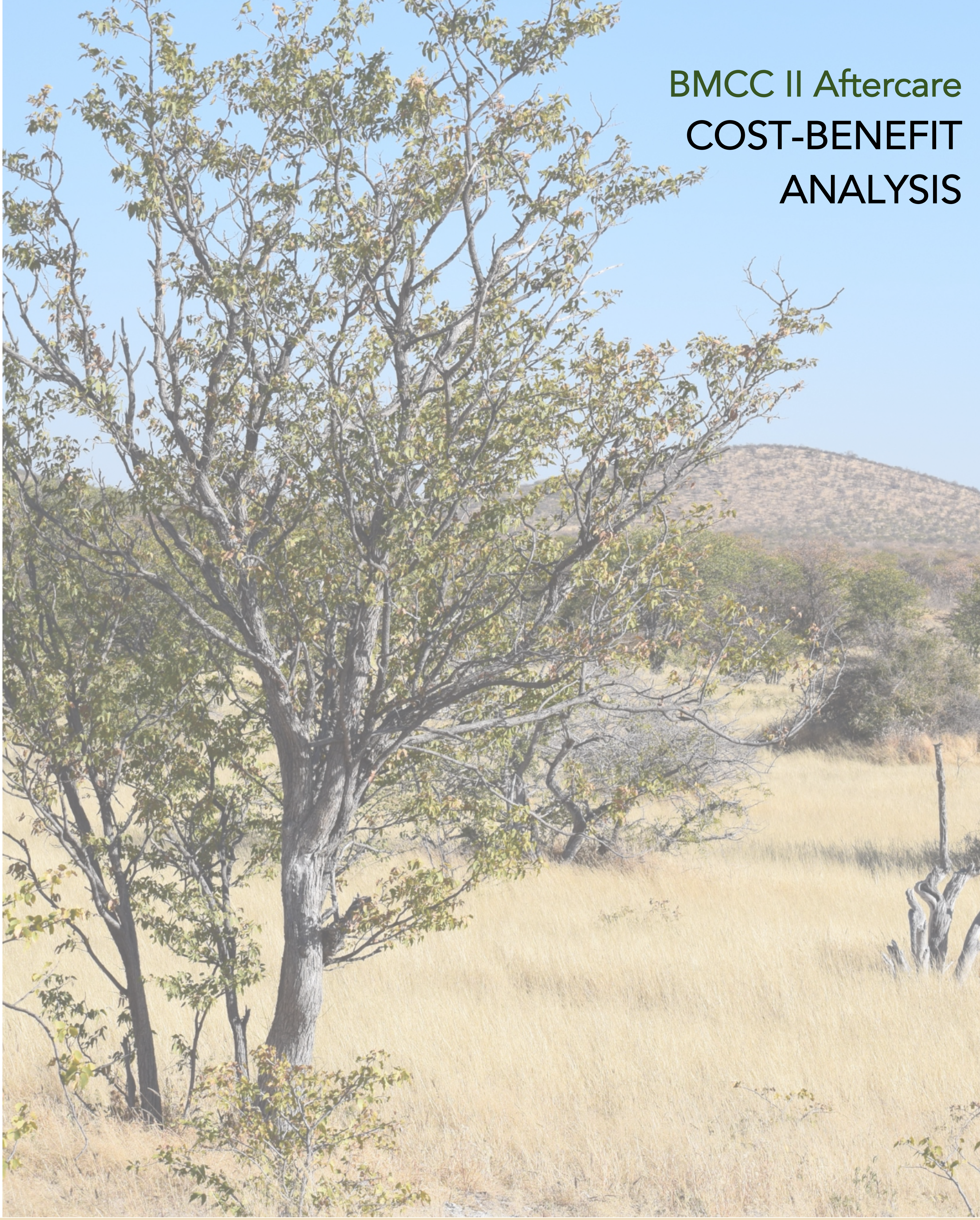
BMCC II Aftercare
COST-BENEFIT ANALYSIS



NAMIBIA NATURE FOUNDATION
76 – 78 Frans Indongo Street
Windhoek, Namibia
TEL: + 264 61 248345
FAX: +264 61 248344
EMAIL: juliette@nnf.org.na

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Juliette Perche (NNF), Cornelis van der Waal (Agri-Ecological Services) & Jerome Boys (MAWLR)

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Acronyms

CBA	Cost-Benefit Analysis
ETTE	Evapotranspiration Tree Equivalent
ha	hectare
LV	Leaf Volume
MAWLR	Ministry of Agriculture, Water, and Land Reform
MEFT	Ministry of Environment, Forestry and Tourism
NPV	Net Present Value
TE	Tree Equivalent

1. Background and Aim

Encroaching woody species in Namibia have become a major ecological and economic issue, substantially reducing land productivity in terms of grazing capacity for livestock, suitability for game, and other ecosystem services such as groundwater recharge rates. For this reason, the government of Namibia has integrated bush control in its development targets and aims to thin bush on 18,800 km^2 by the year 2040 (NDP5).

This requires land users to engage in large-scale thinning of woody plants to restore the landscape and increase the grazing capacity of the land. Many land users have engaged into bush thinning activities since the 1980s but it has appeared many woody encroachers do not die after being removed and strongly regrow from the roots and/or stem bases (Strohbach 1998). As a result, the positive effects of bush thinning are mostly short-lived and only persist for 5 to 7 years (Archer et al. 2017) after which the often-denser bush needs to be controlled again preferably by means of thinning to ensure ecosystem stability. To enhance land productivity through bush thinning and restoration efforts, post-harvest treatment of woody plants after thinning is vital to maintain the productivity of the herbaceous layer (Archer & Predick 2014, majority of interviewed experts). Yet, few farmers in Namibia conduct aftercare as they are considered labour intensive and expensive. Initial bush thinning efforts are often very expensive and further investments into post-harvest treatments are either not within the financial capacity of the farmer or not seen as justified due to the uncertainty in effectiveness of post-harvest treatment measures in controlling bush regrowth.

A better understanding of the costs and effectiveness of post-harvest treatments and the long-term financial implications for those who implement them is a necessary step to enable upscaling of these practices, and address financial constraints. Knowledge of the costs and benefits of different measures for land users can pave the way to establishing appropriate incentive mechanisms for sustainable practices to be widely implemented. It also highlights potential trade-offs between environmental impacts and economic benefits faced by land users.

Although little scientific evidence is available on the effectiveness of different post-harvest measures in mitigating regrowth and enhancing land productivity, this study relies on available field studies to provide a starting point for comparisons between measures. This cost-benefit analysis aims at providing evidence on the **net benefits** between different aftercare measures over 25 years, allowing for information-based comparison. In turn, this should facilitate farmers and biomass users to consider different options to minimize costs while maximizing long-term benefits. It also aims at providing evidence on the potential economic and environmental trade-offs of different measures and is thus complementary to the Environmental Assessment study of post-harvest measures.

2. Scope

A review (State of Knowledge Report) of the existing and potential post-harvest treatment measures has been conducted and is attached to this report. Due to data constraints, this study focuses on the following measures, namely: (i) manual cutting, (ii) mechanical rolling, (iii) chemical application (foliar, cut stump and soil-applied), (iv) controlled fires, (v) biological control using goats, as well as two combination scenarios: (vi) fire and goats, and (vii) fire and chemical application. These measures cover a range of options adapted to different levels of financial capacity and are considered diverse enough to address potential issues of different measures in specific landscapes – for instance, fire in areas with a high clay content in the soils. The method of brush packing combined with re-seeding was also analysed, although it should be considered as a complementary measure to other treatments listed above.

This study considers the costs and benefits associated with aftercare measures only, dissociating them from costs and benefits associated with the initial bush thinning / harvesting operation. The difference between bush thinning measures and post-harvest treatment measures is defined as follows:
Post-harvest treatment measures include all measures to contain the regrowth of bush after initial bush thinning -independent of whether the bush is harvested for commercial use or to restore land. Once the

average tree density exceeds 75% of the maximum potential TE/ha, the land is considered re-encroached and in need of another bush thinning operation.

The diversity of ecological and environmental conditions across Namibian landscapes in terms of soil types, rainfall patterns and dominant encroaching species and encroaching levels, make the assessment of impacts of post-harvest measures on woody regrowth complex. Results from empirical studies used for this analysis (e.g. Richter et al. 2001, Honsbein et al. 2012, Boys and Smit, Smit et al. 2015, Groengroeft et al. 2018, Nampower n.p.) only have limited validity as they cover small areas with specific rainfall, soil and vegetation characteristics. Based on available data, and to maximize the relevance of this study, theoretical models were built to reflect an average situation representative of an average-sized farm in the Otjozondjupa region with a high level of bush thickening (see methodology for more details). In that sense, this study is considered as a starting point for further iterations of this approach as empirical evidence is generated in the future and allows for better integration of key factors of diversity and variability within the models.

Furthermore, it should be noted that this analysis focuses only on the costs and benefits to the land users carrying out the post-harvest treatments. This is known as a "financial cost-benefit analysis" to be differentiated from an "economic cost-benefit analysis", which would include external costs and benefits to the wider society.

3. Methodology

3.1. General CBA Method

A Cost-Benefit Analysis is a method used to compare the financial and economic performance of different projects or interventions by translating impacts and benefits into monetary units. The goal of the CBA is to compare different options with different impacts through time to make an informed decision based on the different types of costs and benefits of each option.

The cost-benefit analysis includes three basic steps. First, annual costs and benefits must be identified and quantified in monetary units, then these costs and benefits are added over a set timeline before they are discounted into a Net Present Value (NPV).

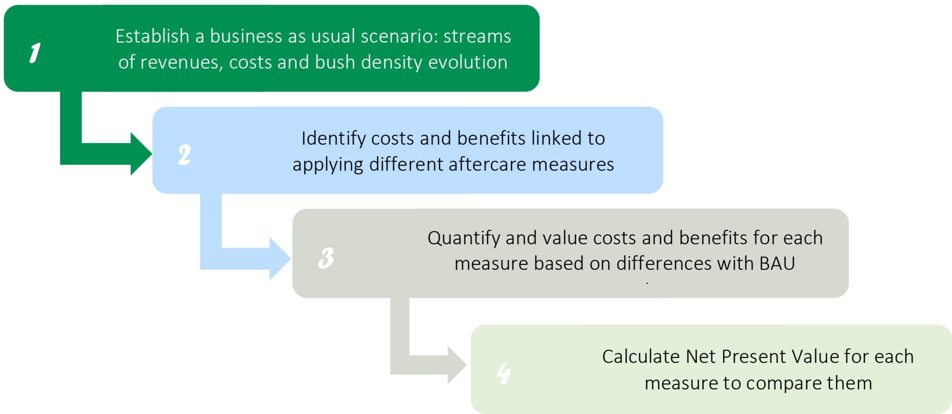
A CBA accounts for the change in value of all benefits and costs associated with the intervention over a set temporal horizon. This timeline can be dependent on the decisions being made, the project lifetime, and levels of uncertainty about future costs and benefits. Shorter temporal horizons will have less uncertainty but also give a truncated result. The **timeline of 25 years** was agreed upon for this study based on consultations with experts and land users. It was agreed as a sensible compromise between the long timeline of ecological processes and shorter-term constraints experienced by land users. Twenty-five years is long enough to see the impact of aftercare on regrowth – based on the average timeline for each species to grow beyond 1.5m – and short enough to appear realistic and attractive to land users.

Annual net benefits are then discounted over this timeline to account for the time preference of individuals (people value present-day costs and benefits more than those that accrue in the future) and to account for the opportunity cost of the investment made (money spent today could have generated more money if saved or invested).

A real discount rate of 4% is used for this study and therefore all values are expressed in 2020 constant prices. Based on the current market interest rate (nominal discount rate) of Agribank loans for bush control activities (8%), and the average inflation rate over the past five years 2015 - 2020 (4.3%), the real discount rate used for this study was set at 4% (deducting inflation rate from nominal rate).

A CBA is meaningful once it is compared to an alternative scenario. For this study, two Business-As-Usual (BAU) scenarios were defined, as presented in Section 3.3 below. Then BAU benefits estimations are deducted from the benefits estimated for each intervention to assess the financial impact of each intervention.

The following steps were undertaken for this CBA study:



3.2. The Typical Farm

To allow for comparison, the costs and benefits attached to post-harvest measures must be evaluated under the same production conditions. For this purpose, the study uses a "typical farm" model. The typical farm parameters were established based on consultations and studies such as MacGregor et al. (2000), who establish three production models for small (3,000 ha), medium (8,000 ha) and large farms (13,000 ha). The average size of a commercial farm in Namibia is commonly assumed to be 5,000 ha (NAU, pers. comm.).

The typical farm used for this study is therefore assumed to be 5,000 ha and derive most of its income from a cow-ox production model (see Section 3.4 below for more details on livestock production). The farm does not derive commercial income from game and does not grow commercial crops. These conditions were established to avoid over-estimating benefits and remain conservatively representative of an average farm in regions most affected by bush thickening (i.e. Otjozondjupa).

Different farm models might influence the streams of benefits derived from post-harvest treatment measures, as well as the financial capacity to invest in aftercare. A sensitivity analysis of farm sizes is conducted for this study looking at the streams of costs and benefits for a farm of 1,000 ha (representing a smaller farm in communal areas) and for a farm of 10,000 ha (reflecting large-scale commercial farmers). Further discussions on the farm model can be found in the "limitations" Section.

3.3. Business as Usual "No Action" Scenarios

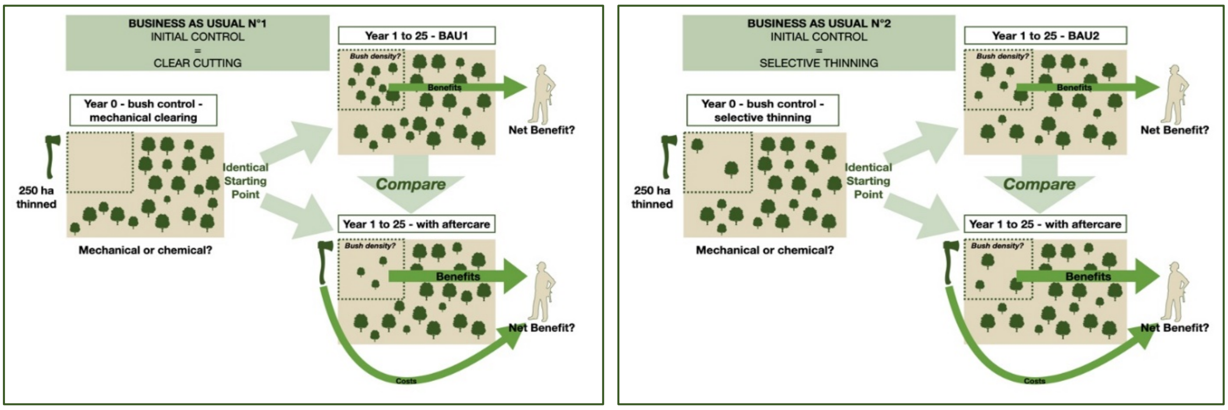
The business-as-usual, or "no action" scenario, is a key component of the cost-benefit analysis as it assumes what would happen if no interventions were conducted. For the assessment of post-harvest measures, we assume that a bush control intervention was conducted in year 0, justifying the "post-harvest" interventions. The Business-as-Usual scenario therefore reflects a situation where bush control is effectively conducted but no aftercare measures are implemented afterwards.

Empirical studies from Boys and Smit, testimonies and expert interviews highlighted that depending on the method used for bush control in Year 0, the bush and grass regrowth under a no-action scenario might vary greatly. This directly affects the intensity of post-harvest measures required (and the associated costs), as well as the additional benefits associated with post-harvest measures as compared to a no-action scenario. To take this diversity into account, it was decided that costs and benefits streams should be analyzed based on two BAU scenarios, representative of two different situations observed on the ground.

- The first Business-as-Usual scenario (BAU1) assumes that the area was almost totally cleared using heavy machinery such as a bulldozer. This scenario is characterized by a very low tree density after control but a fast regrowth rate with seedlings and coppice covering the area within a year or two, and bush density approaching pre-control levels within 7 - 8 years.

- The second business as usual scenario (BAU2) assumes that gradual selective thinning was conducted, leaving big trees untouched. The competition effect of big trees is expected to limit the regrowth of removed bush and therefore slow down the rate of growth compared to the BAU1. Bush does re-grow if nothing is done after the first control, but does not reach its initial density before 15 years.

Regrowth, grass biomass and associated benefits associated with these two scenarios are calculated following the procedure presented in Sections 3.4 to 3.6 below. These benefits are then deducted from the benefits of scenarios with aftercare measures to estimate the additional benefit of the post-harvest treatment compared to the no-action situation, everything else remaining equal. This approach is summarized in the figure below.



3.4. Modelling Regrowth

The main goal and impact of post-harvest treatment measures are to mitigate the regrowth of thinned bush. The main benefits derived from post-harvest treatments are thus directly linked to the bush density in the area (see Section 3.5 for more details on benefits). To quantify the impact of post-harvest measures, a model was built to reflect changes in bush density - expressed in Tree Equivalents per hectare.

Based on Scholes' (1990) model simulating the regrowth of Mopane's basal area after clearing and Case's (2000) discrete logistic model, we developed a logistic regrowth model to simulate bush density changes. This model is presented below:

$$TE_{t-1} \times (1 + (\frac{R \times TE_{t-1}}{TE_{max}})$$

Where :

- TE_{t-1} = Tree equivalent of the preceding year
- R = discrete rate of population growth per year
- TE_{max} = the maximum bush density observed in the landscape.

The choice of parameters was based on the following assumptions:

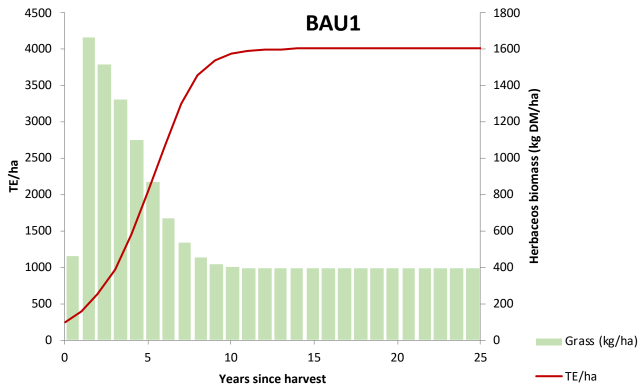
- The maximum bush density observed in the landscape was set at 4,000 TE/ha. This value was based on the analysis of 62 field transects obtained from researchers (J. Boys 44 transects; A. Rothauge 8 transects; C. Van der Waal & T. Wassenaar 10 transects, unpublished raw data), who assessed woody plants in the north-central and northern parts of Namibia. The TE/ha was calculated from the measured tree density and height per transect and the long-term rainfall extracted per transect in a GIS. Using quantile regression, an upper limit was determined for the field data where maximum TE/ha increased with increasing rainfall (See Appendix for further details). Based on this upper limit, a value of 4000 TE/ha was chosen as the maximum TE/ha (bush encroached, woody "carrying capacity") for an area with a mean annual rainfall of approximately 500 mm/yr and where other factors such as soils were not limiting woody density.

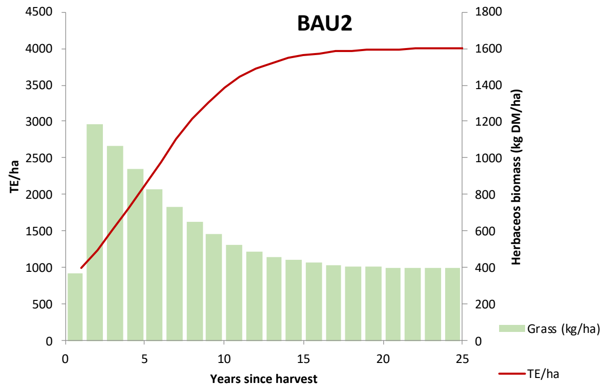
- The maximum discrete rate of population growth (R) was set at 0.64, based on empirical data of regrowth after clear-cutting in the Thornbush Savanna, over three years (Boys and Smit, np). The R (0.64) was calculated for woody regrowth dominated by *Grewia* spp. and *D. cinerea* that replaced the initial dominance of *A. mellifera* and *V. reficiens* in the area after harvesting.

- The R is then assumed to vary depending on the BAU scenario (see below), and post-harvest treatments. It varies between 0.1 and 0.64.

The table and graphs below show the results in bush density evolution from the model for the Business-as-Usual scenarios. The graphs also show the grass growth response to changes in the TE density, this relationship will be further explained in Section 3.5 below.

Years after harvest	BAU1		BAU2	
	R	TE/ha	R	TE/ha
0	0.64	250	0.32	1000
1	0.64	400	0.32	1240
2	0.64	630	0.32	1514
3	0.64	970	0.32	1815
4	0.64	1441	0.32	2132
5	0.64	2031	0.32	2451
6	0.64	2670	0.32	2754
7	0.64	3238	0.32	3029
8	0.64	3633	0.32	3264
9	0.64	3846	0.32	3456
10	0.64	3941	0.32	3607
11	0.64	3978	0.32	3720
12	0.64	3992	0.32	3803
13	0.64	3997	0.32	3863
14	0.64	3999	0.32	3906
15	0.64	4000	0.32	3935
16	0.64	4000	0.32	3955
17	0.64	4000	0.32	3970
18	0.64	4000	0.32	3979
19	0.64	4000	0.32	3986
20	0.64	4000	0.32	3990
21	0.64	4000	0.32	3993
22	0.64	4000	0.32	3996
23	0.64	4000	0.32	3997
24	0.64	4000	0.32	3998
25	0.64	4000	0.32	3999





As shown in the table above, the initial density TE0 differs between BAU1 and BAU2. As BAU2 represents a selective thinning bush control scenario, it is assumed that 1000 TE/ha of tall (above 2 m combining different height strata) trees are left on the land. This value was defined based on forestry recommendations stating that between 750 TE/ha and 1,500 TE/ha should be maintained depending on the dominant encroacher species and for an average long-term rainfall of 500 mm/year (MAWF and MEFT, 2017). For the post-harvest treatment scenarios, it is assumed that the treatment is conducted to achieve this desired density of 1000 TE/ha (long-term annual rainfall ~ 500 mm/yr). The BAU2 scenario assumes that the woody regrowth and recruitment rate is significantly suppressed by the remaining large trees in the landscape, hence lowers the

need for post-harvest treatments (Smit 2004, 2005; Smit et al. 2015). In support, a recent bush thinning trial close to Otjiwarongo found reduced coppicing rates where a good stand of large trees was retained (Boys and Smit).

It is also essential to understand that a high TE/ha value can indicate two different situations: (i) the land is covered by many saplings and small trees (= high number of trees/ha), or (ii) the land is covered by tall trees (= lower number of trees/ha but same TE/ha value). This is due to the construction of the TE indicator: 1 TE = 1 tree of 1.5 m height, 2 TEs could then be equal to 1 tree of 3 m height or 4 trees of 0.5 m height. Our model assumes that TE accounts for competition from both small and large trees, although it is established that small woody plants with shallower roots have a more direct competition with grass. The main difference in our estimations between situation (i) and situation (ii) are reflected in the cost estimations, where the level of efforts required for treatment will be much higher for situation (i) (or BAU1 in our model) as many small plants need to be treated.

Although it is argued that Tree Equivalents are not the most appropriate measure for bush density and bush regrowth, we decided to rely on Tree Equivalents for this study, because it is the indicator used in official government regulations and recommendations, and was used in other studies with useful data (e.g. Richter et al. 2001). It is also easier to measure on the ground (only tree density and height required). The model could however easily be used with Evapotranspiration Tree Equivalent (ETTE) measures – as it was trialled for the water benefits calculations (See Section 3.4 below).

The table below summarizes the assumptions used for our calculations. These assumptions could be changed in further iterations of the model.

Table 1: Key assumptions of the bush regrowth model

Maximum rate of population growth (R)	0.64
Minimum rate of population growth (R)	0.1
Maximum bush density observed in the landscape (TE_{max})	4000 TE/ha
Bush density observed in the landscape after clear-cutting ($TE_{0\text{-}BAU1}$)	250 TE/ha
Bush density observed in the landscape after selective thinning ($TE_{0\text{-}BAU2}$) – desired density	1000 TE/ha
Long-term average rainfall	500mm/year
Dominating encroacher species	*Acacia ssp.* and *Terminalia sericea*.
Soil characteristic	Moderate depth and fertility, loamy texture

3.5. Benefits Identification and Quantification

The benefits associated with post-harvest measures and the mitigation of bush regrowth were identified during discussions with key stakeholders from the working group, various experts and farmers. The two main quantifiable benefits to land users associated with a lower regrowth of bush were the following: (i) increased production of grass on the land, and (ii) increased groundwater recharge. Other ecosystem services associated with bush thinning / harvesting and post-harvest measures -such as carbon sequestration- were not included as they affect a broader set of agents than just the land user. Game-related benefits were also not included for reasons mentioned in Section 3.2 above and further in Section 5.1.

