameters are reported in the technical document (Gray and Cavanagh 2020).

Agricultural system

To calculate crop offtake of Cd in the CadBal model, the user is required to firstly select the agricultural system of their LMU, categorised as either i) a grazed or annual crop or ii) a short rotation crop.

Grazed or annual crop

For grazed or annual crop where a single crop is grown for one or more years, including crops grazed by livestock, the user is required to select a crop type from a dropdown list in the CadBal model. A default plant uptake factor (PUF) is then assigned based on the crop selected from a table stored in the CadBal model (Table 1). The user will then be asked if the crop is grazed or not grazed.

For grazed crops, a default value of 1% biomass removal will be assigned for that crop. For crops that are not grazed e.g. a cut and carry system or an annual food crop, the user is required to enter the proportion (2 to 100%) of the crop biomass that is harvested from their LMU. The user is then required to enter the P fertiliser application rate and select the P fertiliser product applied to the crop from a dropdown list, input the anticipated dry matter or fresh weight yield for the crop, and the application rate and Cd concentration of lime and/or farm dairy effluent (FDE) if applied to their LMU.

Table 1: Plant uptake factors (PUF) used in the CadBal model for crops grown on volcanic and non-volcanic soils for grazed and annual crops. Data are from Cavanagh et al. (2015; 2017); Rietra et al. (2017); Lin et al. (2015); Smolders et al. (2008); Alexander et al. (2006).

Crop type	Volcanic soils PUF	Non-Volcanic soils PUF
Chicory, plantain, fodder beet, kale	0.67	2.30
Pasture, ryegrass, lucerne, maize	0.09	0.24
Potato	0.28	0.73
Wheat, barley, oats	0.50	
Kumara, beans, peas, sweetcorn	0.39	
Carrots, broccoli, cauliflower, cabbage, beetroot, Asian greens, leeks, turnips, swedes	1.75	

Short rotation crop

For short rotation crops, the user is required to select from up to a maximum of six crops grown in a rotation period of either one, two or three years. The crop types are available from a dropdown list for which a default PUF will be assigned from a table stored in the CadBal model (Table 2). The assumption for short rotation crops is that 100% of the edible yield is removed. For each crop, the user is required to enter the P fertiliser application rate and select the P fertiliser product applied to the crop from a dropdown list, input the anticipated dry matter or fresh weight yield (based on the edible portion) for each crop, and the application rate and Cd concentration of lime, if applied to their LMU.

Table 2: Plant uptake factors (PUF) used in the CadBal model for crops grown on volcanic and non-volcanic soils for short rotation crops. Data are from Cavanagh et al. (2015; 2017); Rietra et al. (2017); Lin et al. (2015); Smolders et al. (2008); Alexander et al. (2006).

Plant type	Volcanic soils	Non-volcanic soils
Potato	0.28	0.73
Onion	0.32	0.68
Spinach	2.8	4.5
Lettuce	0.42	3.1
Wheat, barley, oats	0.5	
Kumara, beans, peas, sweetcorn	0.39	
Carrots, broccoli, cauliflower, cabbage, beetroot, Asian greens, leeks, turnips, swedes	1.75	
Silverbeet	4.2	

Rate of P fertiliser

The user is required to enter the rate P fertiliser is applied to their LMU in units of kg P ha^{-1} yr^{-1}. This can be the amount of P fertiliser from a single product or from the application of more than one product in a year. For example, if P fertiliser is applied to different crops which have different P requirements.

Cadmium in P fertiliser products

The user is required to select the name/s of the P fertiliser product they apply from a dropdown list in the CadBal model. This is because different P fertiliser products have different assumed maximum Cd concentrations. The products are grouped into either direct application phosphate rock, sulphuric acid derived, phosphoric derived or nitric acid derived products as categorised in the Tiered Fertiliser Management System (TFMS) (Table 3). There is also the option for the user to enter their own 'other' Cd concentration for their P fertiliser product in units of mg Cd kg^{-1} P.

Table 3: Assummed maximum cadmium (Cd) limit (mg Cd kg^{-1} P) in different phosphate fertiliser product groups (FANZ 2019).

Product group for phosphate fertiliser	Assumed upper limit for Cd concentration (mg Cd kg^{-1} P)	Phosphate fertiliser product
Direct application phosphate rock	280	Direct application phosphate rock/reactive phosphate rock
Sulphuric acid derived products	280	Single superphosphate Sulphur super Potash super Serpentine superphosphate Superphosphate blends
Phosphoric acid derived products	220	Triple superphosphate Di-ammonium phosphate Mono ammonium phosphate
Nitric acid derived products	100	Compound fertiliser prills

Rate of lime application

The user has the option to enter the rate lime is applied to their LMU in units of kg lime ha^{-1} yr^{-1}.

Cadmium in lime

If lime is applied the user will be required to either select the default lime concentration of 0.15 mg kg^{-1} or enter their own 'other' lime Cd concentration in units of mg Cd kg^{-1}.

Rate of FDE application

The user has the option to enter the rate FDE is applied to their LMU in units of mm FDE ha^{-1} yr^{-1}.

Cadmium in FDE

If FDE is applied the user will be required to either select the default FDE concentration of 0.55 µg Cd L^{-1} or enter their own 'other' FDE Cd concentration in units of µg Cd L^{-1}.