The monetary values attached to an increase in grass production were assumed to be mostly reflected by an increase in livestock carrying capacity and in turn increased income from livestock production. The impact of increased grass production on game populations and associated income were not included to avoid overestimations of benefits for farmers who do not commercially use game. However, this ecosystem service could be included in iterations of this study (see Limitations and Way Forward Sections for further details).

The utilization of wood for biomass production such as charcoal was not included as it is assumed that farmers targeting restoration of grass cover would avoid letting the bush regrow to a level that is useable for

commercial purposes. Thus, the use of wood after post-harvest measures would be minimal. The utilization of wood for bushfeed was also not included for similar reasons.

The quantification of benefits from livestock production and groundwater recharge are directly linked to the regrowth model presented in Section 3.4 above. The approach to quantification and valuation is further detailed in the sub-sections below.

Livestock Production

To calculate the increase in net income from livestock production associated with post-harvest measures the following steps were undertaken:

1. Calculating grass density in kg/ha,
2. Calculating grazing capacity and the equivalent number of cattle heads that could be kept on the area that received bush thinning and post-harvesting measures,
3. Calculating the net income per year generated from the herd kept on that area based on a cow-ox production model.

Grass Biomass

The aboveground grass production in kg/ha was calculated for each year in each scenario based on the TE/ha model. The relationship between TE/ha and grass biomass was estimated based on the empirical relationship described by Richter et al. (2001) for a South African thinning experiment and Namibian data collected for Nampower during a study in 2018 (See Appendix A.2 for further details on the model).

Using statistical inference, an exponential regression model was estimated as follows:

$$Grass = 1950 \times e^{(-0.0003 \times TE)}$$

The model was slightly adapted to balance the potential overestimation of grass response to bush density, to incorporate the anticipated grass responses under below-average rainfall conditions e.g. median annual rainfall conditions. Based on multiple trials and sensitivity assessments of different parameters, the following model was established for the calculation of grass density:

$$Grass = 1950 \times e^{(-0.0004 \times TE)}$$

The grass levels estimated using the above model were also considered more in line with the realities in the field.

Grazing Capacity

Grass production varies by year according to the evolution in bush density and as a result of post-harvest measures. As presented above, grass biomass was calculated in kilogram of dry matter per ha for every year in every scenario, and for each grass level an associated grazing capacity in kilogram of live weight per hectare was calculated. To calculate the grazing capacity, the study assumed the following (Stehn, 2008):

- The dry matter intake of cattle was set at 3% of body weight per day.
- 35% of the available grass material was grazable.
- Cattle graze for a period of one year (365 days).
- Cattle average live weight is 376 kg.

The total grazing capacity of the area (250 ha for the central scenario) under post-harvest treatment was then calculated and the associated number of cattle head that could be kept in that area estimated assuming an average live weight of 376 kg per head.

Net Income from Livestock Production

An increase in the grazing capacity is associated with increased productivity. Based on this assumption, the net farm income after post-harvest treatments was estimated for a 250-hectare area (central scenario).

The net farm income was calculated by subtracting operational expenses from the income generated from the sales of cattle. To determine the income generated, which is quantity multiplied by price, the study used July 2020 nominal producer prices (in Namibian dollars per kilogram-carcass) sourced from the Meat Board of Namibia. The estimated expenses included labour costs, fuel, feed and licks, electricity, repair and maintenance, medicine and veterinary services, insurance and licenses, marketing costs and sundries (e.g. telephone bill, bank costs, clothing). The input prices were nominal and collected from input outlets such as Agra in July 2020. Furthermore, expenses such as labour, feed and licks, medicine and veterinary services, and marketing costs were allowed to vary with increasing cattle numbers. The costs of other expenses were assumed to be fixed at 5% of the total cost on a 5 000-hectare farm (based on NAU profitability calculations). The calculation only included direct operational expenses and excluded any debt repayment, taxes or owner's remuneration.

Assumptions made in the cash flow model were the following:

- In a cow-ox production system 29% of cattle were cows;
- 20% of cows were heifers;
- The production system had an 80% calving percentage;
- Producers marketed 25% of old cows, at least one unproductive slaughter heifer, and all oxen that were 24 - 30 months old.

For each post-harvest treatment scenario, the yearly net income generated by stocking the targeted area was calculated. To calculate the additional income attributable to the post-harvest measure, the net income that would have been generated under a business-as-usual scenario was subtracted from the net income generated in the post-harvest treatment scenario.

Groundwater Recharge

To estimate the benefits derived from an increase in available groundwater as a result of lower bush densities associated with post-harvest treatments, a two step approach was undertaken. First, a schematic model of evolution in groundwater recharge was defined to quantify changes in available groundwater on the "typical farm", then the value of water was estimated using different methods and sources.

Quantifying Changes in Recharge

A model similar to the grass response model was built to simulate changes in groundwater recharge as a result of changes in bush density. An exponential model was developed linking changes in leaf volume (hence tree transpiration) to the groundwater recharge rate. It was reasoned that groundwater recharge rates decreased non-linearly as bush leaf volume increased because of increasing losses due to canopy interception and water run-off with increasing bush density.

The Tree Equivalents indicator was not suitable to reflect changes in groundwater recharge, as it does not consider canopy cover, which is a major determinant of water interception, infiltration and in turn groundwater recharge. Instead, Evapotranspiration Tree Equivalents were calculated using the regrowth model presented in Section, 3.4 above as follows:

$$ETTE_{t-1} \times (1 + (\frac{R \times ETTE_{t-1}}{ETTE_{max}})$$

Where :

- $ETTE_{t-1}$ = Evapotranspiration Tree equivalent of the preceding year
- R = discrete rate of population growth
- $ETTE_{max}$ = the maximum bush density observed in the landscape, set at 11,000 ETTE based on DAS Local Resource Assessment empirical data of bush densities in encroached areas (Smit et al. 2015).

The Leaf Volume was then calculated based on logistic regression inference from empirical data collected in the Thornbush Savanna over 3 years (Boys and Smit).

$$LV = 0.49 \times ETTE_{t-1}^{1.0003}$$

The groundwater recharge rate was then linked to the Leaf Volume using an exponential regression model similar to the grass response model:

$$GR = GR_{max} \times e^{-0.0002 \times LV}$$

Where:

- GR = groundwater recharge rate (bounded between 1% and 3%)
- GR_{max} = the highest recharge rate allowed in the model (3% as explained below)
- LV = Leaf Volume

Parameters for this model were directly informed by existing literature and empirical assessments of recharge rates in Namibia in bush thickened and bush thinned areas (Christelis and Struckmeier 2011, Christian et. al. 2010, Groengroeft et al. 2018). Based on these studies, the lowest recharge rate was established at 1% and a conservative 3% was chosen as an upper bound.

Box 1. Scientific Literature on Recharge Rates.

The Ministry of Agriculture, Water, and Land Reform (MAWLR) currently assumes an average groundwater recharge rate across the entire country of 1% of Namibia's rainfall (Christelis and Struckmeier 2011).

Data on changes in groundwater recharge rates at different bush densities are limited. The most recent study was conducted by Groengroeft et al. (2018) and assessed the effect of *Acacia / Senegalia mellifera* density on potential groundwater recharge. They found a lower water infiltration and a faster drying soil in below-canopy areas of *S. mellifera*, compared to intercanopy space. This could impact the potential for deep drainage resulting in groundwater recharge **three times larger in intercanopy areas than below the canopy.** In a bush thickened situation there is relatively few intercanopy areas, hence less groundwater recharge.

Christian et. al. (2010) cite a highly localised study of the Platveld Aquifer, where the recharge rate was estimated to improve to 8% in a thinned area. However, it should be noted that this estimate was based on a single rainfall event and is therefore not robust. A more realistic estimate for the Platveld area was estimated to be 4%. The authors also cite estimates of recharge rates of 6% observed in the Otavi Mountain Lands in the 1970s (before significant bush thickening) compared to a recharge rate of 1% in the late 1990s (under significantly bush thickened conditions).

For each scenario, the ETTE, Leaf Volume and associated potential rate of recharge were calculated. Then the volume of water recharge in m^3 per year was estimated based on the size of the area (250 ha in the central scenario) and the long-term annual average rainfall (450 mm). An example of the results is presented in the table below:

Table 2: Groundwater recharge estimate examples – Business as Usual scenario 1, first five years

Years after harvest	ETTE/ha	Leaf Volume/ha	Recharge rate	Total recharge in m^3 / p.a.
0	1000	491	2.7%	30 593
1	1582	777	2.6%	28 894
2	2449	1203	2.4%	26 535
3	3667	1801	2.1%	23 541
4	5231	2570	1.8%	20 186

5	6987	3433	1.5%	16 986

The total recharge in cubic meters per year is estimated by multiplying the recharge rate with the total rainfall expected in the area targeted for post-harvest treatment (in the central scenario 0.45 meters of rainfall per year times 250 ha – or 250,000 square meters – equals an average of 1.125 million cubic meters every year over the whole area).

In the post-harvest measures scenario, the water consumption from additional cattle heads, and goats for some scenarios, was deducted from the total recharge estimate to calculate an "additional water available", and thus avoid double-counting of benefits.

Valuing Water

Three main methods to value water were considered for this study: (i) value transfer from MacGregor et al. (2000) and the 2006 Natural Resources Accounts (MAWF, 2006) estimations; (ii) avoided costs from drilling a new borehole; and (iii) market prices from 2020 water tariffs.

The table below summarizes the different values of water considered for this study, all adjusted to 2020 prices. Based on the wide range observed - N$0.35 to more than N$50 - a conservative value was used for the central scenario, and a sensitivity analysis is conducted for each scenario with values of water at N$0.3 (avoided costs) and N$25 (water tariffs).

Namwater bulk water tarriffs (Grootfontein)	25	N$/m3	Namwater
Marginal value of water for agricultural production	**2.01**	N$/m3	MacGregor et al. 2000*
Shadow price from avoided cost (borehole drilling)	0.8	N$/m3	Own calculations for a 250m deep borehole*
NRA value-added of water in commercial land	53.54	N$/m3	MAWF (2006), Technical Summary of Water Accounts
NRA value-added in communal areas	28.8	N$/m3	MAWF (2006), Technical Summary of Water Accounts
NRA groundwater abstraction cost	12.136	N$/m3	MAWF (2006), Technical Summary of Water Accounts

* See Appendix A.3 for more details

3.6. Costs Assessment

Information on costs was collected from interviews with farmers and technical reports on different harvesting practices and their costs. A list of main sources for each measure is available in Appendix A4.

Most costs were estimated based on self-reported financial data from commercial farmers. For manual and chemical applications, a cost per plant treated was calculated and the total costs were estimated based on the number of treated plants, which varies between scenarios. The details will be explained in the scenario descriptions below.

For most scenarios the labour intensity based on a 60 to 90 days harvesting period was calculated, and the average farmworker salary used was about N$2,100 per month or N$100 per day for casual workers.

4. Results

Scenario 1: Yearly Manual Cutting

Under this scenario, it is assumed that the land user carries out a manual post-harvest intervention every year. Simple tools are used to cut and uproot coppice and saplings. The first year of treatment is assumed to be one year after the bush thinning intervention.

The impact and level of effort required to mitigate regrowth are assumed to be slightly different for the clear-cutting and selective thinning starting points (BAU1 and BAU2).

BAU1: Under the clear-cutting scenario, the initial bush density at Year 0 (i.e. year of thinning intervention) is assumed to be 250 TE/ha. The manual post-harvest intervention gradually brings the density to 1000 TE/ha by clearing undesired plants and leaving some desired trees to grow. The discrete rate of population growth is set at a maximum 0.64 until Year 10 when it slows down to 0.32. The effort needed is assumed to be high, with an average of 2,500 plants to treat per hectare in Year 1, decreasing by 30% every year until it reaches a stable low regrowth state in Year 7 with 200 plants to cut per hectare. The costs of manual cutting (including labour and equipment) vary between N$195 per hectare in Year 1 and N$16 per hectare at the stable state from Year 8 onwards (reflecting a very small weed control effort).

BAU2: Under the selective thinning scenario, the initial bush density at Year 0 is assumed to be at the desired 1000 TE/ha. The manual post-harvest intervention is meant to keep this density stable at 1000 TE/ha – leaving big trees on the land and clearing all undesired saplings and coppice. The discrete rate of population growth is assumed to be 0.32 (50% of maximum rate) due to the competitive effect of big trees on regrowth. The effort needed is assumed to be low with an average of 500 plants to treat per hectare in Year 1, decreasing by 30% every year until it reaches a stable low regrowth state in Year 5 with 100 plants to cut per hectare. The costs vary between N$39 per hectare in Year 1 and N$8 per hectare at the lower stable state from Year 6 onwards.

The benefits quantification provided the following results:

Table 3: Summary of benefits, scenario 1 - yearly manual cutting

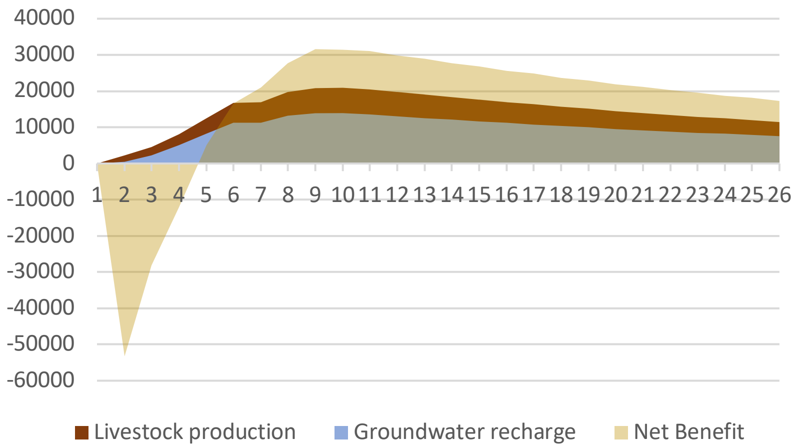
	After clear-cutting	After selective thinning
Grass density (tons/ha)	1.3 - 1.7 tons/ha	1.3 tons/ha (constant)
Carrying capacity (kg/ha)	41.8 - 55 kg/ha	41.8 kg/ha (constant)
Number of cattle heads kept on 250 ha	27 to 36	27
Groundwater recharge rate (% of annual rainfall)	1.9% - 2.6%	1.9% (constant)

Further details and graphic representation on these estimates are available in Appendix B1.

Although carrying capacity and groundwater recharge potential are high during the first couple of years after clear-cutting (BUA1) it rapidly reaches levels similar to the selective thinning scenario, but with higher costs of manual post-harvest interventions due to more intense regrowth after clear-cutting.

As presented in Figures 1 and 2 below, manual post-harvesting represents a loss to the farmer in the first three years for the clear-cutting scenario and in the first year for the selective thinning scenario. The net benefits derived from the post-harvest treatment remain positive afterwards (benefits higher than the costs).

Figure 1: Benefit flows, Scenario 1 : yearly manual aftercare, after clear-cutting, N$ (2020 prices)

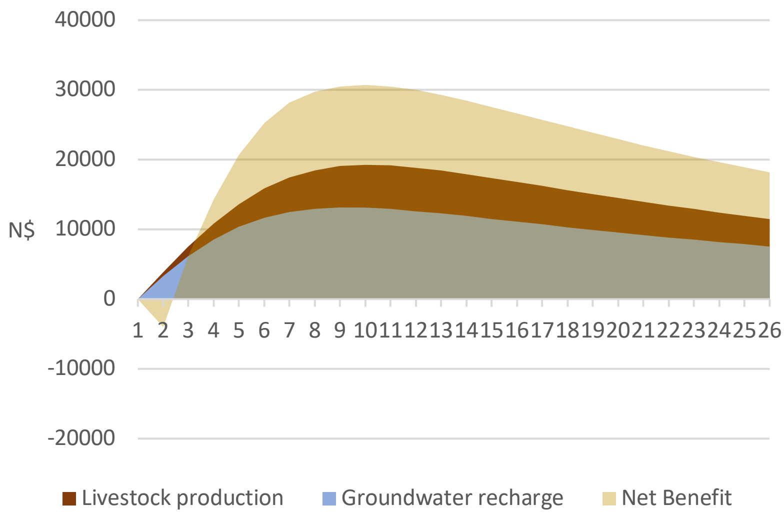


Additional livestock production enabled by manually controlled regrowth on an annual basis and the resulting higher grass availability range from N$2,185 in Year 1 to a high N$20,000 per year between Year 8 and Year 10 and slowly decreasing to stabilize around N$12,000 in Year 25.

A higher rate of groundwater recharge could avail up to 10,000m3 of water per year from Year 10 onwards, valued between N$13,000 and N$7,500 depending on the time horizon.

The net benefits of manually treating post-harvest regrowth after a initial clear-cutting of bush are negative between Year 1 and 4, but increase to a high N$31,000 between Year 8 and 10, and then decrease slowly towards N$17,000 in Year 25. **The overall net present value of this intervention is N$418,394, reflecting an overall net benefit over 25 years** (N$1,674 per hectare).

Figure 2: Benefit flows, Scenario 1 : yearly manual aftercare, after selective thinning, N$ (2020 prices)



Benefit flows under the selective thinning scenario appear slightly higher (Figure 2) than under the clear-cutting scenario (Figure 1) due to lower treatment costs as explained above. In this case, additional livestock production enabled by manually controlling regrowth annually and the resulting higher grass availability range from N$3,855 in Year 1 to N$19,000 per year between Year 8 and Year 10 and slowly decreasing towards N$11,500 in Year 25.

A higher rate of groundwater recharge could avail an additional 7,000m3 of water as soon as Year 4 and up to 10,000m3 of water per year from Year 17 onwards generating between N$7,500 and N$13,000 per year from Year 4 onwards.

The net benefits of manually treating post-harvest regrowth after selective initial thinning are negative in Year 1 only. The net benefits then increase to a high N$30,500 between Year 8 and 10, and then decrease slowly towards N$18,100 in Year 25. **The overall net present value of this intervention is N$571,540 reflecting an overall net benefit over 25 years** (N$2,286 per hectare).

Overall, this shows that controlling regrowth through manual cutting of coppice and saplings every year is beneficial over a 25 years horizon, although it requires some funding to cover upfront costs in the initial years. Using selective thinning as an initial control approach however significantly reduces these upfront costs, leading to a full cost recovery after Year 2.

Employment considerations

In order to complete the post-harvest treatment over 250ha in one season (around 90 working days), about 9 workers would be employed for this purpose on the first year, then 6 on year 2 down to 1 worker from year 7 onwards under BAU1. Under BAU2 about 2 workers would be employed on year 1, down to 1 from year 3 onwards, starting year 5 the worker would only need to work 45 days to cover the area. The average farmworker salary is N$1,200 per month or about N$57 per day of work, to which is added a coverage for food, accommodation and transport for workers.

Scenario 2: Bi-annual Manual Cutting

This scenario has similar assumptions to Scenario 1, but the post-harvest manual intervention is only conducted every two years, which reduces the costs but also leads to slightly higher bush densities in between intervention years.

<u>BAU1:</u> Under the clear-cutting scenario the initial bush density at Year 0 (i.e. year of thinning intervention) is assumed to be 250 TE/ha. The manual post-harvest intervention gradually brings the density to 1000 TE/ha by clearing undesired plants and leaving some desired trees to grow. The effort needed is assumed to be high, with an average of 2,500 plants to treat per hectare on Year 1, decreasing by 30% after each intervention year until it reaches a stable low regrowth state in Year 15 with 200 plants to cut per hectare. The costs of manual cutting (including labour and equipment) vary between N$195 per hectare in Year 1 and N$16 per hectare at the lower stable state from Year 15 onwards.

<u>BAU2</u>: Under the selective thinning scenario, the initial bush density at Year 0 is assumed to be at the desired 1000 TE/ha. The manual post-harvest intervention is meant to keep this density stable at 1000 TE/ha – leaving big trees on the land and clearing all undesired saplings and coppice. The effort needed is assumed to be low with an average of 500 plants to treat per hectare in Year 1, decreasing by 30% after each intervention year until it reaches a stable low regrowth state in Year 9 with 100 plants to cut per hectare. The costs vary between N$39 per hectare in Year 1 and N$8 per hectare at the lower stable state from Year 9 onwards.

The benefits quantification provided the following results:

Table 4: Summary of benefits, scenario 2 - Biennial manual cutting

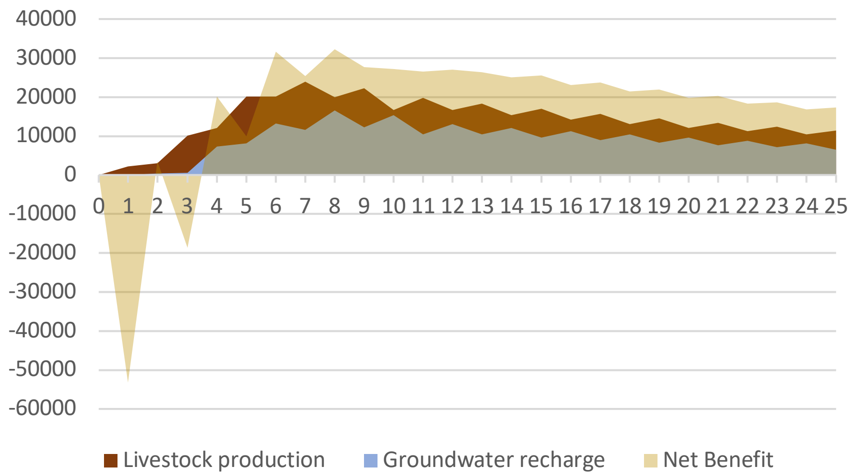
	After clear-cutting	After selective thinning
Grass density (tons/ha)	1.19 - 1.7 tons/ha	1.19 - 1.3 tons/h
Carrying capacity (kg/ha)	36.4 - 55 kg/ha	30 - 41.8 kg/ha
Number of cattle heads kept on 250 ha	24 to 36	25 to 28
Groundwater recharge rate (% of annual rainfall)	1.7% - 2.7%	1.8% - 1.9%

Further details and graphic representation on these estimates are available in Appendix B2.

Although carrying capacity and groundwater recharge potential are high during the first couple of years after clear-cutting it rapidly reaches levels similar to the selective thinning scenario, but with higher costs of manual post-harvest interventions due to more intense regrowth after clear-cutting.

As presented in Figures 3 and 4 below, manual post-harvesting represents a loss to the farmer in the first three years for the clear-cutting scenario and in the first year for the selective thinning scenario. The net benefits derived from the post-harvest treatment remain positive afterwards (benefits higher than the costs).

Figure 3: *Benefit flows, Scenario 2: biennial manual aftercare, after clear-cutting, N$ (2020 prices)*

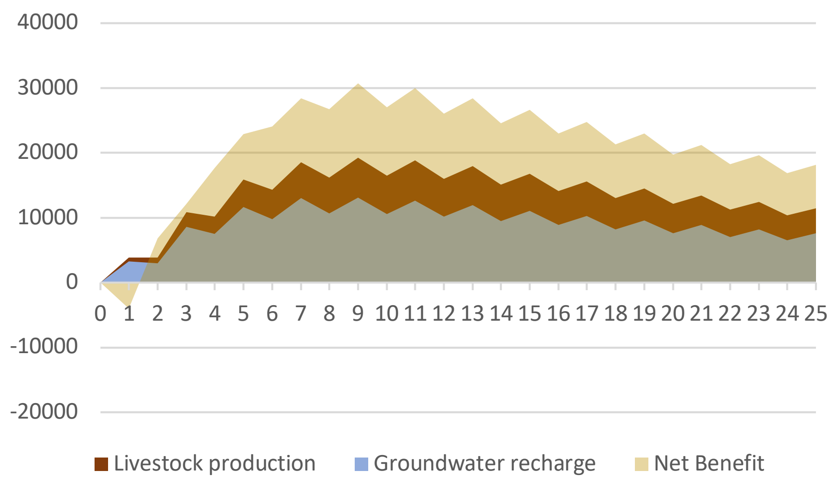


Additional livestock production enabled by manually controlling regrowth every 2 years ranges from N$2,185 in Year 1, to a high N$24,000 in Year 7 and slowly decreasing towards N$11,500 in Year 25.

A higher rate of groundwater recharge could avail between 8,500 m^3 and 10,240m^3 of water per year from Year 10 onwards, valued between N$7,500 and N$13,000.

The net benefits of manually treating post-harvest regrowth after initial clear-cutting of bush are negative in Year 1 and Year 3 but remain positive afterwards. It reaches N$32,000 in Year 8 and then decreases slowly towards N$17,000 in Year 25. **The overall net present value of this intervention is N$437,448, reflecting an overall net benefit over 25 years** (N$1,750 per hectare).

Figure 4: Benefit flows, Scenario 2: biennial manual aftercare, after selective thinning, N$ (2020 prices)



Benefit flows under the selective thinning scenario appear slightly higher (Figure 4) than under the clear-cutting scenario (Figure 3), due to lower treatment costs. In this case, additional livestock production enabled by manually controlled regrowth and the resulting higher grass availability range from N$3,855 in Year 1, to a high N$19,000 per year in Year 9 and slowly decreasing towards N$11,500 in Year 25.
A higher rate of groundwater recharge could avail an additional 7,000m^3 of water as soon as Year 4 and between 8,500 and 10,200m^3 of water per year from Year 13 onwards, generating between N$7,000 and N$13,000 per year from Year 3 onwards.

The net benefits of manually treating post-harvest regrowth after selective initial thinning are negative in Year 1 only. The net benefits then increase to N$30,722 in Year 8 and then decrease slowly towards N$18,000 in Year 25. **The overall net present value of this intervention is N$534,191 reflecting an overall net benefit over 25 years** (N$2,137 per hectare).

Similar to Scenario 1, manual post-harvest treatments appear to be more viable when conducted after a selective thinning approach. There are little differences between Scenario 1 and 2, although Net Present Values are slightly higher for Scenario 2, which suggests that conducting manual post-harvest treatment every second year is slightly more beneficial than intervening every year.

Employment considerations
In order to complete the post-harvest treatment over 250ha in one season (around 90 working days), about 9 workers would be employed for this purpose on the first year, two years later for the second intervention 6 workers would be employed, then 4, then 3, down to 1 worker employed on the seventh intervention in year 11 and onwards. Under BAU2 about 2 workers would be employed on year 1, down to 1 from the third intervention in year 5 and onwards, starting year 9 the worker would only need to work 45 days every two years to cover the area. The average farmworker salary is N$1,200 per month or about N$57 per day of work, to which is added a coverage for food, accommodation and transport for workers.

Scenario 3: Heavy Mechanical - Roller

In this scenario, post-harvest treatment is conducted by using a bulldozer dragging three rollers covering a 9m width. Because of the unselective nature of this method, it is considered unrealistic to use this method after a selective thinning effort. This method was therefore evaluated only based on Business-as-Usual 1, where we assume that the land was cleared during the initial control.

Under this scenario, the initial bush density at Year 0 (i.e. year of thinning intervention) is assumed to be 250 TE/ha. The mechanical post-harvest treatment is conducted every 5 years starting in Year 4. The discrete rate of bush growth is set at a maximum 0.64 and remains stable, as it is assumed that this method is unselective

and therefore does not lead to a stable state in the long-term. Every intervention brings the bush density down to 500 TE/ha to reflect the limited possibility to be selective when using this method. The costs of running and maintaining the equipment as well as labour costs are estimated at N$ 447 per hectare.

The benefits quantification provided the following results:

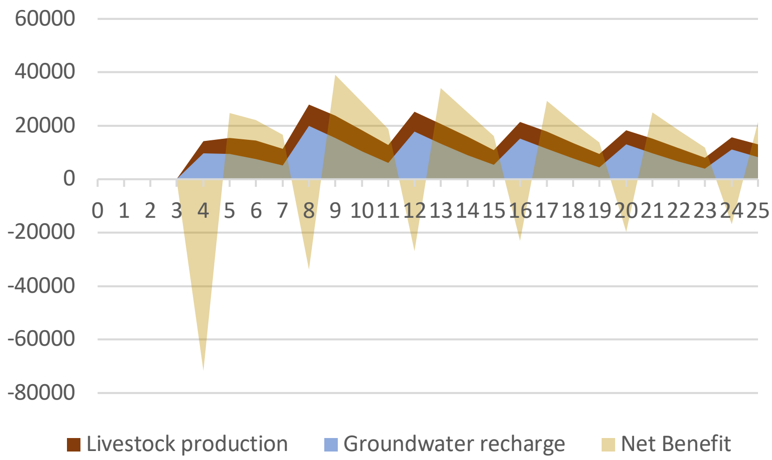
Table 5: *Summary of benefits, scenario 3 - mechanical post-harvest treatment*

	After clear-cutting
Grass density (tons/ha)	0.98 - 1.6 tons/ha
Carrying capacity (kg/ha)	31.4 - 53.1 kg/ha
Number of cattle heads kept on 250 ha	21 to 35
Groundwater recharge rate (% of annual rainfall)	1.5% - 2.6%

Further details and graphic representation on these estimates are available in Appendix B3

With relatively fast bush regrowth and an intervention every 4 years, the benefits derived from this post-harvest treatment measure vary widely. As shown in Figure 5 below, net benefits peak after the intervention but rapidly decrease. Moreover, the running costs of the bulldozer and roller create a negative net benefit (i.e. a net cost) in the year of intervention. However, **the 25-years Net Present Value is positive, at N$174,052**, suggesting that this measure is viable in the long-term for an average sized farm.

Figure 5: *Benefit flows, Scenario 3: mechanical aftercare,, N$ (2020 prices)*



The net benefits presented above do not include potential costs of purchasing a bulldozer and roller, as it is assumed that this purchase is initially made for bush thinning / harvesting interventions and therefore is not fully attributable to aftercare.

A cost estimate including the purchase of equipment and capital costs from a loan to cover this purchase, led to a negative Net Present Value, suggesting that it would not be viable to make this purchase just for post-harvest treatment purposes.

Employment considerations

This scenario assumes that only one bulldozer is used for post-harvest treatment, and therefore involves the employment of one driver for about 88 working days per year of intervention (every five years). The salary for a driver is about N$500 with a bonus of N$5 per hectare covered.

Scenario 4: Chemical – Foliar Arboricide

Under this scenario, the land user is undertaking foliar application of arboricides – assuming the application of a mix between Access or Browser (active ingredient: Picloram) and crop oil selectively applied to each plant. The application is conducted every year for the first three years after bush thinning and then once every three years. Simple equipment for application and workers' protection is used.

BAU1: Under the clear-cutting scenario, the initial bush density at Year 0 (i.e. year of thinning intervention) is assumed to be 250 TE/ha. The foliar arboricide post-harvest intervention maintains the regrowth at a very low level with a discrete rate of population growth of 0.2 after the first year of application. As a result, the bush density remains at low levels, gradually increasing towards 1000 TE/ha by Year 20 as some desired plants are left to grow, while the regrowth of undesired plants is systematically treated. The level of effort needed is assumed to be high at the start, with an average of 2,500 plants to treat per hectare in Year 1, decreasing by 50% after every intervention until it reaches a stable low regrowth rate in Year 9 with 200 plants to treat per hectare. The costs of foliar arboricide application (including labour and equipment) vary between N$246 per hectare in Year 1 and N$20 per hectare at the lower stable state from Year 9 onwards.

BAU2: Under the selective thinning scenario, the initial bush density at Year 0 is assumed to be at the desired 1000 TE/ha. The chemical post-harvesting intervention is meant to keep this density stable at 1000TE/ha – leaving big trees on the land and clearing all undesired saplings and coppice. The discrete rate of population growth is assumed to be reduced to 0.128 (50% of the BAU2 rate) after the first year of intervention. The effort needed is assumed to be low with an average of 500 plants to treat per hectare in Year 1, decreasing by 50% after every intervention until it reaches a stable low regrowth in Year 6 with 100 plants to treat per hectare. The costs vary between N$49 per hectare in Year 1 and N$10 per hectare at the lower stable state from Year 6 onwards.

The benefits quantification provided the following results:

Table 6: Summary of benefits, scenario 4 - foliar arboricide application

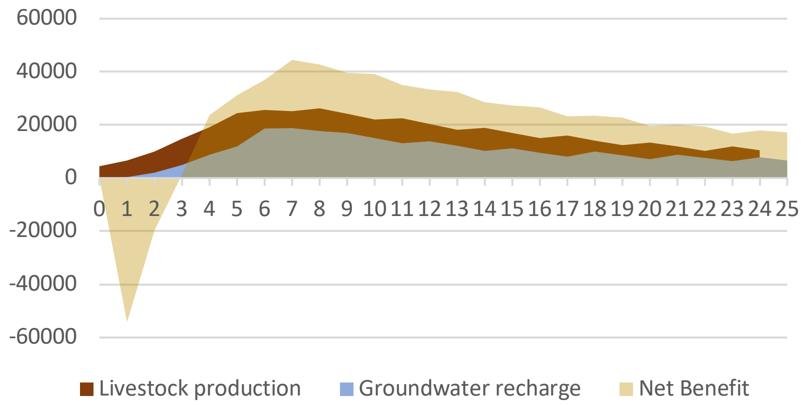
	After clear-cutting	After selective thinning
Grass density (tons/ha)	1.3 - 1.8 tons/ha	1.2 – 1.3 tons/ha
Carrying capacity (kg/ha)	37 - 57 kg/ha	38.6 - 41.8 kg/ha
Number of cattle heads kept on 250 ha	26 to 38	26-28
Groundwater recharge rate (% of annual rainfall)	1.7% - 2.7%	1.8% - 1.9%

Further details and graphic representation on these estimates are available in Appendix B4.

Bush density between Year 1 and 10 is lower after clear-cutting compared to selective thinning. This leads to slightly higher grass densities and groundwater recharge rates under BAU1 in the short-term. However, these eventually converge towards similar levels after Year 10.

As presented in Figures 6 and 7 below, foliar-applied chemical post-harvesting incurs a net loss to the farmer in the first three years for the clear-cutting scenario and in the first year for the selective thinning scenario. The net benefits derived from the post-harvest treatment remain positive afterwards (benefits higher than the costs).

Figure 6: Benefit flows, Scenario 4: foliar arboricide, after clear-cutting, N$ (2020 prices)

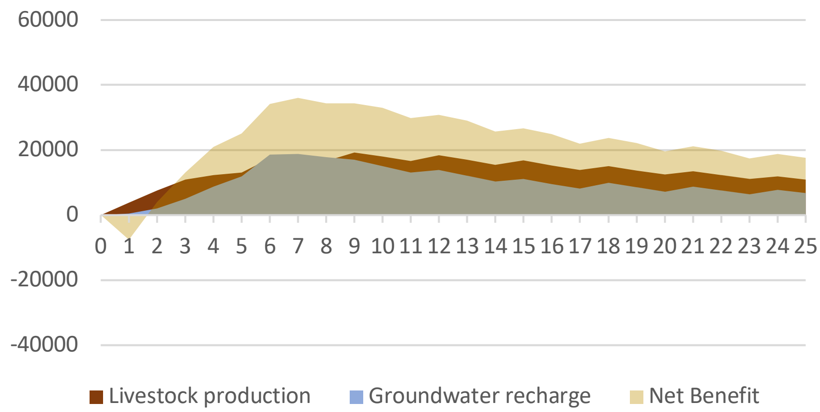


Under the BAU1 scenario, additional livestock production enabled by higher grass densities ranges from N$4,459 in Year 1, to a high N$25,662 in Year 6 and slowly decreasing towards N$10,500 in Year 25.

A higher rate of groundwater recharge could avail up to 12,000 m^3 in Years 6 to 10. It would stabilize between 7,800 m^3 and 10,000m^3 of additional water per year from Year 12 onwards, generating between N$6,700 and N$14,000 per year.

The net benefits of using foliar-chemical treatment after a clear-cutting are negative over the first three years of intervention but remain positive afterwards. It reaches a high N$44,474 in Year 7 and then decrease slowly towards N$17,200 in Year 25. **The overall net present value of this intervention is N$549,714, reflecting an overall net benefit over 25 years** (N$2,199 per hectare).

Figure 7: Benefit flows, Scenario 4: foliar arboricide, after selective thinning, N$ (2020 prices)



Benefit flows under the selective thinning scenario appear slightly lower (Figure 7) than under the clear-cutting scenario (Figure 6). In this case, additional livestock production enabled by the post-harvest treatment generates from N$3,855 in Year 1, to a high N$19,254 in Year 9 and slowly decreasing towards N$10,860 in Year 25.

A higher rate of groundwater recharge could avail an additional 8,500m^3 and 10,000m^3 of water per year from Year 9 onwards, generating between N$6,700 and N$17,000 per year.

The net benefits of foliar-applied chemical treatment after a selective initial thinning are negative in Year 1 only. The net benefits then increase to a high N$36,060 in Year 7 and then decrease slowly towards N$17,600

in Year 25. **The overall net present value of this intervention is N$577,093 reflecting an overall net benefit over 25 years** (N$2,308 per hectare).

In this case, there is a small difference in cost-effectiveness between chemical post-harvest treatments after clear-cutting and after selective thinning. In both cases, the use of foliar-applied arboricide appears to be highly beneficial over 25 years, although it requires initial capital investment capacity –especially after initial clear-cutting– to cover for the net loss in the first years of application.

Employment considerations

In order to complete the post-harvest treatment over 250ha in about 3 months or 60 days of work, under BAU1 about 9 workers would be employed for this purpose on the first year of intervention, then 4 the following year, and 2 the year after, while only one worker would employed for the triennal follow ups after that. Under BAU2, 2 workers would be employed on the first year of intervention and then 1 the two following years, while the follow ups would require one worker to work about 20 days every three years from year 6 onwards. The average casual worker salary in this case is N$60 per day of work with an additional cover for food, accommodation and transport.

Scenario 5: Chemical – Cut Stump + Foliar Arboricide

Under this scenario, the land user is applying arboricide on cut stumps immediately after bush thinning. Then a foliar-applied arboricide is used as a follow-up post-harvest treatment. The treatment is assumed to be a mix between 2% Access or Browser (Picloram) and crop oil, applied selectively on each plant. The application is conducted in Year 0 for the cut stump and then every three years for the foliar treatment (starting in Year 2). Simple equipment for application and workers' protection is used.

BAU1: Under the clear-cutting scenario, the initial bush density at Year 0 (i.e. year of thinning intervention) is assumed to be 250 TE/ha. The cut stump application and foliar arboricide post-harvest intervention maintains the regrowth at a very low level with a discrete rate of population growth assumed to be 0.2 from Year 0. Thus, the bush density remains at low levels gradually increasing towards 1000 TE/ha by Year 20 as some desired plants are left to grow, while the regrowth of undesired plants is systematically treated. The level of effort needed is assumed to be high at the start, assuming an application on 3000 cut stumps per hectare in Year 0. However, this effort is drastically reduced by the low regrowth rate (only 25% of treated plants regrow) leading to a stable low level of 150 plants per hectare to be treated by Year 5. The cost of cut stump application is estimated at N$295 per hectare. The first foliar-applied chemical follow-up is estimated to cost about N$75 per hectare, while following interventions cost N$15 per hectare from Year 5 onwards.

BAU2: Under the selective thinning scenario, the initial bush density at Year 0 is assumed to be at the desired 1000 TE/ha. The chemical post-harvest intervention is meant to keep this density stable at 1000 TE/ha – leaving big trees on the land and clearing all undesired saplings and coppice. The discrete rate of population growth is assumed to be 0.128 (50% of the BAU2 rate) from the start. The effort needed is assumed to be low with an average of 750 cut stumps to treat per hectare in Year 0 with a 25% regrowth rate leading to a stable low level of 100 plants per hectare to be treated by Year 5. The cost of cut stump application is estimated at N$74 per hectare. The first foliar-applied chemical followup is estimated to cost about N$18 per hectare, while following interventions cost N$10 per hectare from Year 5 onwards.

The benefits quantification provided the following results:

Table 7: Summary of benefits, scenario 5 – cut stump and foliar arboricide application

	After clear-cutting	After selective thinning
Grass density (tons/ha)	1.1 - 1.7 tons/ha	1.2 – 1.3 tons/ha
Carrying capacity (kg/ha)	37 - 55 kg/ha	38.6 - 41.8 kg/ha
Number of cattle heads kept on 250 ha	24 to 37	26-28

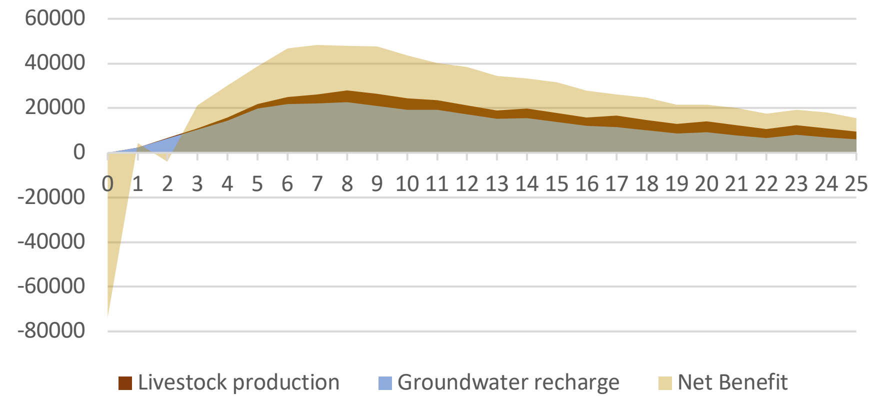
Groundwater recharge rate (% of annual rainfall)	1.7% - 2.7%	1.8% - 1.9%

Further details and graphic representation on these estimates are available in Appendix B5.

Bush density is lower between Year 1 and 15 after clear-cutting compared to selective thinning, which leads to slightly higher grass densities and groundwater recharge rate under BAU1 in the short-term. However, these eventually converge towards similar levels after Year 15.

As presented in Figures 8 and 9 below, cut stump and foliar-applied chemical post-harvest treatments incur a significant net loss to the farmer in the first three years for the clear-cutting scenario (- N$73,740 in Year 0) and in the first year for the selective thinning scenario (- N$18,435 in Year 0). The net benefits derived from the post-harvest treatments remain positive afterward (benefits higher than the costs).

Figure 8: *Benefit flows, Scenario 5: cut stump and foliar arboricide, after clear-cutting, N$ (2020 prices)*

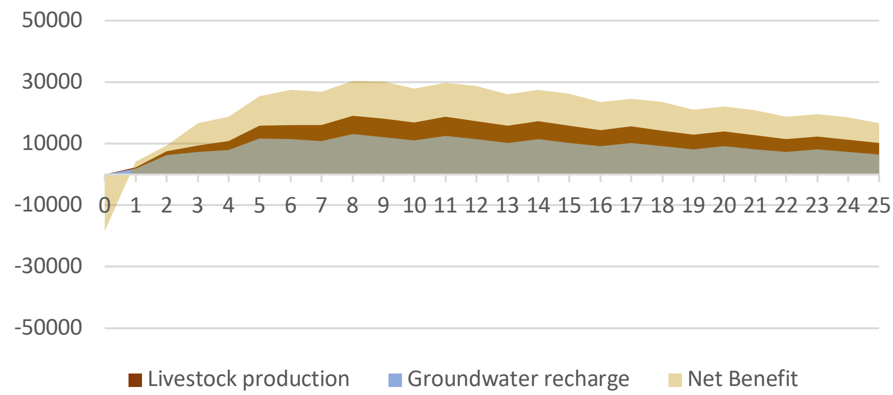


Under the BAU1 scenario, additional livestock production due to higher grass densities ranges from N$2,254 in Year 1, to a high N$27,930 in Year 8 and slowly decreasing towards N$9,540 in Year 25.

A higher rate of groundwater recharge could avail up 15,000 m^3 in Years 7 to 11, generating up to N$22,650 in Year 8. It would stabilize between 7,800 m^3 and 10,000 m^3 of additional water per year from Year 19 onwards, generating between N$5,950 and N$9,930 per year.

The net benefits of using this method after clear-cutting are negative in Year 0 and in Year 2 when the first foliar follow-up is implemented. It then remains positive. It reaches a high of N$50,586 in Year 8 and then decrease slowly towards N$15,480 in Year 25. **The overall net present value of this intervention is N$714,148, reflecting an overall net benefit over 25 years** (N$2,857 per hectare).

Figure 9: *Benefit flows, Scenario 5: cut stump and foliar arboricide, after selective thinning, N$ (2020 prices)*



Benefit flows under the selective thinning scenario appear significantly lower (Figure 9) than under the clear-cutting scenario (Figure 8). In this case, additional livestock production enabled by the post-harvest treatment generates from N$2,568 in Year 1, to a high N$19,000 in Year 9 and slowly decreasing towards N$10,229 in Year 25.

A higher rate of groundwater recharge could avail an additional 7,000 m^3 as soon as Year 5, and then between 8,000 m^3 and 10,000 m^3 per year from Year 8 onwards, generating between N$6,500 and N$13,150 per year.

The net benefits of cut stump and foliar-applied chemical treatment after a selective initial thinning are negative in Year 0 only. The net benefits then increase to a high N$36,400 in Year 7 and then discounts down to N$16,700 in Year 25. **The overall net present value of this intervention is N$565,773 reflecting an overall net benefit over 25 years** (N$2,263 per hectare).

In this case, there is a significant difference in cost-effectiveness between post-harvest treatments after clear-cutting and after selective thinning. In both cases, the use of cut stump and foliar-applied arboricides appears to be highly beneficial over 25 year. The NPV under BAU1 is N$150,000 higher than under BAU2. However, it is important to note that in the case of treatment after clear-cutting a significant initial capital investment is required to cover for the net loss in the first years of application.

Employment considerations
In order to complete the post-harvest treatment over 250ha in about 3 months or 60 days of work, under BAU1 about 10 workers would be employed for the cut stump application on year 0, then 3 for the first follow up two years latzer, and 1 worker for 30 days every three years after that.. Under BAU2, 3 workers would be employed for the cut stump application on year 0 and then one worker for 40 days on year 2 for the first follow up and one worker for 20 days every three year after that. The average casual worker salary in this case is N$60 per day of work with an additional cover for food, accommodation and transport.

Scenario 6: Chemical – Soil-applied Arboricides

Under this scenario, the land user is applying a soil-applied arboricide every three years to reduce regrowth. The soil-applied aboricide (active ingredient: Bromacil) is applied selectively (1) to the soil surface within the root zone of targeted plants. Simple equipment for application and workers' protection is used.

<u>BAU1:</u> Under the clear-cutting scenario, the initial bush density in Year 0 (i.e. year of thinning intervention) is assumed to be 250 TE/ha. The first application of soil-applied arboricides is undertaken in Year 1, which significantly reduces the discrete rate of population growth to 0.2 from Year 2 onwards. Thus, the bush density remains at low levels, gradually increasing towards 1000 TE/ha by Year 10 as some desired plants are left to grow, while the regrowth of undesired plants is systematically treated. The level of effort needed is assumed to be high at the start, with an average of 2,500 plants to treat per hectare in Year 1. A very low regrowth rate of 25% leads to a stable low level of 150 plants per hectare to be treated as soon as the third intervention (Year 7). The costs of soil-applied arboricide treatment (including labour and equipment) vary between N$171 per hectare for the first application, N$43 for the second and down to N$11 per hectare at the lower stable state from the third application onwards.

<u>BAU2</u>: Under the selective thinning scenario, the initial bush density in Year 0 is assumed to be at the desired 1000 TE/ha. The chemical post-harvest intervention is meant to keep this density stable at 1000TE/ha – leaving big trees on the land and clearing all undesired saplings and coppice. The first application is undertaken in Year 2, which reduces the discrete rate of population growth to 0.2. The rate of growth further decreases to 0.128 (50% of the BAU2 rate) after the second application, due to residual effects of soil-applied arboricides. The effort needed is assumed to be low with an average of 500 plants to treat per hectare for the first application. Due to the low regrowth rate (25% of plants regrow), a stable low level of 100 plants

[1] It should be noted that soil-applied arboricides are not considered selective as they can have a considerable impact beyond the targeted plant. This is addressed below and in the Environmental Assessment.

per hectare must be treated by the third application. The cost of the first application is estimated at N$35 per hectare, while the following applications are estimated to cost N$8 - N$9 per hectare.

The benefits quantification provided the following results:

Table 8: Summary of benefits, scenario 6 – soil-applied arboricide

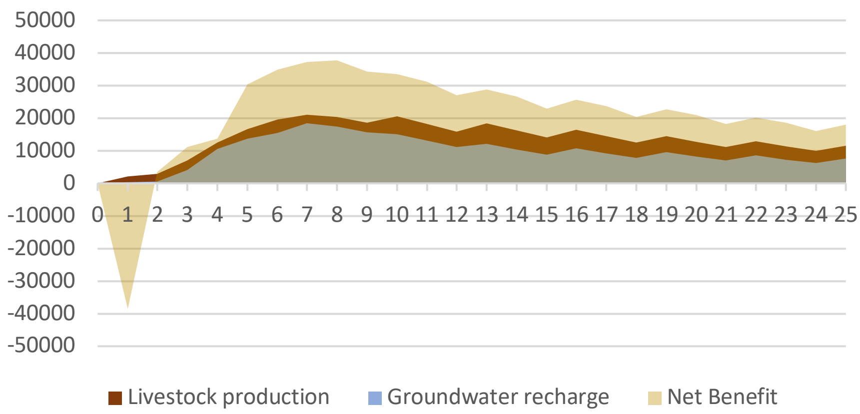
	After clear-cutting	After selective thinning
Grass density (tons/ha)	1.1 - 1.7 tons/ha	1.2 – 1.3 tons/ha
Carrying capacity (kg/ha)	37 - 55 kg/ha	38.6 - 41.8 kg/ha
Number of cattle heads kept on 250 ha	24 to 37	26-28
Groundwater recharge rate (% of annual rainfall)	1.7% - 2.7%	1.7% - 1.9%

Further details and graphic representation on these estimates are available in Appendix B6.