Rate of FDE pond solids application

The user has the option to enter the rate FDE pond solids are applied to their LMU in units of kg pond solids ha^{-1} yr^{-1}.

Cadmium in FDE pond solids

If FDE pond solids are applied the user will be required to either select the default FDE pond solids concentration of 0.09 mg kg^{-1} dry weight (DW) or enter their own 'other' FDE pond solids Cd concentration in units of mg Cd kg^{-1}.

Soil order

The user is required to select the soil order for their LMU from a dropdown list in the CadBal model (Table 4). If the user does not know the soil order of their LMU, it may be obtained from Smap (https://smap.landcareresearch.co.nz) or from their local regional council.

Table 4: Soil order (Hewitt 2010) and mean soil bulk density (kg m^{-3}) based on data extracted from the National Soil Database (Wilde and Ross 1996).

Soil order	Bulk density (kg m^{-3})
Allophanic	764
Brown	1004
Gley	859
Granular	1010
Melanic	984
Organic	428
Oxidic	961
Pallic	1236
Podzol	875
Pumice	866
Recent	1110
Semi-arid	1373
Ultic	1064

Soil bulk density

When a soil order is selected for the LMU, a default bulk density value is assigned from a lookup table stored in the CadBal model, based data extracted from the National Soil Database (Wilde and Ross 1996) (Table 4). There is also the option for the user to enter their own 'other' bulk density value in units of kg m-3.

Soil depth

The user is required to select the soil depth Cd concentrations will be modelled for their LMU. A default soil depth of 0 – 0.150 m has been assigned because in the context of the TFMS, a 'critical and definitive' measure of soil Cd is based on concentrations calculated at this depth. There is also flexibility for the user to select two 'other' soil depths (0 – 0.075 m and 0 – 0.100 m) where soil Cd data is commonly available or enter their own soil depth in units of m.

Initial soil cadmium concentration

The user is required to enter the current total soil Cd concentration for their LMU measured at the 0 – 0.150 m depth in units of mg Cd kg^{-1} soil. However, as described above, they can also enter a soil Cd concentration measured at 0.075 m and 0.100 m soil depths or other soil depth. Soil Cd concentrations should be obtained using the sampling and analysis protocols outlined in the TFMS (FANZ 2019).

Sediment yield based on landuse

The user is required to select the landuse that best represents their LMU from a dropdown list in the CadBal model (Table 5). Land use is categorised into sheep, dairy, winter crop, mixed (sheep/beef), deer and market garden/arable cropping. A sediment load based on landuse is used along with the total soil Cd concentration to calculate Cd loss via soil erosion in the CadBal model. The sediment loads are a summary of paddock and catchment scale values measured for a range of New Zealand sites reported in Gray and Cavanagh (2018). The user can also enter their own 'other' sediment load in units of kg ha^{-1} yr^{-1}.

Table 5: Median sediment loads (kg ha^{-1} yr^{-1}) from sheep, dairy, winter crop, mixed, deer and market garden/arable cropping landuse (Gray and Cavanagh 2018).

Landuse	Sediment load kg ha^{-1} yr^{-1}
Sheep	595
Dairy	131
Winter crop	1012
Mixed (largely sheep and beef)	988
Deer	2068
Market garden/arable cropping	500

Atmospheric accession

The user is required to select a Cd input from atmospheric accession for their LMU from a dropdown list in the CadBal model (Table 6). Atmospheric accession has been categorised by region. If data for their region is not available, the user can select the New Zealand average (220 mg ha^{-1} yr^{-1}) or enter their own 'other' atmospheric accession value in units of mg Cd ha^{-1} yr^{-1}.

Table 6: Atmospheric accession of cadmium (Cd) (mg ha^{-1} yr^{-1}) at six regions in New Zealand across two years of monitoring (Gray et al. 2003).

Region	Cd (mg ha^{-1} yr^{-1})
Northland	210
Waikato	270
Taranaki	90
Manawatu/Whanganui	360
Canterbury	210
Southland	90

Cadmium leaching

To calculate Cd leaching loss, the user is required to enter input parameters for soil pH (measured in water), soil organic matter (OM) content (%), and the total soil Cd concentration (mg kg^{-1}) for the soil depth soil Cd concentrations are being modelled in the LMU.

The user is also required to enter a measurement of annual drainage (mm) for their LMU. Given the importance drainage has on the amount of Cd leaching, it is important accurate data is used. The preference is for the user to use annual drainage data obtained using OVERSEER® for their LMU. If this data is not available, a drainage value will be assigned based on the region and soil order selected for the LMU that takes into account rainfall and PET and if any irrigation is applied.

Model output

- The outputs from the CadBal model are soil Cd accumulation over time (annual iterations up to 100 yr) in mg Cd kg-1.
- The user can also calculate the time in years (limited to 1000 yr) to reach three user defined soil Cd targets (1.0, 1.4 and 1.8 mg Cd kg-1) that align with triggers 2, 3 and 4 in the TFMS (FANZ 2019), or enter their own soil Cd target.
- The user can also calculate the maximum Cd concentration in fertiliser (mg Cd kg-1 P) in order not to exceed a pre-defined soil Cd target in a specified number of years.
- They can then re-run the CadBal model using this maximum fertiliser Cd value.

References

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