Bush density is lower between Year 1 and 10 after clear-cutting compared to selective thinning, which leads to slightly higher grass densities and groundwater recharge rate under BAU1 in the short-term. However, these eventually converge towards similar levels after Year 10.

As presented in Figure 10 below, soil-applied chemical post-harvest treatments incur a net loss to the farmer in the first year for the clear-cutting scenario (- N$38,553 on year 1). The net benefits derived from the post-harvest treatment remain positive afterward (benefits higher than the costs).

Figure 10: Benefit flows, Scenario 6: soil-applied arboricide, after clear-cutting, N$ (2020 prices)

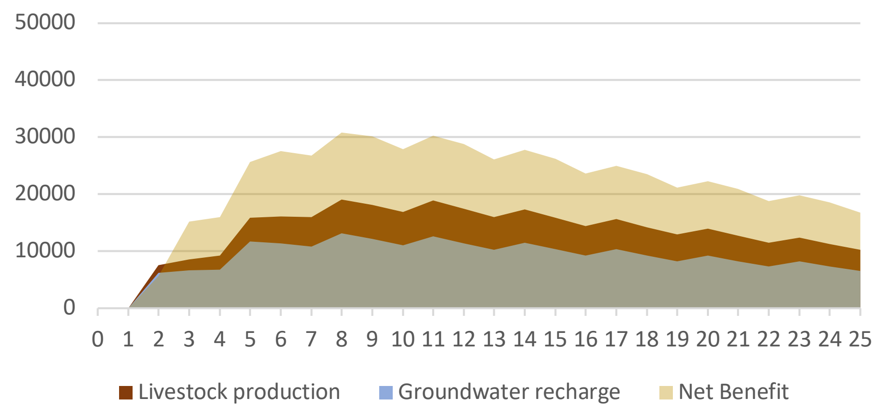


Under the BAU1 scenario, additional livestock production generates N$2,185 in Year 1, N$21,000 in Year 7 and slowly decreases towards N$10,000 in Years 24 and 25.

A higher rate of groundwater recharge could avail up to 12,000 m^3 in Years 7 and 8, generating up to N$18,400. It would stabilize between 8,000 m^3 and 10,000 m^3 of additional water per year from Year 11 onwards, generating between N$7,500 and N$13,000 per year.

The net benefits of using soil-applied arboricides after clear-cutting are negative in Year 1 but then steadily increase to reach a net positive of N$37,750 in Year 8, and then decrease slowly towards N$18,000 in Year 25. **The overall net present value of this intervention is N$539,410, reflecting an overall net benefit over 25 years** (N$2,158 per hectare).

Figure 11: Benefit flows, Scenario 6: soil-applied arboricide, after selective thinning, N$ (2020 prices)



Under the selective thinning scenario, the use of soil-applied arboricides starting in Year 2 does not incur a net loss to farmers with net benefits equal to zero in Year 1 and positive from Year 2 onwards.

In this case, additional livestock production enabled by the post-harvest treatment generates from N$7,523 in Year 2, to a high N$19,000 in Year 8 and slowly decreasing towards N$10,229 in Year 25.

A higher rate of groundwater recharge could avail an additional 7,000 m^3 as soon as Year 5 and between 8,000 m^3 and 10,000 m^3 per year from Year 7 onwards, generating between N$6,500 and N$13,150 per year.

The net benefits of soil-applied chemical treatment after a selective initial thinning reach a high N$30,822 in Year 8, and then discounts down to N$16,700 in Year 25. **The overall net present value of this intervention is N$555,355 reflecting an overall net benefit over 25 years** (N$2,221 per hectare).

In this case, there is only a small difference in cost-effectiveness between soil-applied chemical post-harvest treatments after clear-cutting and after selective thinning. In both cases, the use of soil-applied arboricides appears to be beneficial over 25 years. In the case of treatment after clear-cutting, some initial capital investment is required to cover the net loss in the first year of application, which is not the case for treatments after selective thinning.

Employment considerations

In order to complete the post-harvest treatment over 250ha in about 3 months or 60 days of work, under BAU1 about 2 workers would be employed for this purpose on the first year of intervention, then 1 worker for 30 days for the first follow up, and one worker for 6 days every three years after that. Under BAU2, only one worker would be employed for 25 days on the first year of intervention and then for 6 days every three years for follow ups. The average casual worker salary in this case is N$60 per day of work with an additional cover for food, accommodation and transport.

Scenario 7: Controlled Burning

Under this scenario, the land user is conducting controlled burning after initial thinning every four years on average. This reflects a best case scenario for fire use, which depends on appropriate rainfall after fire and the vulnerability of treated species to fire (assuming mainly *Acacia / Senegalia* ssp. and *Terminalia sericea*). For the cost estimation, it is assumed that 5 people are required to manage the fire on 250 ha for an average of 2 days and each worker is paid N$100 per day.

Another key cost of using fire as a post-harvest treatment measure is the inability to use the land for grazing for at least 12 months before and 6 months after the fire (to allow fuel load to accumulate before the fire and then to let grass regrow). This was taken into account in both costs and benefits calculations for this

scenario. In the cost calculation, it was assumed that the farmer would have to rent grazing space for his/her cattle for N$100 per head per month over 18 months while the area under treatment is left untouched. In the benefits calculations associated with livestock production, the production of the area under treatment was set to 0 during the year of fire intervention, which led to an estimate of the opportunity cost equal to the potential benefit that could have been generated under the BAU scenarios. This opportunity cost (equal to the negative of the associated BAU expected benefit) has been included in the cost-benefit calculations.

BAU1: Under the clear-cutting scenario, the initial bush density in Year 0 (i.e. year of thinning intervention) is assumed to be 250 TE/ha. The first fire intervention is undertaken in Year 2, which significantly reduces the discrete rate of population growth from 0.64 to 0.5 from Year 2 onwards. Every intervention significantly reduces bush density, although some regrowth remains, causing the bush density to oscillate between 800 TE/ha (after fire) and 2000 TE/ha (before fire) from Year 15 onwards.

BAU2: Under the selective thinning scenario, the initial bush density in Year 0 is assumed to be at the desired 1000 TE/ha. The first fire intervention is undertaken in Year 4, which reduces the discrete rate of population growth by 20% from 0.32 to 0.26 from Year 4 onwards. Every intervention significantly reduces bush density to 800 TE/ha, which is slightly below the targeted 1000 TE/ha reflecting the lack of selectiveness of this method. The fire intervention maintains the bush density between 1300 TE/ha (before fire) and 800 TE/ha (after fire) throughout 4 year-cycles.

The benefits quantification provided the following results:

***Table 9:** Summary of benefits, scenario 7 – Controlled veldfire.*

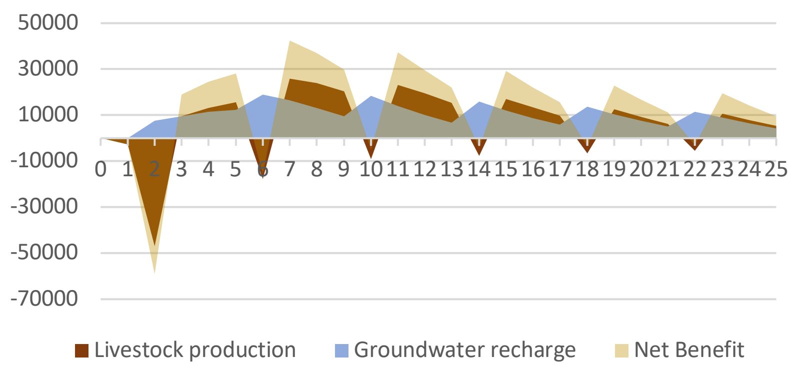
	After clear-cutting	After selective thinning
Grass density (tons/ha)	0.8 - 1.7 tons/ha	0.9 – 1.4 tons/ha
Carrying capacity (kg/ha)	26 - 55 kg/ha	30 - 45 kg/ha
Number of cattle heads kept on 250 ha	17 to 33 (and 0 on fire years)	20-28 (and 0 on fire years
Groundwater recharge rate (% of annual rainfall)	1.5% - 2.7%	1.7% - 2%

Further details and graphic representation on these estimates are available in Appendix B7.

Bush density is lower between Year 1 and 15 after clear-cutting compared to selective thinning, which leads to slightly higher grass densities and groundwater recharge rate under BAU1 in the short-term. However, these eventually converge towards similar levels after Year 15.

As presented in Figures 12 and 13 below, using fire for post-harvest treatment incurs net losses to the farmer in years when fire is applied. However, these net losses decrease significantly after the first fire intervention. Moreover, the net benefits generated in years with no intervention cover the previous net loss within one year in most cases.

***Figure 12:** Benefit flows, Scenario 7: controlled veldfire, after clear-cutting, N$ (2020 prices)*

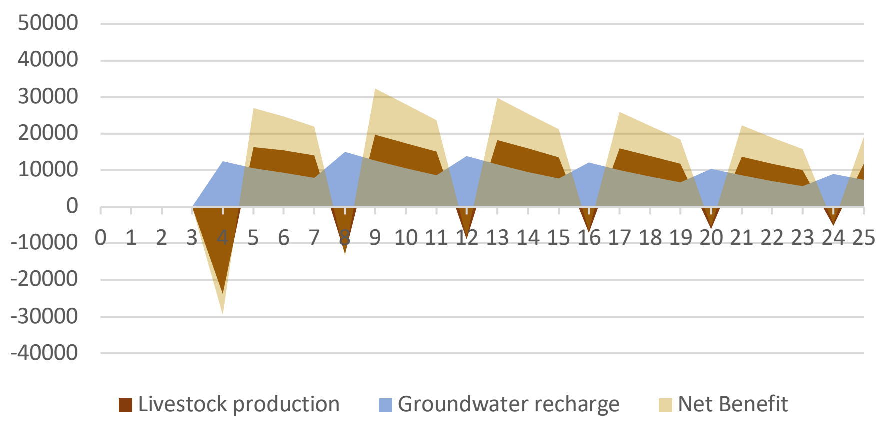


Under the BAU1 scenario, the losses associated with the opportunity cost of not grazing in Year 2 are quite high (almost N$47,000), but decrease for the following interventions to N$17,000 in Year 6 and between N$7,000 and N$5,000 afterward. The benefits generated from increased livestock production in years between intervention ranges between N$25,880 and N$20,291 in Years 7 to 10 and then gradually decrease to range between N$10,700 and N$5,400 in Years 23 to 25.

A higher rate of groundwater recharge could avail up 13,000 m^3 after the third fire intervention. It would oscillate between 5,000 m^3 and 13,000m^3 of additional water per year from the third intervention onwards, generating between N$5,900 and N$13,900 per year.

The net benefits are negative in the years of intervention but range between N$9,000 to N$42,000 in years between fire interventions. **The overall net present value of this intervention is N$338,464, reflecting an overall net benefit over 25 years despite some years of losses** (N$1,353 per hectare).

Figure 13: *Benefit flows, Scenario 7: controlled veldfire, after selective thinning, N$ (2020 prices)*



Under the selective thinning scenario, the losses associated with the opportunity cost of not grazing in Year 4 are estimated at N$23,806, and then decrease for the following interventions to N$12,000 in Year 8 and between N$8,000 and N$5,000 afterward. The benefits generated from increased livestock production in years between interventions ranges between N$19,000 and N$15,000 in Years 9 to 11 and then gradually decreases to range between N$13,000 and N$10,000 in Years 21 to 23.

A higher rate of groundwater recharge could avail up to 10,200 m^3 after the second fire intervention. It would then stabilize between 7,000 m^3 and 11,000m^3 of additional water per year from the third intervention onwards, generating between N$4,200 and N$18,000 per year.

The net benefits are negative in the years of intervention but range between N$15,000 to N$32,000 in years between fire interventions. **The overall net present value of this intervention is N$309,000, reflecting an overall net benefit over 25 years despite some years of losses** (N$1,236 per hectare).

The positive net present values for both cases suggest that it remains beneficial to use fire as a post-harvest treatment measure despite the opportunity cost of not using the land for 18 months. The difference between using fire after clear-cutting or after selective thinning is quite limited in this case, as using fire cannot be considered a selective measure, and the impact on bush density to similar despite differences in the initial thinning approach.

Employment considerations

Controlled burning creates short-term employment but has low labour intensity, in this case study about 5 workers would be employed for 2 days every four years, with an average salary of N$100 per day in both BAU1 and BAU2.

Scenario 8: Biological Control – Extensive Goat Stocking

In this scenario, the only method used to control regrowth is the extensive stocking of goats on thinned land. The goats are left to browse freely over the whole area with minimal management. In Year 1, the farmer will purchase the entire herd for a stocking rate of 40 kg per hectare under BAU1 and 30 kg per hectare under BAU2, as the number of saplings available for browse is expected to be lower under the selective thinning scenario [2]. The price of purchase is N$35 per kg based on the average auction price for 2020. The purchased goats are assumed to weigh 20 kg on average. The herd size for BAU1 is estimated at 500 heads and at 375 heads for BAU2. It is then assumed that the farmer will sell half of its herd every year and buy the same number of heads within the same year. The goats are assumed to weigh 35 kg on average and are sold live at N$30 per kg. The purchased goats are assumed to be 20 kg at N$35 per kg [3]. The average mark-up between bought and sold goats is thus assumed to be N$350 per head.

The labour costs of managing a herd of goats are based on the assumption that one shepherd manages up to 200 goats for the whole year at a salary of N$1,200 per month.

The impact of the goat herd on grass and water availability is deducted from the quantification of the benefit assuming that 30% of goats food intake is from grazing [4], and that each goat consumes 10 L of water per day.

<u>BAU1:</u> Under the clear-cutting scenario, the initial bush density in Year 0 (i.e. year of thinning intervention) is assumed to be 250 TE/ha. The introduction of goats is assumed to significantly reduce the discrete rate of population growth to 0.2 in the first year. However, as goats cannot control all the regrowth it is assumed that the rate of growth slowly increases over time (about 10% per year), which means bush density increases slowly but slightly higher every year. It thus increases from 250 TE/ha in Year 0 to 3171 TE/ha in Year 25, inducing that another measure to limit regrowth is required to control regrowth in the medium-term. In this case, the goat stocking rate is set at 40 kg per hectare.

<u>BAU1:</u> Under the selective thinning scenario, the initial bush density in Year 0 (i.e. year of thinning intervention) is assumed to be 1000 TE/ha. The introduction of goats is assumed to reduce the discrete rate of population growth to 0.1 in the first year, slowly increasing by 5% every year as the competition from big trees limits the regrowth rate. The bush density thus gradually increases from 1000 TE/ha in Year 0 to 2142 TE/ha in Year 10 and 3920 TE/ha in Year 25. This suggests that another measure to control regrowth is required in addition to stocking goats. In this case, the stocking rate is set at 30 kg per hectare.

The benefits quantification provided the following results:

***Table 10:** Summary of benefits, scenario 8 – Goat stocking.*

	After clear-cutting	After selective thinning
Grass density (tons/ha)	0.5 - 1.7 tons/ha	0.4 – 1.3 tons/ha
Carrying capacity (kg/ha) – after goat inclusion	9.7 – 47.5 kg/ha	7.7 – 35.3 kg/ha
Number of cattle heads kept on 250 ha	6 to 32	5-23
Groundwater recharge rate (% of annual rainfall)	1.1% - 2.7%	1% - 1.9%

Further details and graphic representation on these estimates are available in Appendix B8.

[2] These stocking rates were based on personal communications with Wolfie Von Wielich and reports from the Omatjene Research Station (Bester et al.)

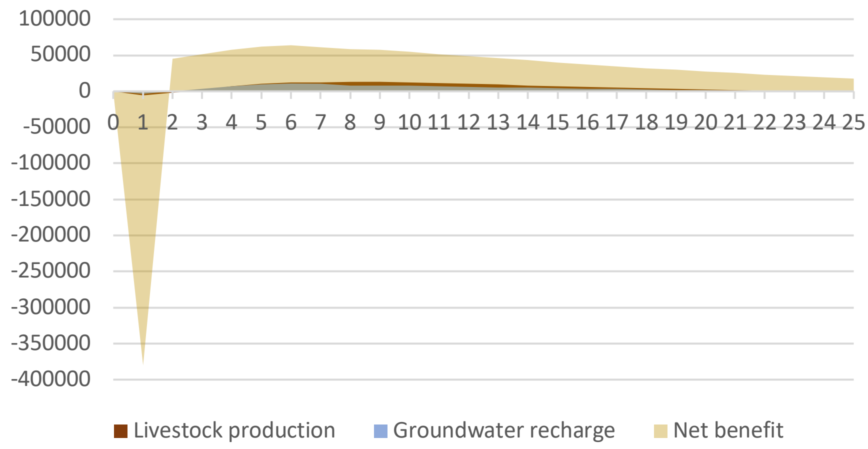
[3] Based on Meat Board auction price and weight statistics for 2020. https://www.nammic.com.na/index.php/library/send/51-other/43-monthly-statistics

[4] Assuming a food intake of 3% of the goats' weight per day with an average weight of 25kg.

There is considerable variation in benefits between the first 10 years when grass levels are relatively high. From Year 10 onwards, the groundwater recharge rate and carrying capacity levels decrease to levels similar to the no-action scenario. Bush density is kept lower after clear-cutting compared to selective thinning, which leads to higher grass densities and groundwater recharge rate under BAU1.

As presented in Figures 14 and 15 below, the purchase of goats for post-harvest treatments incurs a significant net loss to the farmer in the first year of intervention (- N$380,000 under BAU1 and – N$283,000 under BAU2). This loss is recovered by Year 8 under BAU1 and by Year 9 under BAU2.

Figure 14: Benefit flows, Scenario 8: goats stocking, after clear-cutting, N$ (2020 prices)

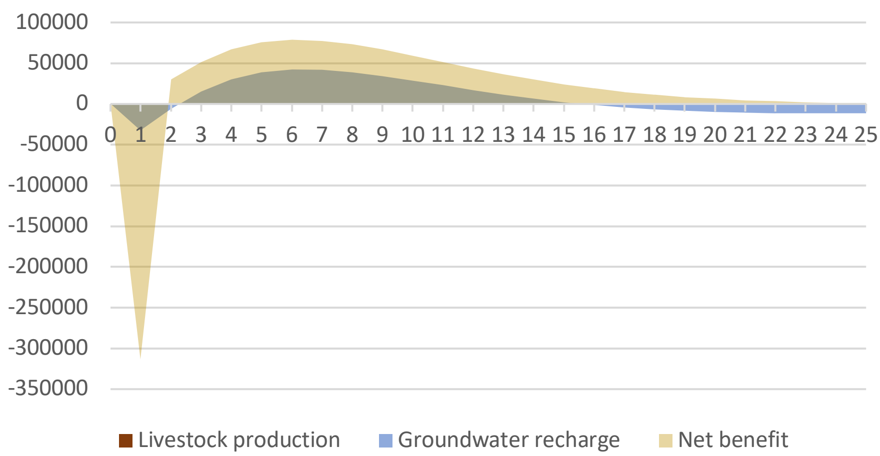


Under the BAU1 scenario, benefits from increased livestock production range from 0 to a N$13,100 in Year 8 and slowly decreases to negative values by Year 24 as the bush thickens.

Higher rates of groundwater recharge start to provide benefits from Year 3 onwards, availing between 1,800 m^3 in Year 3, up to 6,800 m^3 in Year 6 and slowly decresing to 0 in Year 24 as the bush thickens. The value generated by this additional water ranges between N$700 (Year 23) and N$13,700 (Year 6).

The overall net benefits become positive from Year 2, ranging from N$17,000 to N$63,900. **The overall net present value of this intervention is N$629,600 reflecting an overall net benefit over 25 years** (N$2,518 per hectare).

Figure 15: Benefit flows, Scenario 8: goats stocking, after selective thinning, N$ (2020 prices)



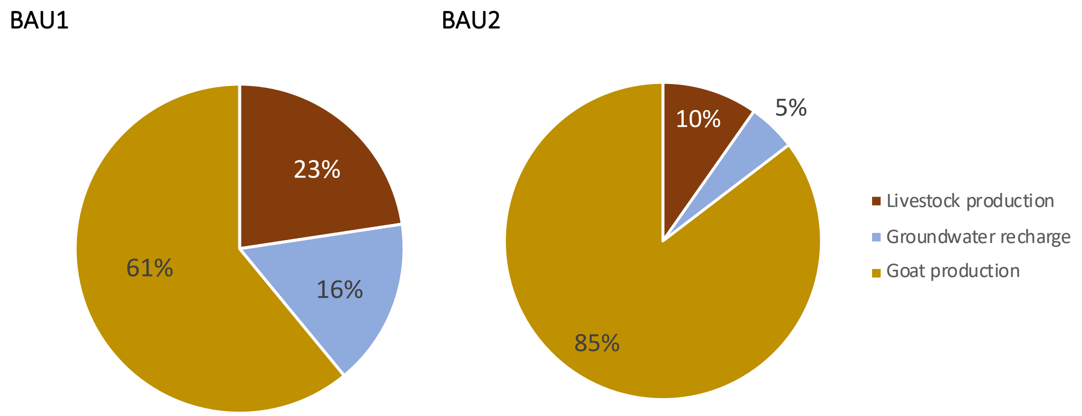
Under the selective thinning scenario, benefits from increased livestock production range from 0 to N$6,166 in Year 7 and slowly decrease to negative values by Year 16.

Higher rates of groundwater recharge start to provide benefits from Year 3 onwards, availing between 681 m^3 in Year 3, up to 2,200 m^3 in Years 6 and 7 and decrease to negative values from Year 15 onwards. The value generated by this additional water ranges between 0 and N$3,400 (Year 6 to 7).

The net benefits become positive from Year 2, ranging from 0 to N$40,100. **The overall net present value of this intervention is N$337,240 reflecting an overall net benefit over 25 years** (N$1,348 per hectare).

The use of goats to control regrowth is attractive as goat production itself can generate substantial income, leading to fairly high NPVs for this measure. However, it should be noted that their impact on bush regrowth is limited and is not sufficient to prevent re-thickening of bush within 25 years. Most of the net income generated from this measure is derived from stable goat production (61% under BAU1 and 85% under BAU2, see Figure 16 below), rather than from increasing grazing capacity and groundwater recharge.

Figure 16: *Share of net benefits by source under Scenario 8*



Employment considerations
In order to manage a herd size of 500 goats under BAU1, about 3 sheperds should be employed under long-term contracts. Under BAU2 2 sheperds should be employed. In this case sheperds would be paid the average farmworkers salary of N$1,200 plus food, accommodation and transport.

Scenario 9: Combination of Fire and Goats

Under this scenario, the land user is stocking goats on thinned land to control regrowth and is also conducting controlled burns every ten years on average. Assumptions related to goat stocking and fire management are the same as in Scenarios 7 and 8.

<u>BAU1:</u> Under the clear-cutting scenario, the initial bush density in Year 0 (i.e. year of thinning intervention) is assumed to be 250 TE/ha. The introduction of goats is assumed to drastically reduce the discrete rate of population growth to 0.2 in the first year. However, as goats cannot control all the regrowth it is assumed that the rate of growth increases over time (about 10% per year), which means bush density increases slowly with slightly higher increases every year. The use of fire disrupts this growth pattern: Fire interventions in Year 8 and Year 18 reduce the growth rate to 0.2. The bush density gradually increases from 250 TE/ha in Year 0 to 2022 TE/ha in Year 25.

<u>BAU1:</u> Under the selective thinning scenario, the initial bush density in Year 0 (i.e. year of thinning intervention) is assumed to be 1000 TE/ha. The introduction of goats drastically reduces the discrete rate of population growth to 0.1 in the first year, slowly increasing by 5% every year -as the competition from big

trees limits the intensification of the growth rate. The use of fire disrupts this growth pattern: Fire interventions in Year 8 and Year 18 reduce the growth rate to 0.1 and bush density decreases to 800 TE/ha after fire. The bush density varies between 800 TE/ha after fire and 1702 TE/ha in years before fire.

The benefits quantification provided the following results:

Table 11: Summary of benefits, scenario 9 – Goat stocking and fire

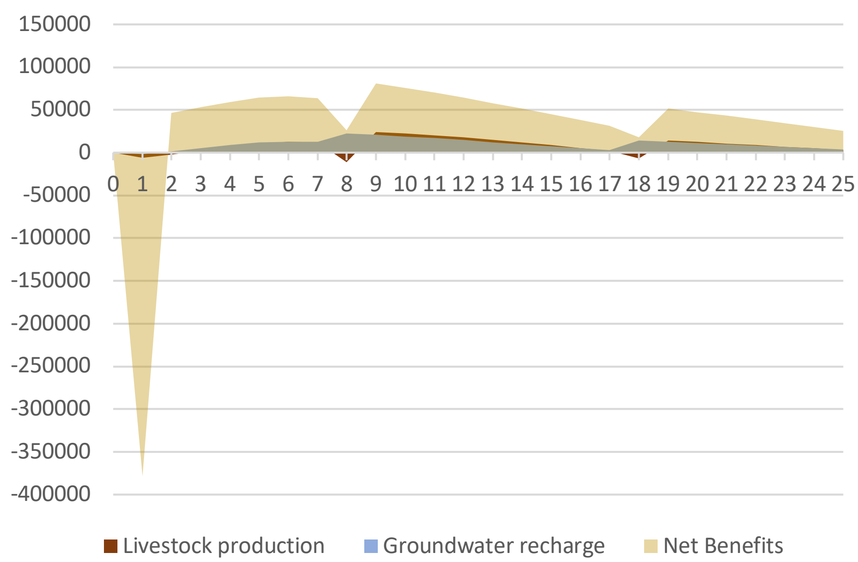
	After clear-cutting	After selective thinning
Grass density (tons/ha)	0.9 - 1.7 tons/ha	0.9 – 1.3 tons/ha
Carrying capacity (kg/ha) – after goat inclusion	19.9 – 47.5 kg/ha	29.5 – 40 kg/ha
Number of cattle heads kept on 250 ha	13 to 32	17-26
Groundwater recharge rate (% of annual rainfall)	1.6% - 2.7%	1.6% - 2%

Further details and graphic representation on these estimates are available in Appendix B9.

Bush density is lower after clear-cutting compared to selective thinning, which leads to higher grass densities and groundwater recharge rate under BAU1.

As presented in Figures 17 and 18 below, the purchase of goats for post-harvest treatments incurs a significant net loss to the farmer in the first year of intervention (- N$380,000 under BAU1 and – N$283,000 under BAU2). The year of fire intervention also incurs a net loss for farmers due to the opportunity cost of not using the land for 18 months. This loss is recovered by Year 8 under BAU1 and by Year 9 under BAU2.

Figure 17: Benefit flows, Scenario 9: goats stocking and fire, after clear-cutting, N$ (2020 prices)

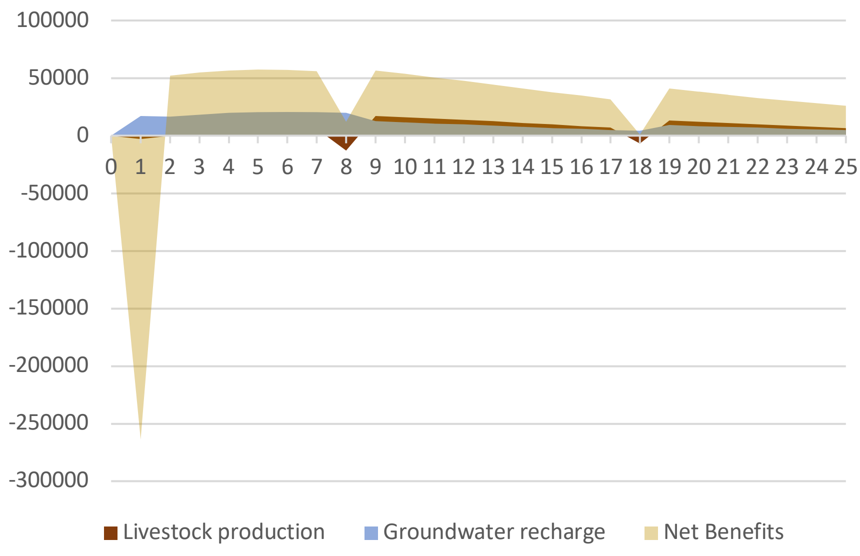


Under the BAU1 scenario, benefits from increased livestock production range from 0 to N$24,000 in Year 9, then slowly decreasing to N$2,800 in Year 25. For the years with fire intervention, the opportunity cost of not using the land for livestock production is estimated at N$11,100 in Year 8 and N$6,500 in Year 18.

Higher rates of groundwater recharge start to provide benefits from Year 2 onwards, availing between 730 m^3 in Year 3 to 15,264 m^3 in Year 8. The value of additional water resources per year ranges between N$1,350 and N$22,600.

The overall net benefits become positive from Year 2 ranging from N$25,700 to N$80,000 in years with no fire intervention. **The overall net present value of this intervention is N$805,126 reflecting an overall net benefit over 25 years** (N$3,220 per hectare).

Figure 18: Benefit flows, Scenario 9: goats stocking and fire, after selective thinning, N$ (2020 prices)



Under the selective thinning scenario, benefits from increased livestock production range from 0 to N$17,000 in Year 9. In the years of fire intervention, the opportunity cost of not using the land for livestock production is estimated at N$12,200 in Year 8 and N$6,600 in Year 18.

Higher rates of groundwater recharge start to provide benefits from Year 2 onwards, availing between 759 m^3 in Year 3 and beyond 9,000 m^3 in Years 18 and 19. The value generated by this additional water ranges between 0 (until year 3) and N$12,500 (Year 9).

The yearly net benefits become positive from Year 2 ranging from N$27,000 to N$56,700 in years with no fire intervention. **The overall net present value of this intervention is N$581,108 reflecting an overall net benefit over 25 years** (N$2,324 per hectare).

The combination of controlled fire and goat stocking appears to be a highly beneficial measure indicated by the high NPVs. However, it should be noted that almost half the benefits generated are derived from goat production in both cases, hiding a limited impact on increasing ecosystem services such as grass production and groundwater recharge.

Employment considerations
The combination of controlled fire and goats stocking would require the employment of 2-3 sheperds all year long on long-term contracts, and 5 casual workers for about 2 days for fire internvetions every 10 years or so.

Scenario 10: Combination of Fire and Foliar Treatment

Under this scenario, the land user combines foliar-applied chemical treatments every three years and controlled veldfires in Year 2 and 12. Assumptions related to foliar-applied chemicals and fire management are the same as in Scenarios 4 and 7. It should be noted that in these two cases, the impact of fire is mainly reflected in the reduction of costs as it significantly reduces the number of plants to be treated with chemicals.

BAU1: Under the clear-cutting scenario, the initial bush density in Year 0 (i.e. year of thinning intervention) is assumed to be 250 TE/ha. The foliar arboricide and fire post-harvest interventions maintain the regrowth at a very low level with a discrete rate of population growth of 0.2 after Year 2. Thus, bush density remains at low levels, gradually increasing towards 1000 TE/ha by Year 20 as some desired plants are left to grow, while regrowth of undesired plants is systematically treated. The level of effort needed is quite low, as a fire intervention is conducted before the first chemical application, bringing the number of plants to be treated down to 750 per hectare in Year 3. This is based on an assumption of 30% regrowth after a fire.

This number decreases by 50% after every chemical intervention until it reaches a stable low regrowth state in Year 13 after the second fire with 150 plants to treat per hectare. The costs of foliar arboricide application vary between N$73 per hectare in Year 3 after the first fire and N$15 per hectare at the lower stable state from Year 13 onwards.

BAU2: Under the selective thinning scenario, the initial bush density in Year 0 is assumed to be at the desired 1000 TE/ha. The chemical post-harvest intervention is meant to keep this density stable at 1000 TE/ha, while fire intervention reduces the density down to 800 TE/ha. The discrete rate of population growth is reduced to 0.128 after the first year of chemical intervention. The effort needed is assumed to be low with an average of 150 plants to treat per hectare after the first fire intervention this is based on an assumption of 30% regrowth after a fire. The number of plants to be treated reaches a low stable state of 100 plants to treat per hectare as soon as the second chemical intervention. The costs of foliar-applied chemical intervention are thus low, at N$17 per hectare for the first application and N$10 to N$11 per hectare for the second application and onwards.

The benefits quantification provided the following results:

Table 12: Summary of benefits, scenario 10 – Foliar-applied chemical and fire

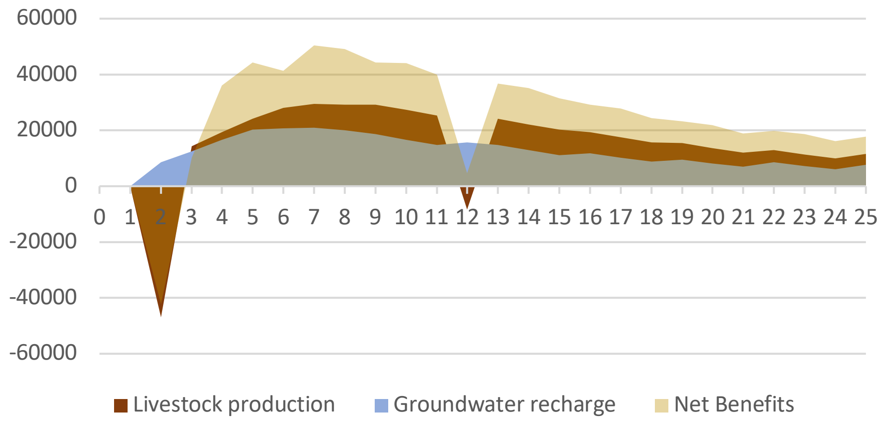
	After clear-cutting	After selective thinning
Grass density (tons/ha)	1.1 - 1.8 tons/ha	1.2 – 1.4 tons/ha
Carrying capacity (kg/ha)	36.9 – 57.5 kg/ha	38 – 45.3 kg/ha
Number of cattle heads kept on 250 ha	24 to 38 (0 on fire years)	25-30
Groundwater recharge rate (% of annual rainfall)	1.7% - 2.8%	1.8% - 2%

Further details and graphic representation on these estimates are available in Appendix B10.

Bush density is lower between Year 1 and 20 after clear-cutting compared to selective thinning, which leads to slightly higher grass densities and groundwater recharge rate under BAU1 in the short-term. However, these eventually converge towards similar levels after Year 20.

As presented in Figures 19 and 20 below, using fire as post-harvest treatment incurs net losses to the farmer in years when fire is implemented. However, the net benefits generated in years with no intervention cover the previous net loss within one year.

Figure 19: Benefit flows, Scenario 10: fire and foliar-applied chemical, after clear-cutting, N$ (2020 prices)

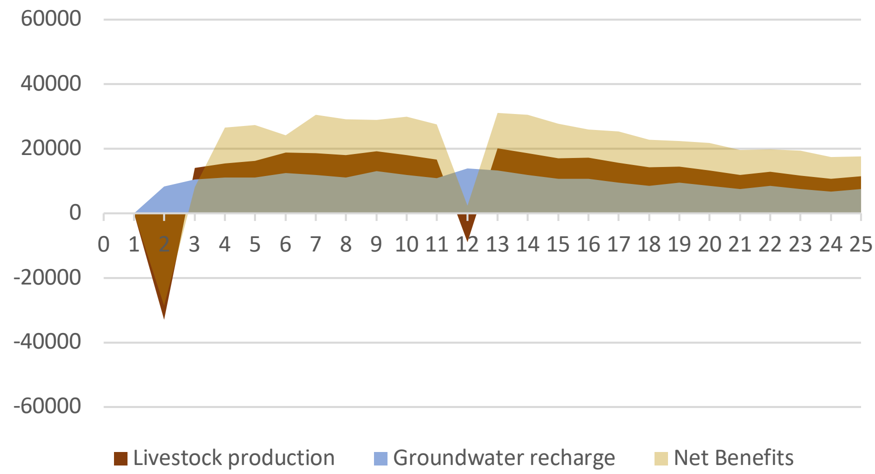


Under the BAU1 scenario, the losses associated with the opportunity cost of not grazing in Year 2 are quite high at almost N$33,000 and about N$8,900 in Year 12. The benefits generated from increased livestock production in years between fire intervention ranges between N$29,500 and N$14,200 in Years 3 to 11 and between N$24,200 and N$9,900 in Years 13 to 25.

A higher rate of groundwater recharge could avail up to 13,000 m^3 after the second chemical intervention. It would oscillate between 7,800 m^3 and 10,000 m^3 of additional water per year from Year 16 onwards, generating between N$7,500 and N$10,700 per year.

The net benefits are negative in Year 2 only and then remain positive ranging between N$10,200 and N$50,000 in years between fire interventions, and at N$4,700 in the year of the second fire intervention. **The overall net present value of this intervention is N$643,580 reflecting an overall net benefit over 25 years** (N$2,574 per hectare).

Figure 20: Benefit flows, Scenario 10: fire and foliar-applied chemical, after selective thinning, N$ (2020 prices)



Under the selective thinning scenario, the losses associated with the opportunity cost of not grazing in Year 2 are estimated at N$33,000 and at N$8,900 in Year 12. The benefits generated from increased livestock production in years between fire interventions ranges between N$19,200 and N$14,000 in Years 3 to 11 and between N$20,100 and N$10,600 in years 13 to 25.

A higher rate of groundwater recharge could avail up 13,000 m^3 after the second chemical intervention. It would oscillate between 7,800 m^3 and 11,000 m^3 of additional water per year from Year 16 onwards, generating between N$6,800 and N$10,700 per year.

The net benefits are negative only in Year 2 and then remain positive ranging from N$8,100 to N$31,100 in years between fire interventions, and at N$2,300 in the year of the second fire intervention. **The overall net present value of this intervention is N$507,239 reflecting an overall net benefit over 25 years** (2,028 per hectare).

The combination of fire and foliar-applied chemicals for post-harvesting treatment appears to be a highly beneficial intervention for farmers, especially after a clear-cutting bush control.

Employment considerations

The combination of controlled fire and chemical treatment would require the employment of 5 casual workers for 2 days every 10 years for fire intervention. For chemical treatment under BAU1 three workers could cover the 250ha in less than 60 days of work for the first intervention, then 2 workers for the second intervention three years later, then one worker for about 30 days every three years for follow ups. Under BAU2 only 1 worker will be employed for 30 days for the first intervention, then for 20 days every three years for follow ups.

Scenario 11: Complementary – Brush Packing and Reseeding

Although brush packing and re-seeding cannot be considered as stand-alone aftercare measures, this scenario has been evaluated to provide information on the potential scale of added benefits from these interventions as a supplement to other post-harvesting measures. Under this scenario, it is assumed that brush packing and reseeding are conducted on 30% of the area that was initially thinned.

The main costs associated with this approach is the opportunity cost of not grazing on the areas that are covered by brush packing during the first year after thinning and the substantial labor effort required to cover a large area with brush packing.

Based on assumptions of improved grass response after re-seeding and a decrease in the bush growth rate by 20% -due to increased competition with the grass layer-, bush and grass densities were quantified. Under both BAU1 and BAU2, bush densities indicate thickening from Year 7 onwards with densities above 2,500 TE/ha from Year 7 to 25.

The benefits quantification provided the following results:

Table 13: *Summary of benefits, scenario 11 – Brush packing and reseeding*

	After clear-cutting	After selective thinning
Grass density (tons/ha)	0.5 – 2.1 tons/ha	0.5 – 1.5 tons/ha
Carrying capacity (kg/ha)	16.1 – 68.3kg/ha	16.2 – 49.6 kg/ha
Number of cattle heads kept on 75 ha (30% of 250ha)	4.2 to 10 (0 for one year after brush packing)	3 – 7 (0 for one year after brush packing)
Groundwater recharge rate (% of annual rainfall)	1% - 2.7%	1% - 1.9%

Further details and graphic representation on these estimates are available in Appendix B11.

This proved that brush packing and reseeding are not sufficient to limit bush regrowth down and must be combined with other interventions to avoid problematic thickening from Year 6 onwards, reducing the potential benefits.

Additional benefits, compared to a no-action scenario, are thus quite limited and are not sufficient to cover the costs of brush packing with negative Net Present Values for both BAU1 (-N$163,563) and BAU2 (-N$157,477) cases.

There is no reliable record of the impact of brush packing on bush regrowth in Namibia, and these estimations are based on studies conducted in South Africa (e.g. Meyer, 2019). Further information from Namibia would be required to reliably estimate the cost-effectiveness of this complementary measure.

Employment considerations

Brush packing and reseeding can be labour intensive, with about 30 workers working for 90 days to cover 75 ha.

4.1. Overall Comparison of Economic Impact

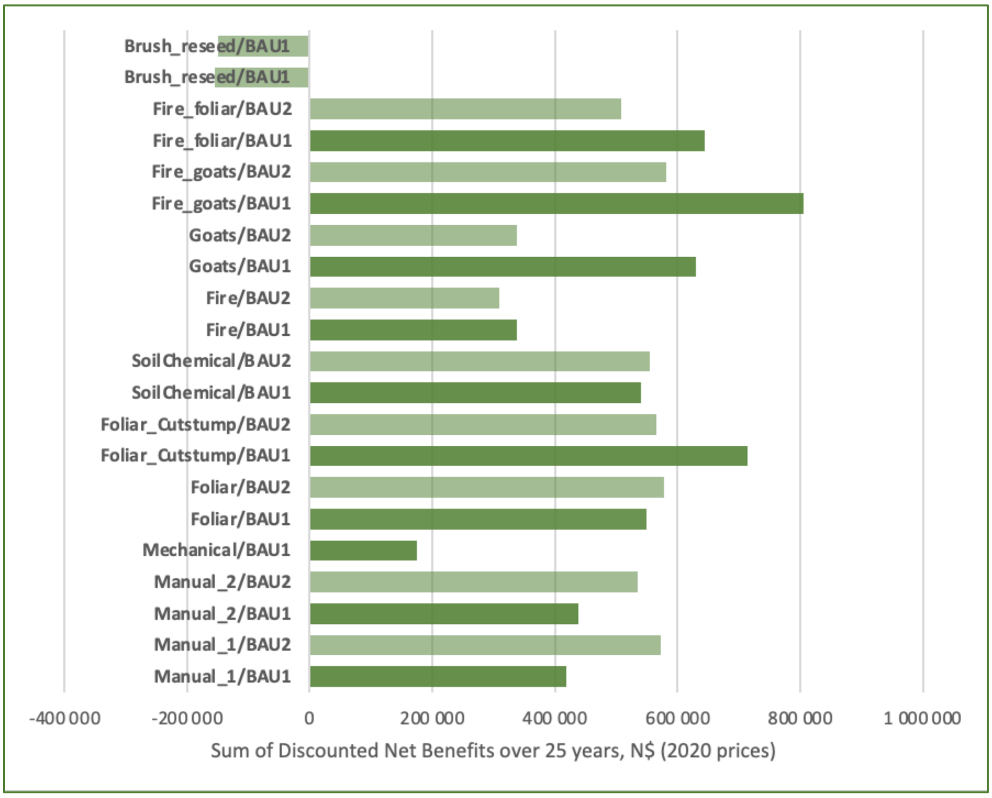
Long-term economic viability

Net Present Values have been calculated for each scenario to assess the viability of each intervention over a 25-year period taking into account the time value of money. They represent the sum of net benefits over that time period discounted over time (at a 4% discount rate).

Positive NPVs suggest that the benefits generated by the intervention overcome the cost over 25 years, while a negative NPV suggests that the intervention generates a net loss for the land users even when taking into account the sum of benefits over 25 years.

As presented in Figure 21 below, most post-harvest measures are estimated to be economically viable under the scenarios and associated assumptions presented for each measure. NPVs range from N$174,052 (for heavy mechanical control) to N$805,126 (for a combination of goat stocking and fire under BAU1)

Figure 21: *Summary of Net Present Values of post-harvesting measures, N$*



According to this analysis, the least beneficial measure is the use of heavy mechanical post-harvest interventions. The most beneficial measure is the combination of goat stocking and controlled fire after an initial clear-cutting intervention. It is essential to note that most of the benefits from methods using goats are derived from goat production, thus hiding a relatively poor performance in keeping bush densities at low levels.

The second most beneficial measure is chemical post-harvest treatment combining cut stump and foliar applications after a clear-cut harvesting intervention. Overall, chemical post-harvest treatments appear to be generating consistently high net benefits (between N$500,000 and N$700,000). Although manual interventions after selective thinning also yield fairly high net benefits (above N$500,000).

In some cases, the net benefits generated by post-harvest measures after selective thinning are more beneficial than after clear-cut harvesting. This difference is relatively small for soil- and foliar-applied chemical treatments, but is substantial for manual treatments.

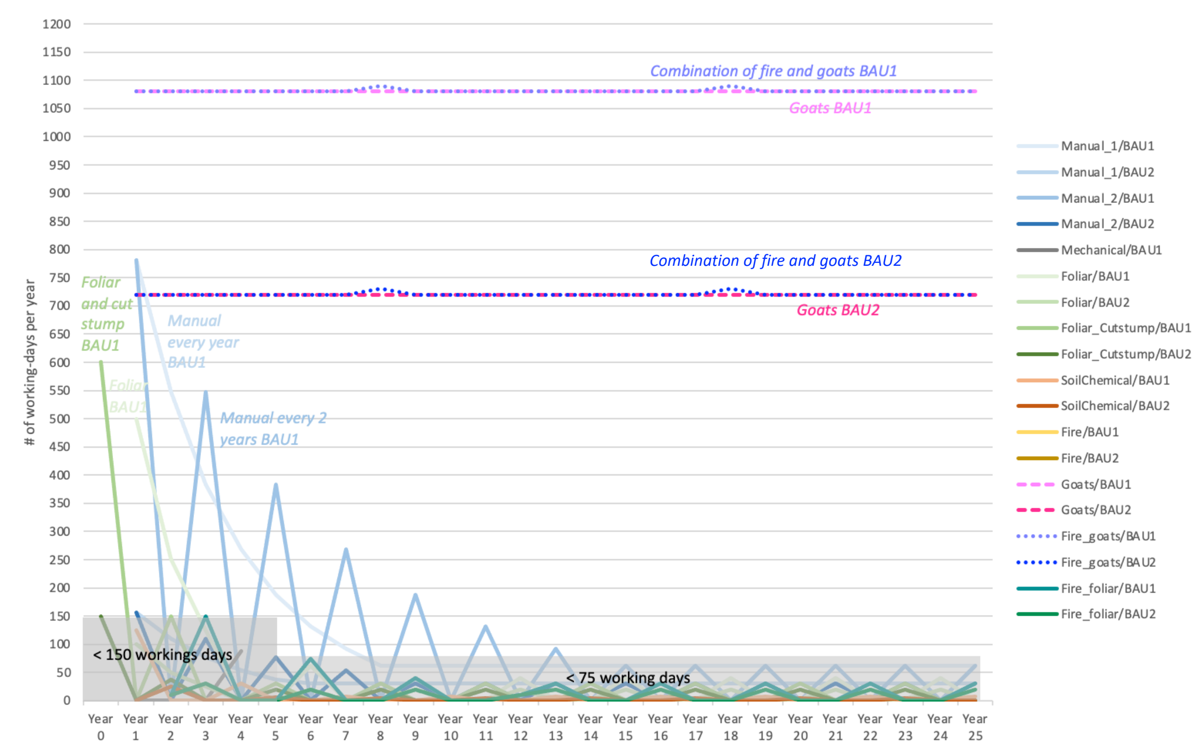
However, in many cases post-harvest measures appear more beneficial when conducted after clear-cut harvesting. This might be due to the maintenance of very low levels of TE/ha such as in Scenario 5 (cut stump + foliar chemicals), Scenario 9 and 10 (combinations of fire and goats, and fire and foliar-applied chemicals) and Scenario 8 (goat stocking).

As described under Scenario 11 above, brush packing and re-seeding are not beneficial if conducted on their own.

Labour intensity

The figure below presents the total number of working days required for each intervention to cover a 250ha area, based on the bush density and methods used. This total number of working days can be divided by the amount of workers employed for the post-harvest measure. It should be noted that, except for the driver employed for mechanical post-harvest measure, all other workers are low-skilled with salaries averaging to N$50-60 per day, and N$100 for for fire management.

Figure 22 : Labour intensity per scenario in number of working days per year.



Most measures are relatively low in labour intensity with less than 150 working days required per intervention period for the first five years, and then less than 75 working days per intervention period from year 5 onwards. The majority of interventions thus offer short-term employment opportunities over a

maximum period of 3 months per year of intervention. The only intervention generating a long-term employment opportunity is goat stocking, which is labour intensive as it requires to employ one to three sheperds all year long. Manual post-harvest treatment can also be labour intensive, especially in the case of high regrowth of bush in the first years of interventions, requiring 500-800 working days in the three first years of intervention. The application of chemicals on cut stump also requires high labour input, if the number of stumps to cover is high (in the case of clear cutting harvest method) this post-harvest measure can require up to 600 working-days, which would potentially involve a high number of workers to limit the time over which the application is made – eg. about 30 workers would be needed to cover the area in one month. On the contrary, the use of controlled fire provides very limited employment opportunity over only 2-3 days per year of intervention.

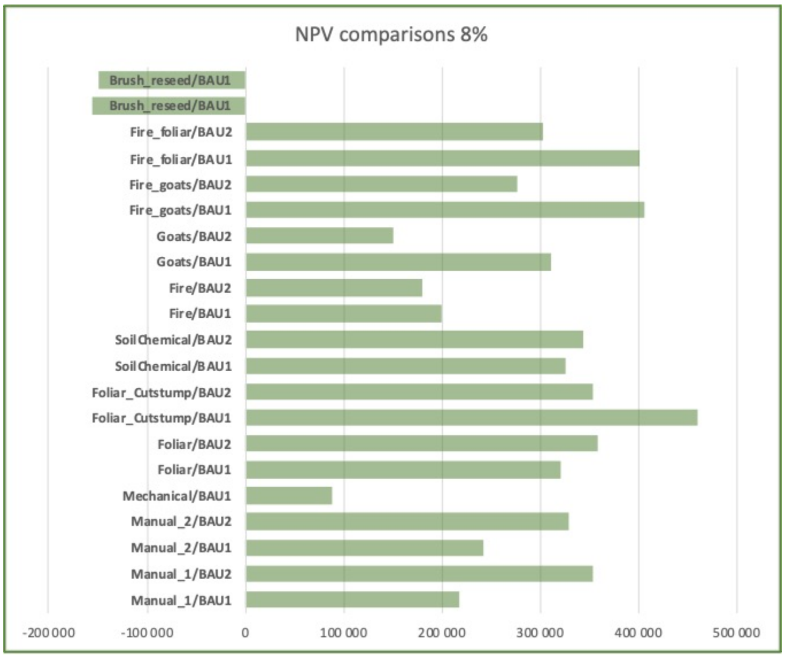
4.2. Sensitivity Analysis

The results of a partial sensitivity analysis focusing on the discount rate, farm size and water values is presented below. This analysis looks at variations in the results by changing a single assumption or parameter while keeping all other parameters equal (as presented in the central case), to determine the NPV's sensitivity to a specific variable.

Discount Rate

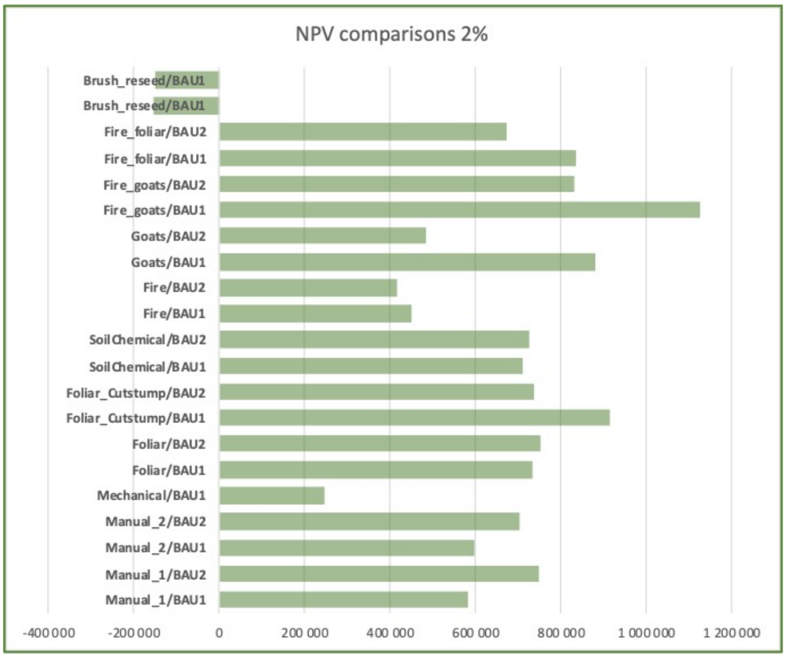
An increase in the discount rate from 4% to 8% (Figure 23) means that the present values of costs and benefits that occur later in the future are lower, while a decrease from 4% to 2% (Figure 24) means that the actors are less short-term oriented and therefore values in the long-term are slightly higher.

Figure 23: *Summary of Net Present Values with 8% discount rate , N$*



In general, the NPVs are lower than under a 4% discount rate scenario. Measures with short- to medium-term impacts, such as the cut-stump and foliar application of chemicals, become more beneficial than measures that are slower to generate benefits. For this reason, the combination of fire and goats is not the most beneficial measure in this scenario.

Figure 24: Summary of Net Present Values with 2% discount rate , N$

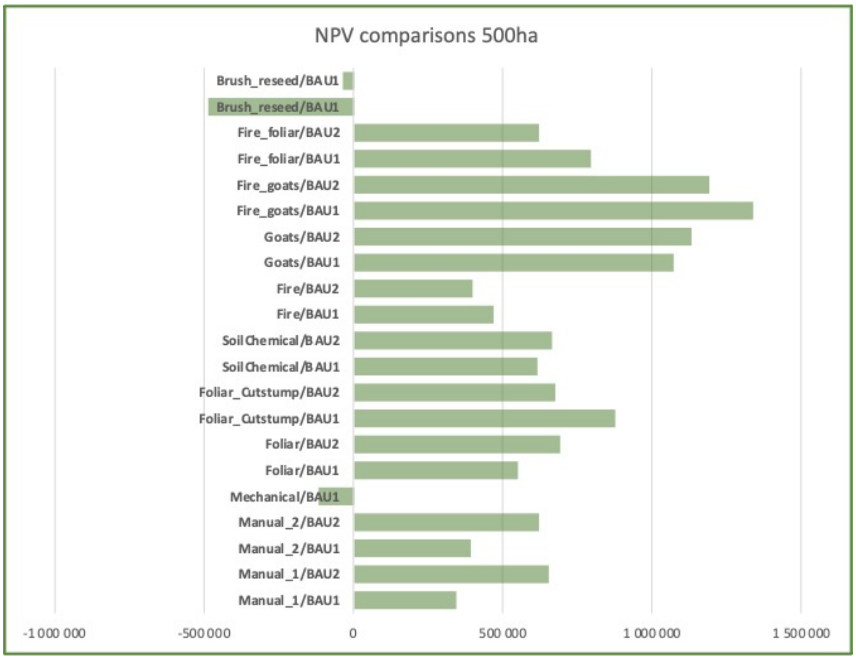


Decreasing the discount rate to 2% increases the NPVs for all measures, but otherwise does not change the ranking between measures compared to a 4% discount rate scenario.

Farm Size / Size of Area under Aftercare

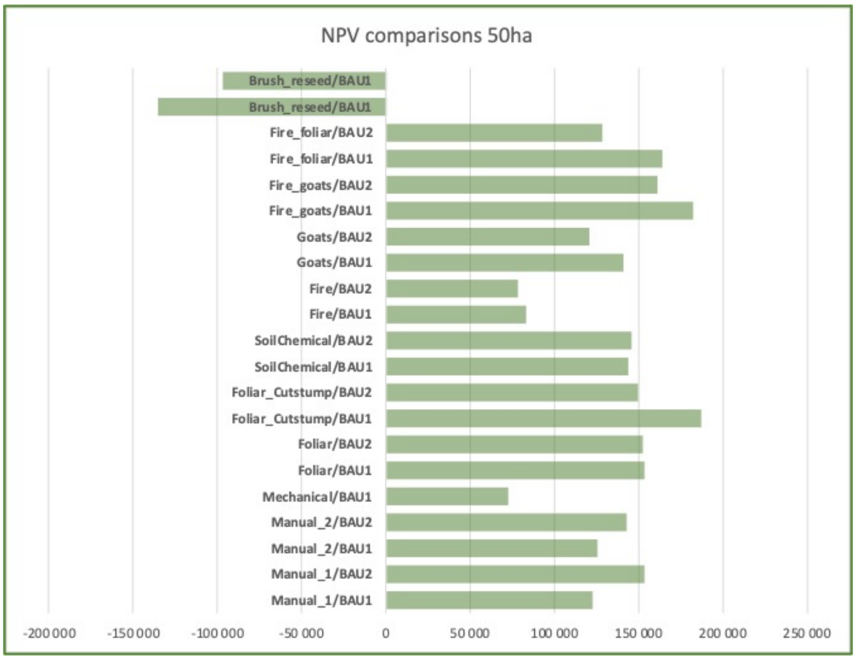
The size of the farm and more specifically the size of the area treated with post-harvest measures can have a significant impact on cost, production levels and in turn the viability of different post-harvest measures. For this reason, we have assessed the impact of farm size on the costs and benefits for a very large farm of 10,000 ha with 500 ha under post-harvest treatment (Figure 25), and a small farm of 1,000 ha with 50 ha under post-harvest treatment (Figure 26).

Figure 25: Summary of Net Present Values with for a large area (500ha) , N$



NPVs for scenarios that include the use of goats become the most beneficial compared to other measures, including all measures using chemicals. The NPV for heavy mechanical post-harvest measures becomes negative if it is implemented over an area of 500 ha, implying that it incurs a net loss to the farmer.

Figure 26: Summary of Net Present Values with for a small area (50ha) , N$

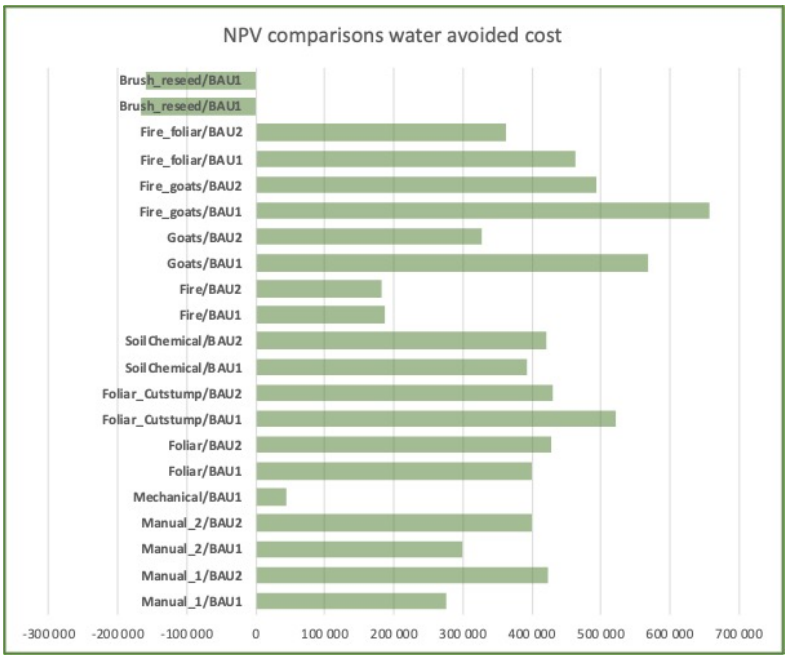


Reducing the area on which post-harvest measures are applied to 50 ha reduces the NPVs for every measure. However, this decrease appears to be proportional and therefore does not change the ranking of measures according to their viability compared to the central case of 250 ha.

Water Values

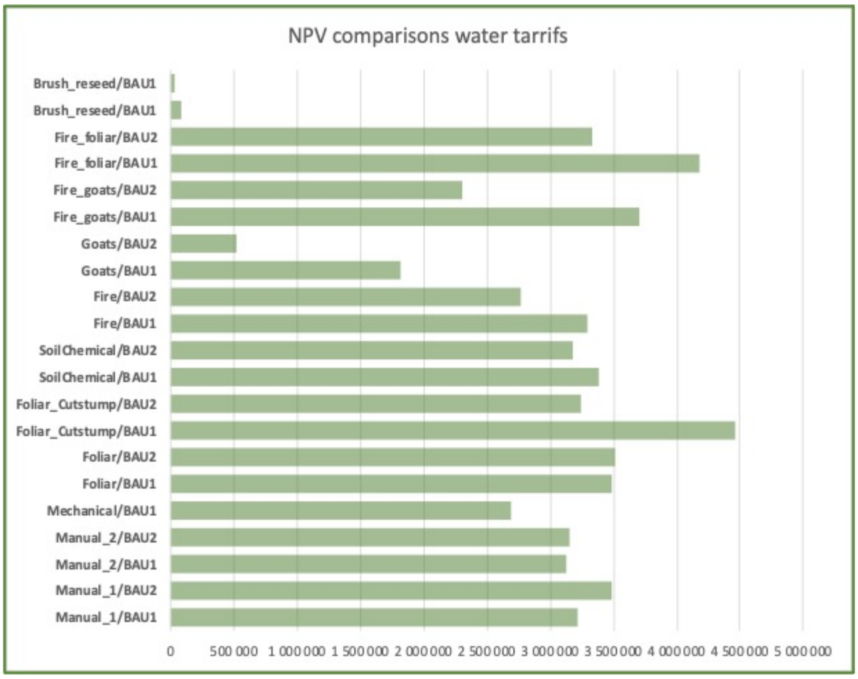
The value of water to land users is not established by market dynamics and therefore does not have a market price that reflects its economic value. Different methods were used to estimate the shadow value of water, and in the central case, the value of N$2.01/m^3 transferred from MacGregor et al. (2000) was chosen. As groundwater recharge is a major component of benefits derived from post-harvest measures, the impact of the price used to calculate the value of water is expected to be significant. The impact of using the avoided costs value (Figure 27) and water tariffs (Figure 28) as a measure to valuate water benefits for a farmer is presented below.

Figure 27: Summary of Net Present Values with low water values , N$



Using avoided costs, the value of water is estimated at N$0.83 per cubic meter. All NPVs are evidently lower than in the central case. There are little changes in the ranking of measures by economic viability, except that the use of combined fire and foliar-applied chemical becomes less beneficial than the combination of fire and goats in all cases.

Figure 28: Summary of Net Present Values with high water values , N$



Bulk water tariffs, at N$25 per cubic meter, were also used as an indicator of the value of water. As expected, this significantly increases all NPVs as it multiplies the value of water by more than 10. It also significantly changes the difference in economic viability between measures. The brush packing and reseeding measures become viable, although with a very small NPV. The use of goats becomes much less viable with the small NPV being the stocking of goats under BAU2 at around N$500,000.

The use of chemicals on cut-stumps followed by foliar application is the most beneficial measure in this case, followed by the combination of fire and foliar-applied chemical treatments.

5. Discussion

5.1. Interpretation of the Results

The results must be viewed against their limitations (outlined below) but none the less provide an important farm-level perspective on the issue of aftercare, which to date has been lacking. Overall, the evaluation of costs and benefits associated with post-harvesting measures suggests that undertaking post-harvest interventions is consistently beneficial for the farmer in the medium-term (25 years). The costs associated with inputs, labour and opportunity cost are always recovered by higher benefits from an increased grazing capacity and higher availability of groundwater, as compared to a no-action scenario after initial bush thinning.

However, in many cases post-harvest treatments require the farmer to have sufficient cash available to cover net losses over the first years of the interventions. This is specifically true for goat stocking, which involves the purchase of a herd of goats and fire, which incurs net losses in the years of fire interventions due to the opportunity cost of not using the land. Cut stump chemical treatments also require a significant investment in Year 0. These initial net losses range from N$7,000 (foliar-applied chemical under BAU2) to N$380,000 (goat stocking under BAU1) with the majority of interventions necessitating an investment of N$30,000 to N$50,000 in the first year of intervention. These upfront costs can be significantly reduced by adopting a selective thinning approach for initial bush thinning, reducing the effort needed to control regrowth in the first years. This suggests that many post-harvest measures could be hard to implement for small-scale farmers with limited cash availability and/or limited access to finance. High interest rates on commercial loans also limit the capacity to invest in interventions with small benefits in the long-term. Considerations to facilitate access to finance for these interventions are presented in the Financial Mechanism Review attached to this report.

Overall, the net benefits generated from post-harvest measures (N$700 to N$3,220 per hectare in total over 25 years) are relatively low compared to the average annual profit of an average sized farm. Although post-harvest measures can generate profits in the long-term, these are likely too small and spread out in time to be an effective incentive for farmers to undertake post-harvest measures without external intervention.

This analysis suggests that environment-friendly post-harvest treatments can be beneficial to the farmer in the long-term. However, the net benefits of chemical-based methods are often higher. This creates an incentive for farmers to resort to chemical-based measures, despite potential negative impacts on soil and other plants (which are costs that cannot be valued in the context of this study and are therefore not reflected in the CBA). This perverse incentive could be addressed by increasing the transaction costs of using chemicals (regulations and/or market barriers), increasing the price of using chemicals (VAT or Environmental Levies) or creating incentives to use environment-friendly practices (subsidies, technical support, labelling, preferential loans – see Financial Mechanism review for further details).

The use of goats is an environment-friendly measure that can be highly beneficial to farmers, as it generates significant income from goat production. However, it should be noted that the relatively high NPV for this scenario hides the limited impact of goats on bush regrowth, which tends to thicken to pre-thinning levels in the medium-term if no other measure is implemented to limit regrowth.

Selective thinning for initial bush control does not consistently have a positive impact on the cost-effectiveness of post-harvest treatments. Based on this analysis, the combination of a selective initial control approach and manual post-harvest treatment creates the most synergies in minimizing costs and enhancing benefits from controlled bush regrowth.

This analysis also suggests that the use of heavy mechanical equipment for post-harvest measures generates limited benefits given the considerable negative impacts on the environment (See Environmental

Assessment). Moreover, this method appears more adapted to follow-up bush thinning (with bush densities higher than 2000 TE/ha) than for post-harvest treatments as it can hardly be used selectively.

This study also analysed the labour intensity of each measure under each scenario, providing some insights on the employment potential of post-harvesting measures. Most measures provide opportunity for short-term employment of low skilled workers, with manual and chemical method requiring significant labour inputs in the first years of intervention, especially if the bush regrowth is high. On average most measures would require 2-5 workers over a period of 2-3 months on the years of intervention. In most cases it is expected that some of the workers hired for harvesting will be retained for post-harvest measures, at least over the first five years of interventions. As the bush regrowth slows down, most measures would not require more than one to two workers for follow ups in later stages (from year 5 to 25). Fire management would create very short-term opportunity for a small amount of casual workers. Long-term employment would only be required when using goats for post-harvest treatment, generating a small amount of jobs full-time over the 25 years period observed.

These interpretations should, however, be taken with a grain of salt as the cost-benefit results might differ siginifcantly for different contexts and different parameters that were not considered in this study. Key limitations are summarized in the section below, followed by recommendations on the way forward.

5.1. Limitations

This analysis should be considered as a first step towards a better understanding of the cost-effectiveness and net benefits associated with post-harvest treatments at the farm level in the context of bush thinning in Namibia. Due to the limited implementation of these measures by farmers and limited scientific knowledge on their impacts, this study faced significant data and information gaps which limited its scope and the applicability of its results. The main limitations of this study are summarized below.

Typical Farm Assumptions

To allow for comparison between net benefits of each measure, a central scenario had to be built based on a “typical farm” model. As explained in the methodology section, this typical farm is assumed to be of an average size of 5,000 ha with livestock production as its only sources of income. The area under bush control and post-harvest treatments is assumed to be only 5% of the farm size. The diversity of farm sizes and production models of commercial and communal farms in Namibia could lead to different net benefits estimations due to potential economies of scale for certain measures (mechanical and fire), or unfeasibility of some measures over very large areas in less than one season (manual post-harvest treatment for instance). Although a size sensitivity analysis has been conducted, it does not take into account the potential non-linear impacts of farm size on the effectiveness of the post-harvest measures and production levels. This reduces the applicability of our results to farms with dramatically different sizes and production models (such as farms with crop, sheep and game production systems). However, it has been assumed that our model represents at least a conservative estimate of potential benefits associated with a livestock-only production with a farm size that is fairly representative of a majority of farms (including resettlement farms). Due to significantly different production and redistribution systems, a study dedicated to cases in communal areas should be considered to ensure better representation of costs and benefits for communal areas.

Regrowth Model

The model established to simulate the changes in bush densities under different scenarios is based on the central scenario assumptions, potentially limiting the applicability of our estimations to some Namibian landscapes. Due to the limited availability of data and information and limited resources, the regrowth model does not integrate different rainfall zones and soil types, which could significantly affect regrowth. However, once precise empirical information becomes available the model could be adapted to include different assumptions about annual average rainfall and soil types.

Another key parameter that could not be integrated into the model at this stage were the responses of different encroaching woody species to different post-harvest treatments. It is known that sicklebush (*Dischrostachys cinerea*) has a stronger regrowth rate under most post-harvesting methods (especially with

fire). To cater for these differences some parameters of the regrowth model would have to be adapted based on empirical data and scenarios would have to be modified.

Furthermore, limited empirical evidence on bush and grass response to specific post-harvest measures in different landscapes necessitated the use of many assumptions -especially on the variation of discrete rates of population growth as a result of post-harvest treatments. Although these assumptions were based on the best available knowledge at this stage, a review should be considered when further empirical data becomes available.
The generally poorer performance of the selective thinning scenarios compared to clear-cutting scenarios is a result of the current model parameters and functions used. In most cases, the loss in grazing capacity and water recharge benefits due to retaining larger trees in the landscape was not compensated by the reduced bush regrowth rate in the selective thinning scenarios. This might partly explain why clear-cutting is currently practised so widely.

Finally, the target of 1000 TE/ha as a the desired bush density could be disputed for reasons mentioned above (variation between species, rainfall..). It was chosen based on the recommendations made by MEFT and MAWLR following recommendations from the SEA of bush thinning, as an average for *Acacia / Senegalia* spp. and *Terminalia sericea* with 450 mm annual average rainfall. This target in our model would have to be adapted for different species composition and rainfall patterns.

Benefit Quantification and Valuation

To quantify the potential increase in grazing capacity associated with post-harvest treatments, an exponential regression linking Tree Equivalents to Grass biomass was established based on empirical data from Richter et al. 2001 and a study conducted for Nampower in 2018 (Van Der Waal, n.p.). Although developed with the best available data, the regression fit indicator is relatively low ($R^2 = 0.29$). This is often due to variable rainfall patterns and different land uses in the study units. For this reason, the model estimates were adapted based on expert reviews and accounts of grass biomass responses for different scenarios. Further work is required to model the relationship between Tree Equivalents and Grass biomass more precisely.

Grazing capacity and the associated increase in net income from livestock production was estimated based on a profitability model established by the Namibian Agricultural Union. The data is based on commercial production models, which might not be representative of production models in communal areas. Furthermore, the benefit estimations are based on a cow-ox production model, which could be considered reductive. This study opted to use the cow-ox production system because of its diversified livestock herd that provide producers the flexibility to market weaners, oxen, and old and unproductive cattle. Most cattle producers aim to optimize production and profits on their investment into the farming operation. Farmers hope to increase their net farm income through bush thinning and subsequent post-harvest treatments. It was therefore considered the most conservative and representative model to use with the available resources. Finally, it should be noted that the model does not take into account potential drought periods. However, potential overestimation of benefits was mitigated by assuming a grazable grass proportion of only 35% of the available grass.

The potential benefits derived from an increase in game population and better game visibility in a thinned farmland were not quantified in this study. At this stage, there is no empirical evidence providing insights on the linkages between increased grass biomass, lower bush densities and revenues from game hunting and game viewing. These benefits could however be estimated based on assumptions. Yet, for this work, it was decided to not include game-related benefits in order to avoid potential overestimation of benefits, and minimize risks of reducing the reliability of our results. Benefits associated with game hunting and viewing in thinned areas should be further studied.

The benefits derived from groundwater recharge were estimated based on evidence from specific areas (Groengroeft et al. 2018) and an average yearly rainfall of 450 mm. In reality, these benefits are expected to be much more variable as rainfall patterns in Namibia are known to be erratic. Moreover, the tangibility of benefits associated with groundwater recharge for farmers is fairly low, as most farmers get water at virtually no cost in the long-term. The value attached to water is therefore a shadow value that could under or over-estimate the actual value of water to farmers – and this value could vary between farmers. The value

transferred from MacGregor et al. (2000) appears to be the most relevant to our typical farmer model, but with only limited applicability across different farm types in Namibia. Moreover, some areas do not have access to drinkable groundwater which would reduce this benefit to almost zero for farmers in these areas.

Costs

There is only limited data on the costs of specific post-harvest interventions. For this study, the information was collected and calculated based on records from farmers' financial reports and interviews. Although these were cross-checked with other records from Rothauge (2019) and a study for Nampower, these estimations might require further review as more land users undertake post-harvest measures to ensure their validity at a national level.

5.3. Scope

This cost-benefit analysis is strictly looking at the benefits and costs to the land users to allow for a reliable comparative assessment. It, therefore, does not include broader costs and benefits such as job creation or income externalities for the tourism industry from keeping a landscape open. Furthermore, costs and benefits associated with the impact of a rehabilitated savanna landscape on biodiversity, carbon stocks or soil quality were also not part of the scope of this study. For this reason, this work should be considered as a starting point for a potential economic cost-benefit analysis that would include costs and benefits to other groups affected by bush thickening.

6. Conclusion

Post-harvest treatments after bush thinning efforts are considered key to maintaining a desired landscape with low bush densities and maximizing the environmental benefits associated with a stable wooded savanna ecosystem. Yet, very few farmers undertake these measures for various reasons including limited financial capacity, uncertainty on cost-effectiveness and short-term interests. Understanding the financial and economic implications of post-harvest measures for farmers is therefore an essential step for the effective promotion of post-harvest treatments that maximize environmental benefits at local and national level.

The analysis of costs and benefits associated with different post-harvest measures highlights potential barriers and perverse incentives limiting the capacity and interest of land users to undertake these measures. This directly informs the potential need for external intervention to incentivize sustainable practices and minimize the adverse environmental impact of bush thinning. For this purpose, this study should be considered in conjunction with the attached Environmental Assessment of post-harvest measures and Review of Financial Mechanisms to provide a comprehensive overview of potential trade-offs between economic viability at a farm level and long-term environmental benefits at local, regional and national levels.

What did we learn?

- Post-harvest treatments can be financially beneficial to farmers if we take into account livestock and water benefits.
- These net benefits are relatively low and might not be enough to incentivize the adoption of these measures without external interventions.
- Most post-harvest measures require some initial capital investments to cover net losses in the first years of intervention, which necessitates appropriate financial capacity from land users. However, the adoption of selective thinning methods for initial bush thinning could substantially reduce the upfront costs of post-harvest treatments.
- In general, chemical-based measures are the most financially attractive for farmers, which suggests that incentive mechanisms should be put in place to reduce the use of chemicals and promote more environment-friendly methods.
- Fire could be beneficial under the right conditions, despite the opportunity cost of not using the land for 18 months.

- The use of goats to limit regrowth is an attractive option financially, as goat production can generate substantial income, it also creates long-term job opportunities for sheperds. However, goats alone cannot fully control regrowth in the medium to long-term, and should be combined with other post-harvest measures.

- Job creation from these measures can be high for labour intensive methods such as manual treatments and chemical applications in the first five years of intervention, with all jobs being short-term and low-skilled. However, in most cases labour requirements are very low in the long-term as bush regrowth slows down.

What is yet to be uncovered?

As explained in the section above, there are considerable knowledge gaps that constrain a better understand and model of the impact of different post-harvesting measures on bush density, grass biomass and related ecosystem services such as groundwater recharge, biodiversity and carbon sequestration. This study should be considered as a first step towards improving this understanding, keeping in mind that further work will be required to cater for the diversity of ecological conditions, production models and benefit-sharing systems in Namibia.

Four priority areas for further research have been identified.

- The viability of different measures for commercial farms and communal conservancies deriving significant income from wildlife through hunting and photographic tourism.

- The value of support measures such as brush packing, sustainable grazing and soil enhancement.

- The broader costs and benefits of adopting post-harvest measures at the level of Namibian society and economy (including job creation and broader ecosystem services).

- The variation in cost-effectiveness of post-harvest measures for different species compositions, rainfall patterns and soil types. Testing the model parameters such as bush regrowth rates, grass biomass responses to bush densities under different rainfall, soil and land use conditions. These should also quantify responses under variable environmental conditions between clear-cutting and selective thinning operations.

What are the next steps?

Review: The scenarios and models developed for this study will be presented to experts and stakeholders to review and refine key assumptions.

Policy considerations: The development of guidelines and incentive mechanisms to promote the adoption of post-harvest treatments after bush thinning should take into consideration the results from this study, acknowledging existing financial incentives and potential financial capacity constraints that currently limit the adoption of appropriate post-harvest measures in Namibia.

Further research and iterations of this cost-benefit analysis study should be promoted to enhance knowledge on the cost-effectiveness of post-harvest treatments, and better understand the broader ecosystem services associated with post-harvest treatments.

Knowledge sharing: The models developed to assess the benefits associated with post-harvest measures could be improved by integrating additional parameters such as rainfall and species composition and refining assumptions based on new empirical findings. For this purpose, the model should be made accessible for use by researchers and policymakers who wish to undertake further research on this topic.

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7. Appendix

Appendix A. Methodology

A.1 Regrowth model

The TE/ha was calculated from the measured tree density and height per transect and the long-term rainfall extracted per transect in a GIS. In African savannas the maximum woody density in an area (excluding riparian and depressions) is limited by mean annual rainfall up to about 650 mm/yr (Sankaran et al. 2005; Bond 2008). Beyond 650mm/yr a close canopy is possible and rainfall is no longer the most limiting factor. Disturbances such as fire and herbivory reduce woody cover below this rainfall threshold in the lower rainfall areas (Sankaran et al. 2005; Bond 2008). Using quantile regression, an upper limit was found for the field data where maximum TE/ha increased with increasing rainfall (90th percentile: R^2=0.95, Maximum Likelihood, P>0.001; Figure A1). Based on this upper limit, a value of 4000 TE/ha was chosen as the maximum TE/ha (bush encroached, woody "carrying capacity") for an area with a mean annual rainfall of approximately 500 mm/yr and where soils were assumed not to limit woody density. (See Appendix for further details on estimations)

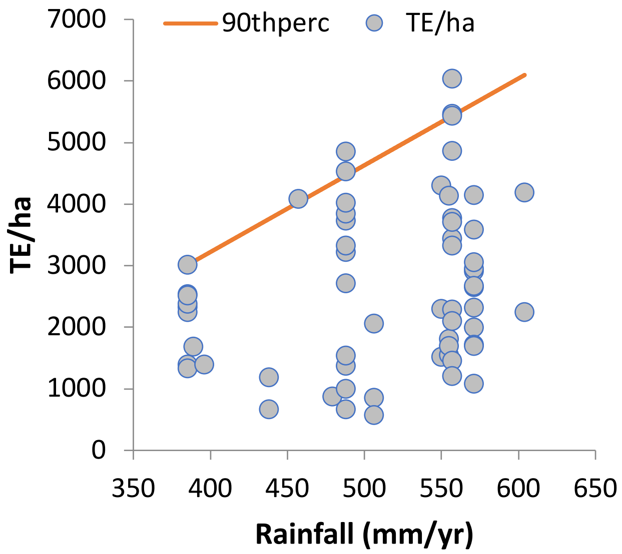


*Figure A 1 : **The tree equivalents measured per field transect (n=62) in north-central and northern Namibia in relation to the long-term mean rainfall. The orange line shows the 90th percentile, indicating that the maximum TE/ha is constraint by water availability, similar to other arid and semi-arid savannas in Africa.***

A.2 Bush density to grass relationship

In the Richter et al. (2001) study tree density was thinned to different intensities in plots and the grass layer response monitored over a four year period at three study sites. The Nampower study measured TE/ha and grass-layer biomass at different sites where the bush was harvested in the past at three study sites in the Otjiwarongo and Otavi areas. In Figure A2 the relationships between TE/ha and grass-layer biomass for the different studies are shown.

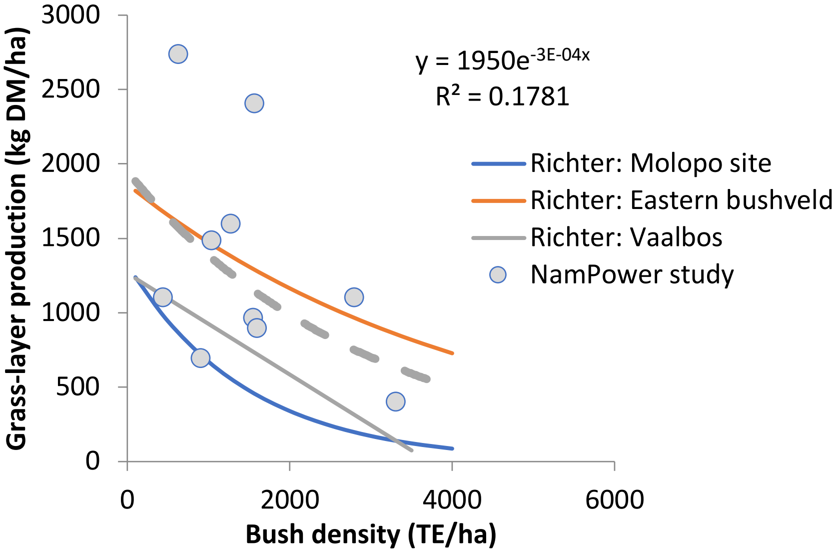


Figure A 2 : The relationship between bush density (TE/ha) and grass-layer production (kg Dry Matter/ha) established for bush harvested sites in South Africa (Richter sites) and Namibia (NamPower study sites). The broken line shows the exponential function established for the Nampower data, which resembles the Eastern Bushveld model established by Richter et al. (2001).

A3. Water Values

MacGregor et al. (2000) calculate the value of water for agricultural production in the Stampriet area. Sixty-six farms were surveyed to model a typical farm production, using enterprise models. From these ouputs, a residual value analysis was conducted to estimate the marginal value production for surveyed farms in the area. The water value is then deriver from the following model:

$$Pw^* = \{TVP - [(PK \times QK) + (PL \times QL) + (PR \times QR)]\}/Qw$$

Where:

- Pw* = the shadow price of water.
- TVP = the industry's total value product (value added)
- P and Q = the prices and quantities of the non-water factor inputs.
- Qw = the quantity of water used.

It is found that while water is a very important and integral resource, the economic efficiency of the farms is poor. A financial water 'value' of N$ 0.03 and an economic water 'value' of N$ 0.64 per cubic metre is calculated.

Borehole drilling avoided costs

In order to estimate the value of water using an avoided cost method, the potential cost of building a borehole in the farm was estimated. This is based on the assumption that if groundwater recharge was to decrease significantly a farmer might have to drill a new borehole to access additional sources of water. An increase in groundwater recharge would avoid the need to rely on an additional borehole, and avoid associated costs. Water engineers and farmers were interviewed to assess the average cost of borehole drilling in Otjrozondjupa. The following cost estimates were used:

drilling per meter	2000	N$/m
pump, solar PV, stands, controls	1500-2000	N$
10L tank	50000	N$
stands for the tank	50000	N$
replacement	50000	every 10 years
maintenance	10000	per year maximum

A timeline of 25 years was assumed to align with the aftercare investment timeline. The borehole depth was assumed to be 250m, relatively deep to reflect the situation where groundwater is becoming scarce, thus justifying the drilling of this new borehole. The borehole yield per day was estimated based on average borehole yield per hour derived from the Stampriet Aquifer survey data from 2000. It was then assumed that one day would equal to 12hours of pumping.

borehole depth (m)	250
Cost (N$)	952 000.0
Lifetime (years)	25
Average yield (m3/day)	125
Average yield (m3/year)	45 656.25
Capacity (m3/25years)	1 141 406.25
Cost/m3 (N$/m3)	0.8

A4. Sources of cost data

Cost information were collected through interviews and desk-based literature review, some parameters result from a combination of different sources. The table below presents the main source of information and data for each method.

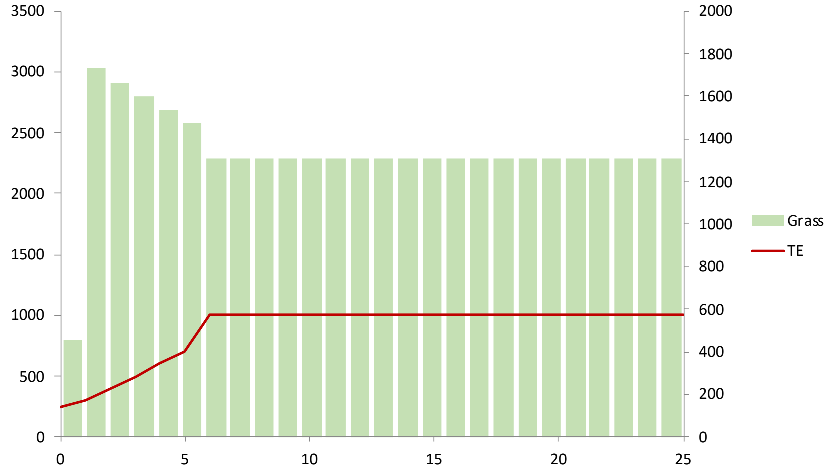
Manual methods	Rudi Scheidt (Farm Erischfelde Okahandja), DAS
Mechanical methods	Koos Briedenhan - Farm Buffelhoek Otjiwarongo, DAS
Chemical methods	Rudi Scheidt (Farm Erischfelde Okahandja)
Fire method	Peter Erb, fire management plan (NAU)
Goat scenario	Wolfie von Wielich (commercial farmer, Omatjene Research Station)
Reseeding	Rudi Scheidt (Farm Erischfelde Okahandja)

Appendix B. Scenario Results

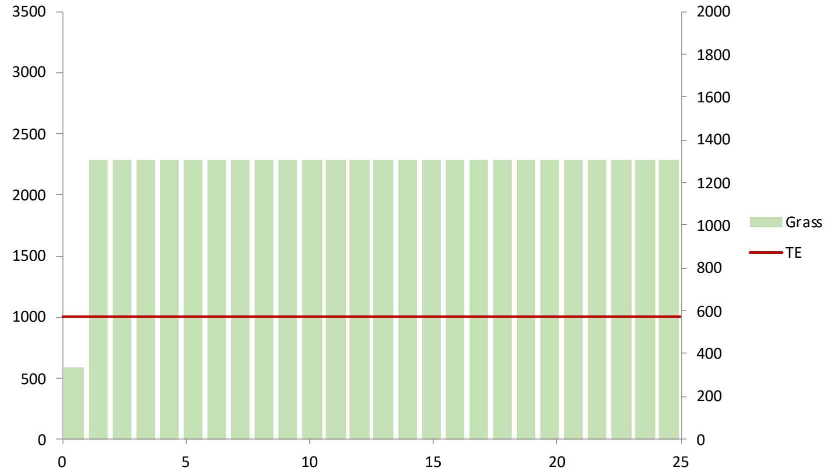
B1. Scenario 1: Yearly manual cutting

Bush density (TE/ha) and grass biomass (kg/ha)

BAU1

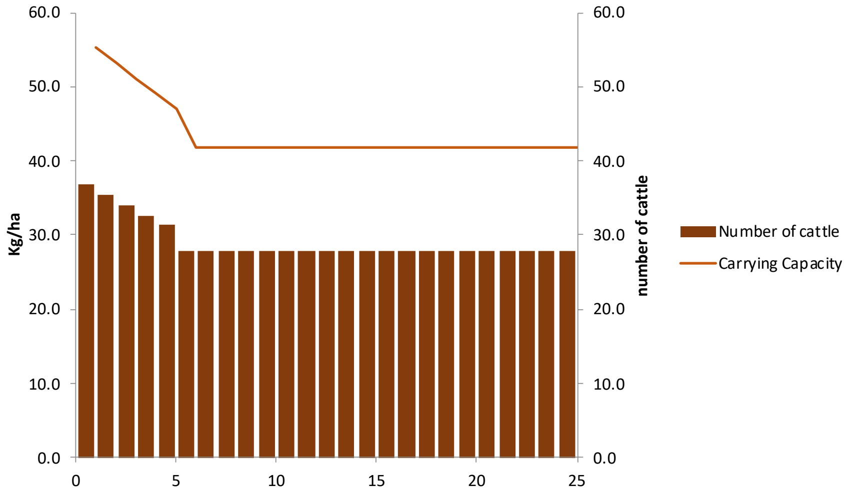


BAU2



Carrying capacity (kg live weight per ha) and number of cattle stocked on 250ha

BAU1



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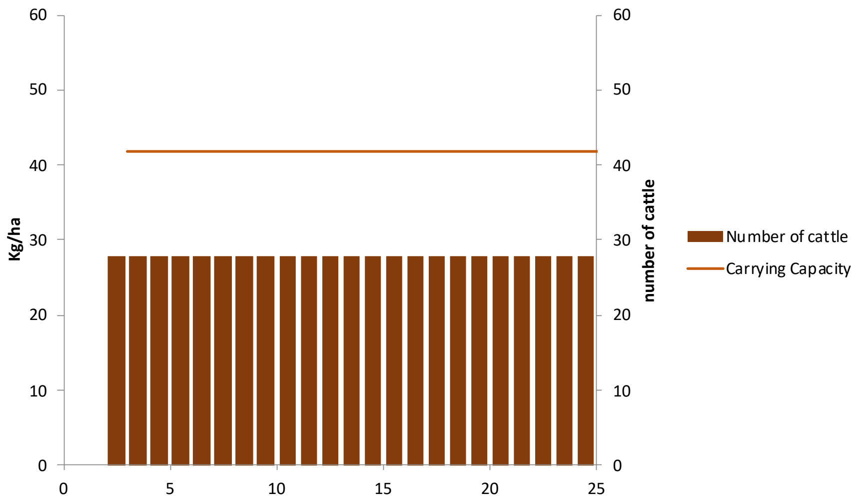
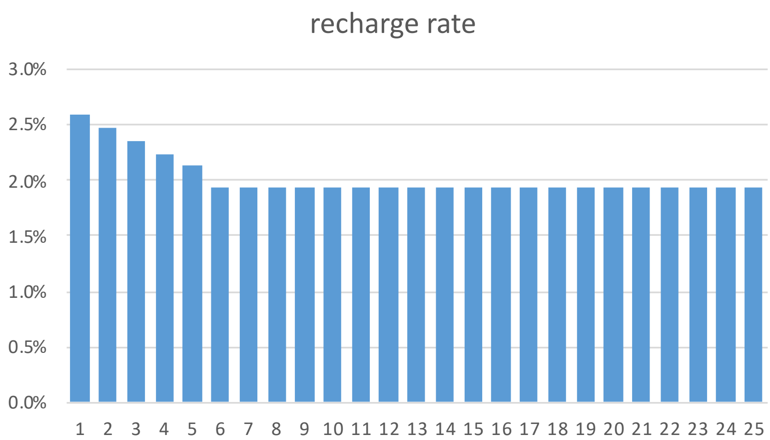
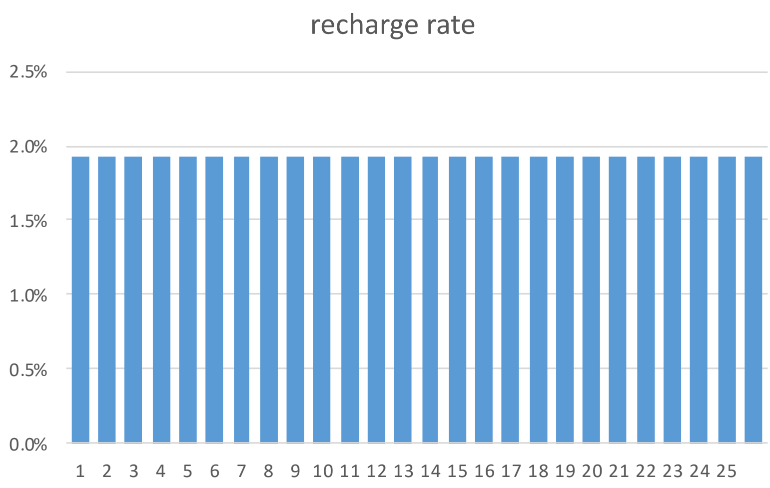


Recharge rate

BAU1



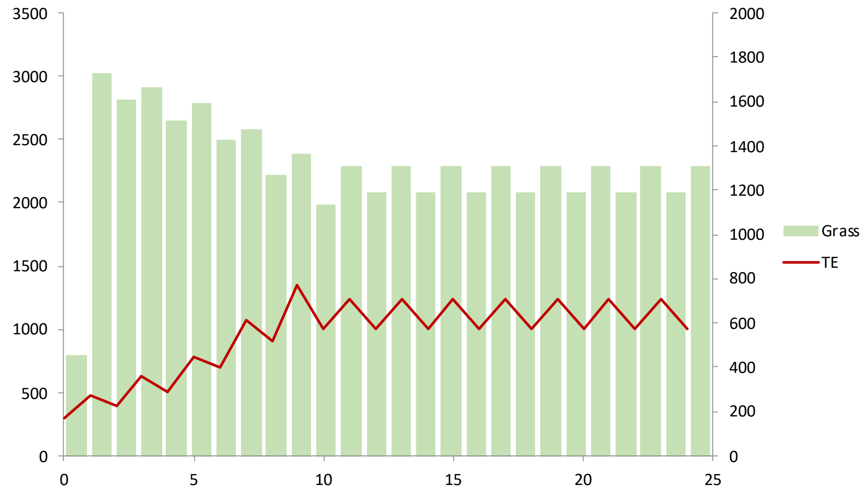
BAU2



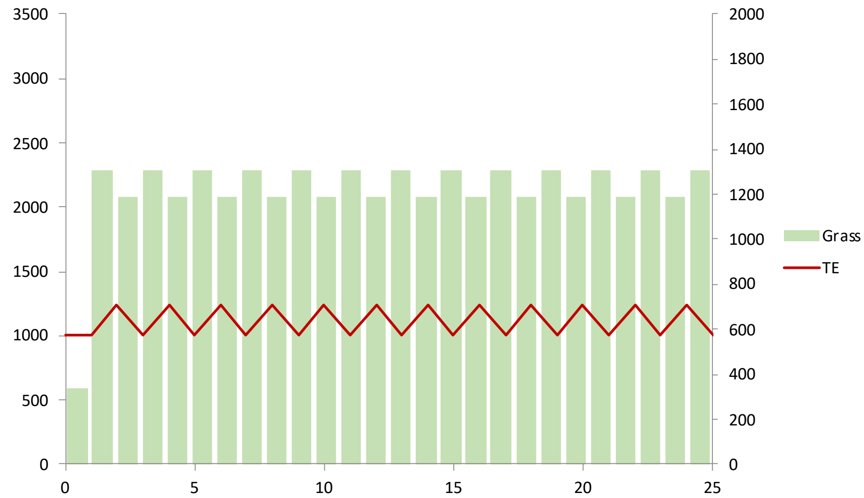
B2. Scenario 2: Biennial manual cutting

Bush density (TE/ha) and grass biomass (kg/ha)

BAU1

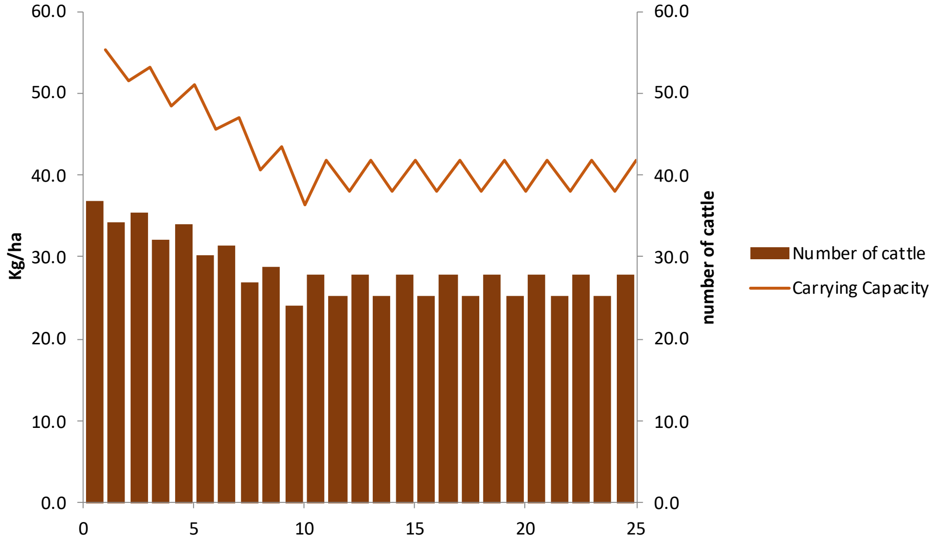


BAU2



Carrying capacity (kg live weight per ha) and number of cattle stocked on 250ha

BAU1



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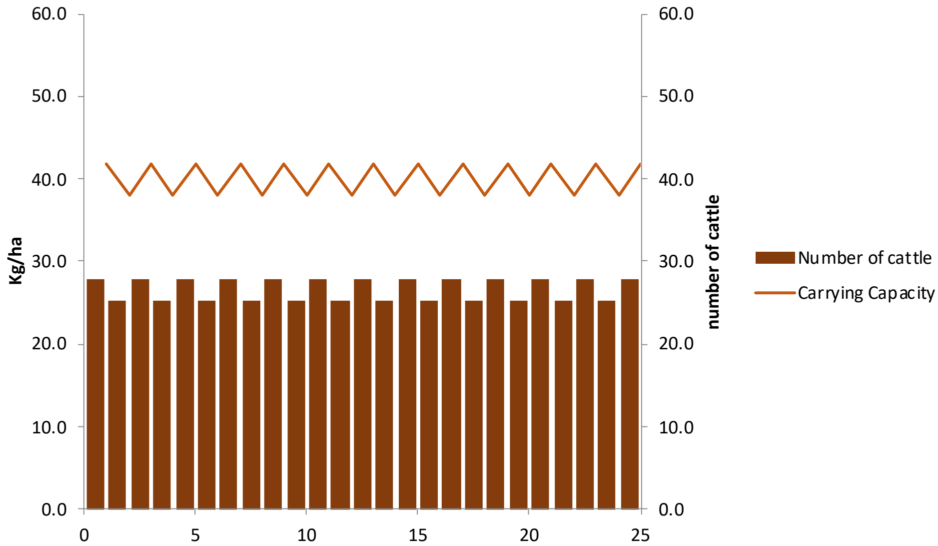
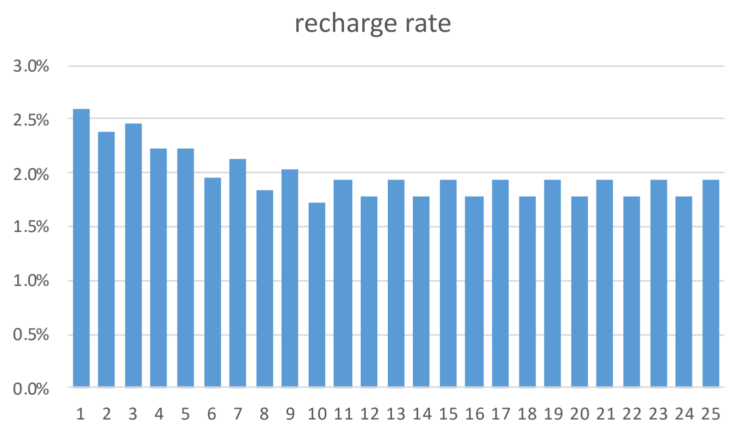


Recharge rate

BAU1



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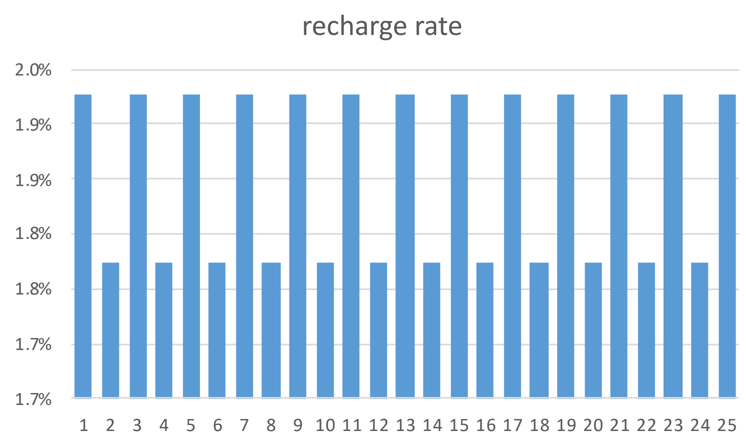
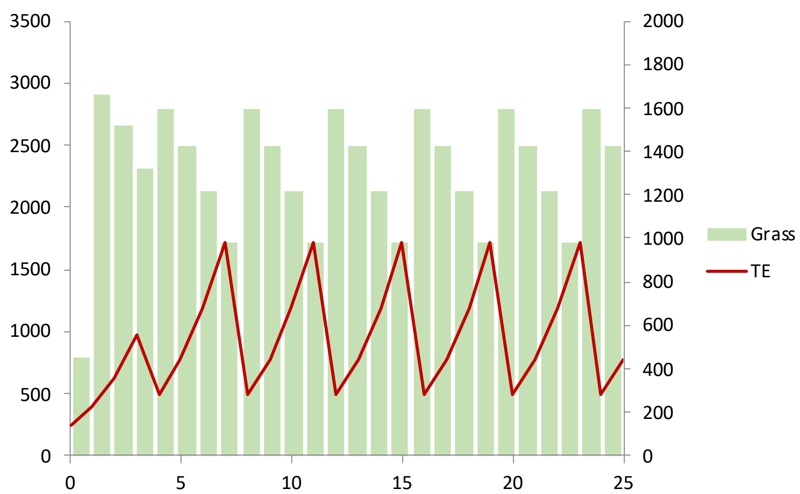
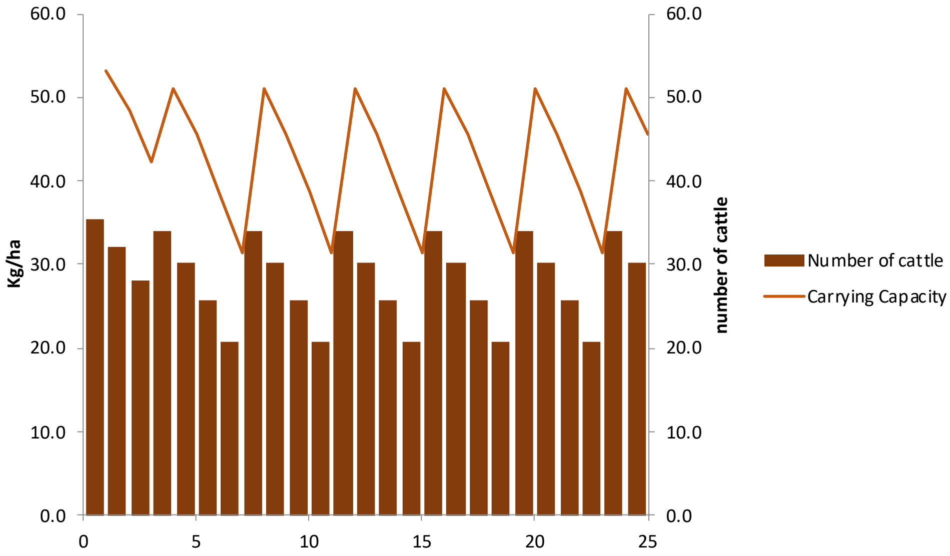


B3. Scenario 3: Mechanical measure

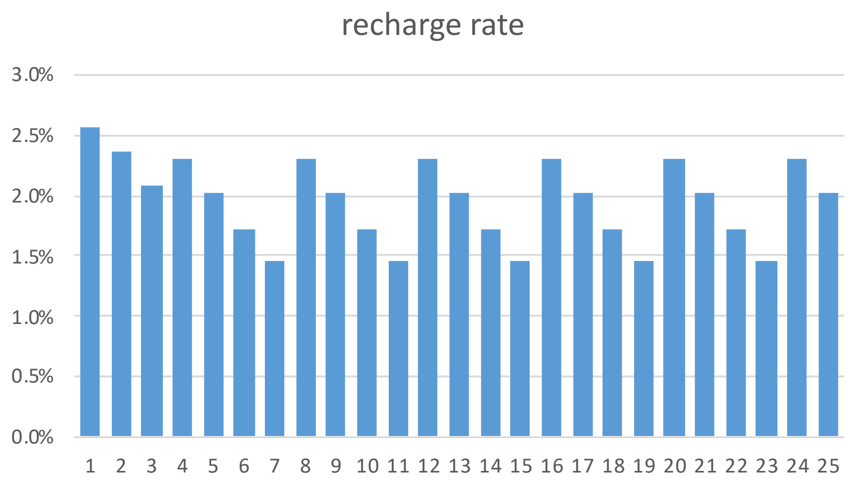
Bush density (TE/ha) and grass biomass (kg/ha)



Carrying capacity (kg live weight per ha) and number of cattle stocked on 250ha



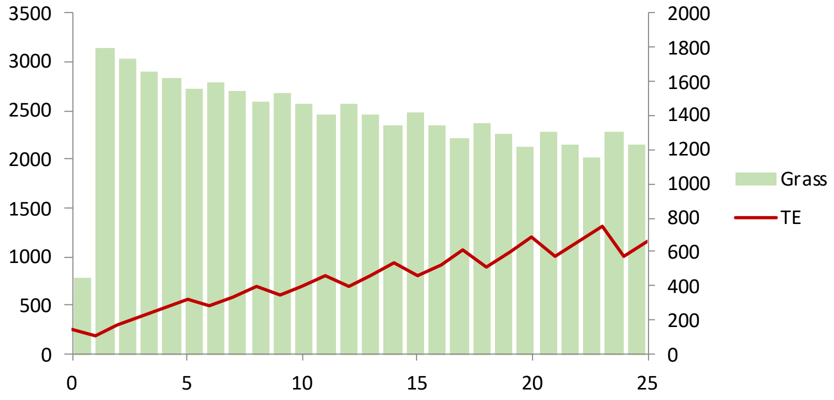
Recharge rate



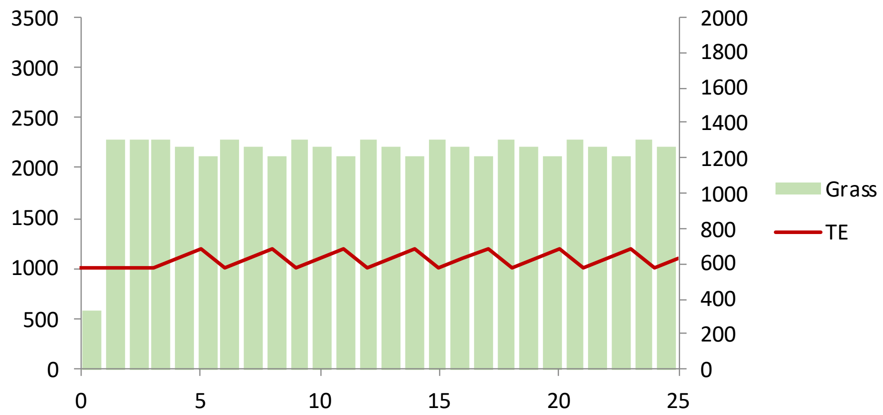
B4. Scenario 4: Chemical – foliar applied

Bush density (TE/ha) and grass biomass (kg/ha)

BAU1

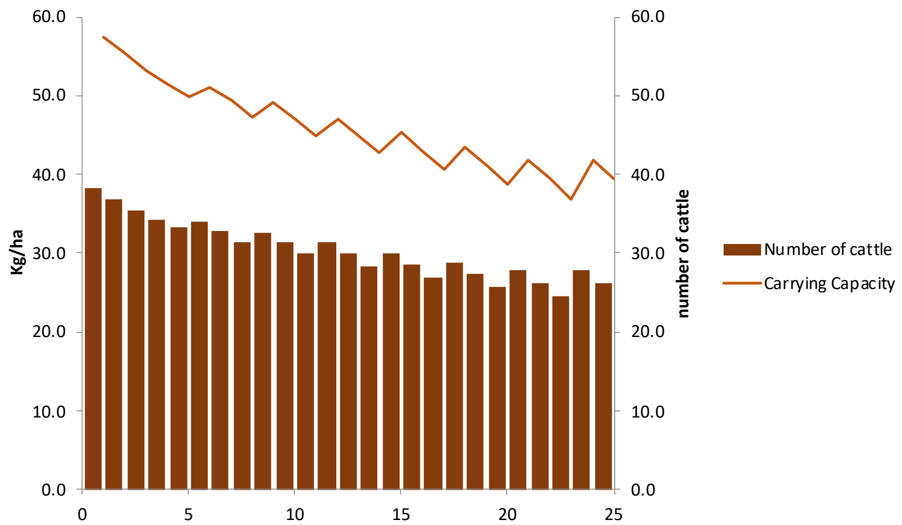


BAU2



Carrying capacity (kg live weight per ha) and number of cattle stocked on 250ha

BAU1



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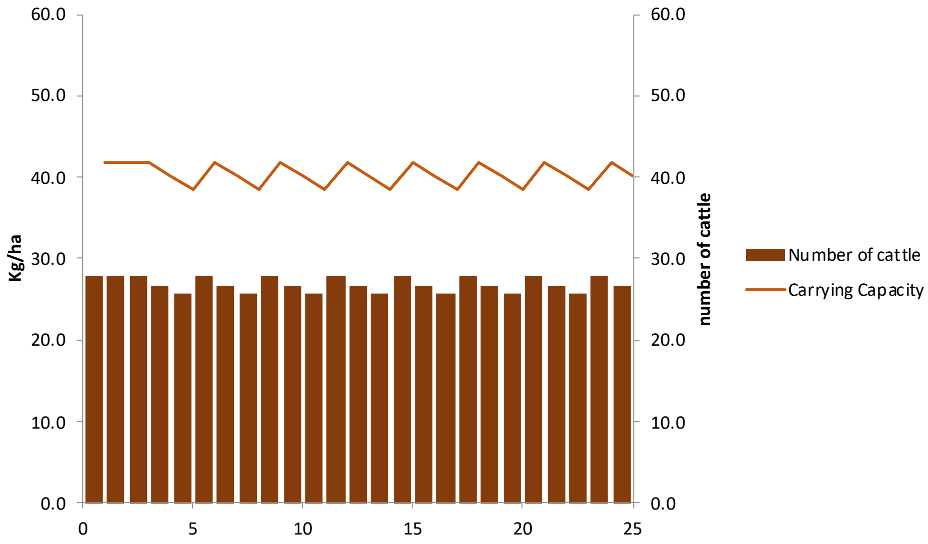
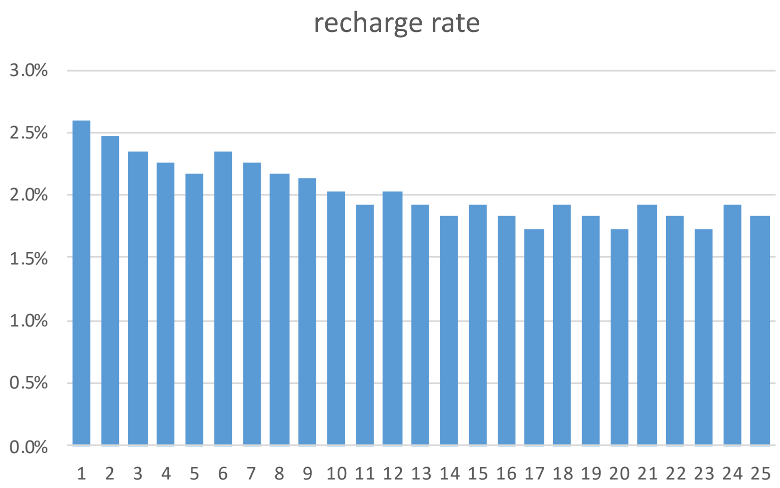


Recharge rate

BAU1



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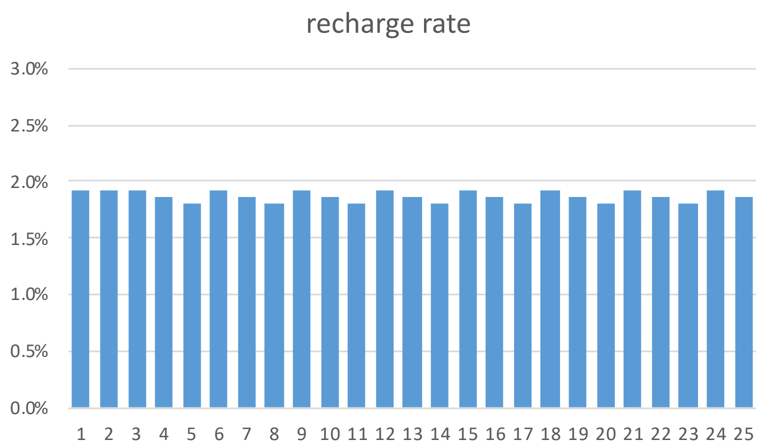
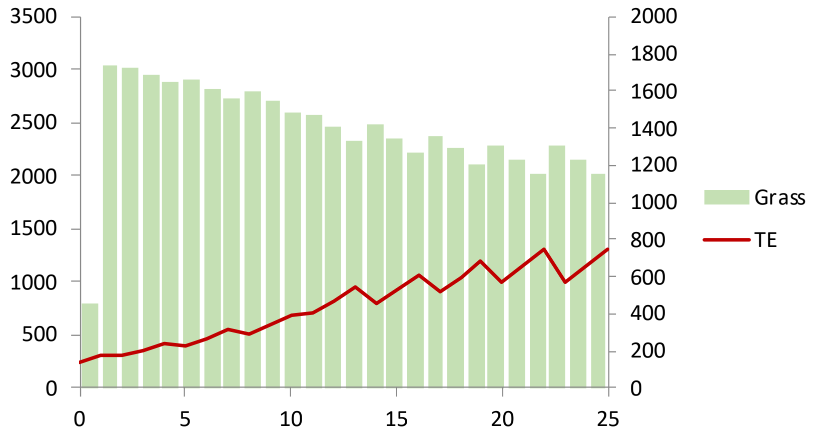


B5. Scenario 5: Chemical – cut stump and foliar applied

Bush density (TE/ha) and grass biomass (kg/ha)

BAU1



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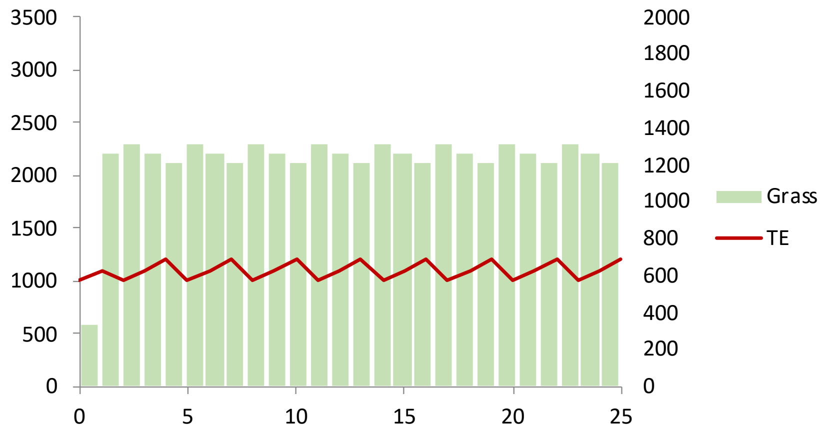
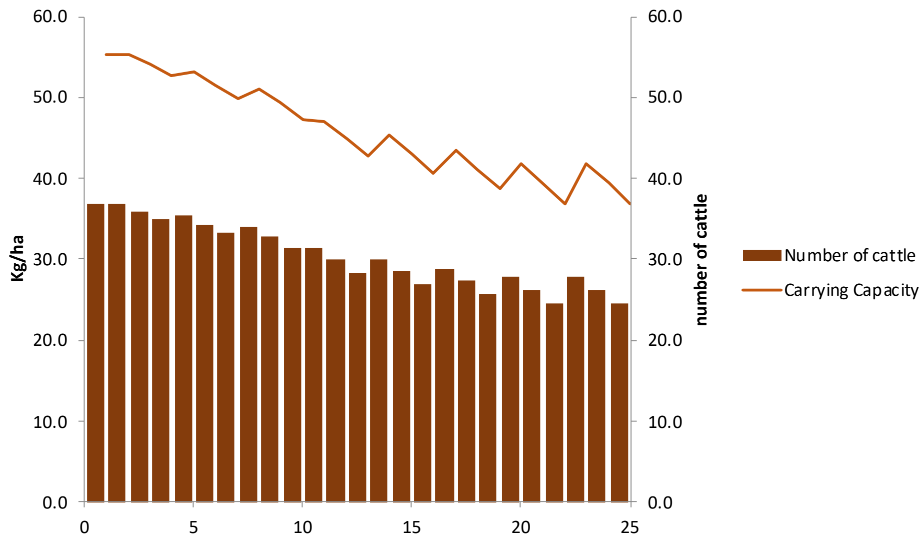


Carrying capacity (kg live weight per ha) and number of cattle stocked on 250ha

BAU1



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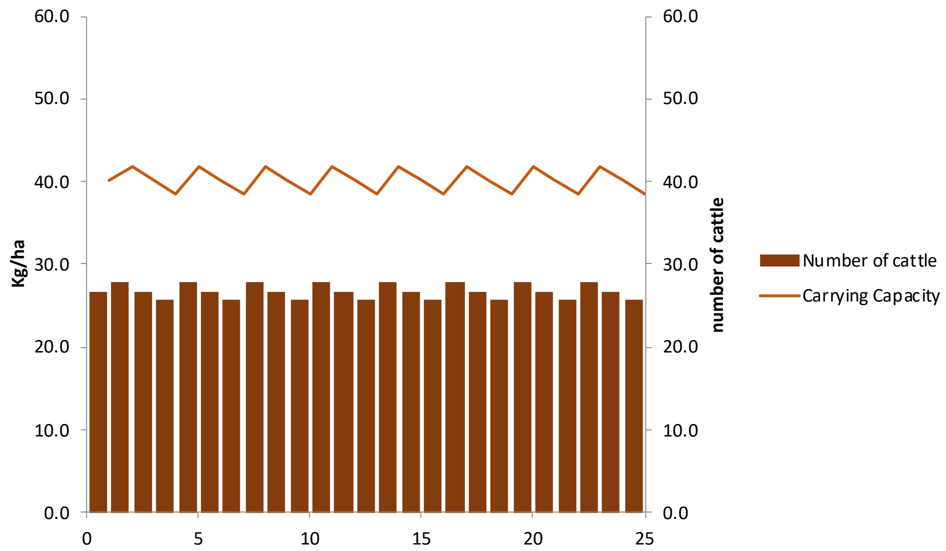
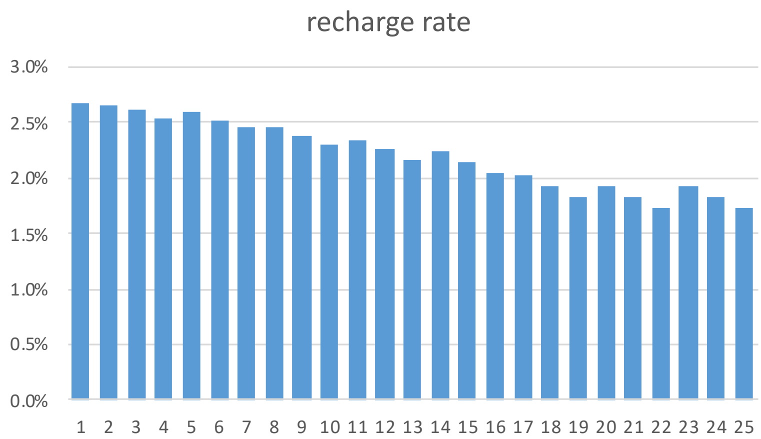


Recharge rate

BAU1



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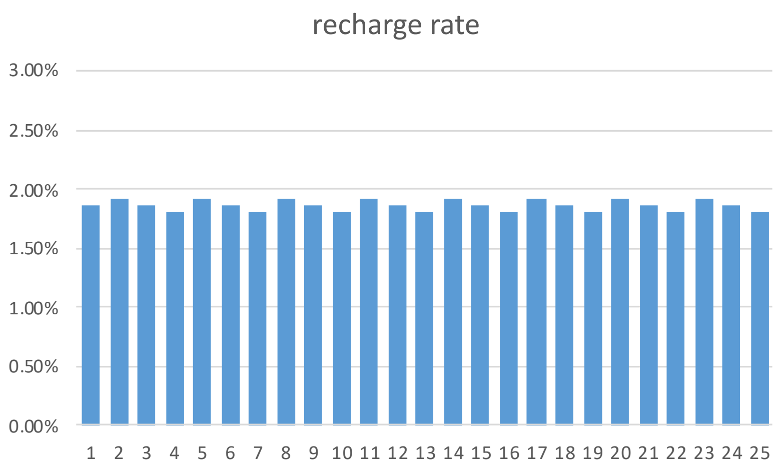
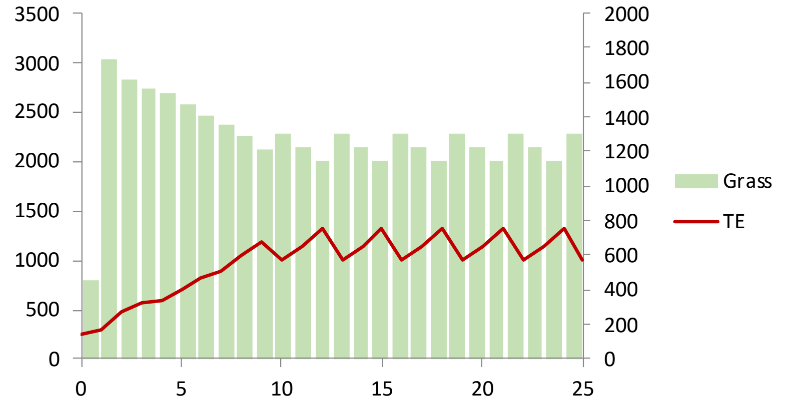


B6. Scenario 6: Chemical – soil applied

Bush density (TE/ha) and grass biomass (kg/ha)

BAU1



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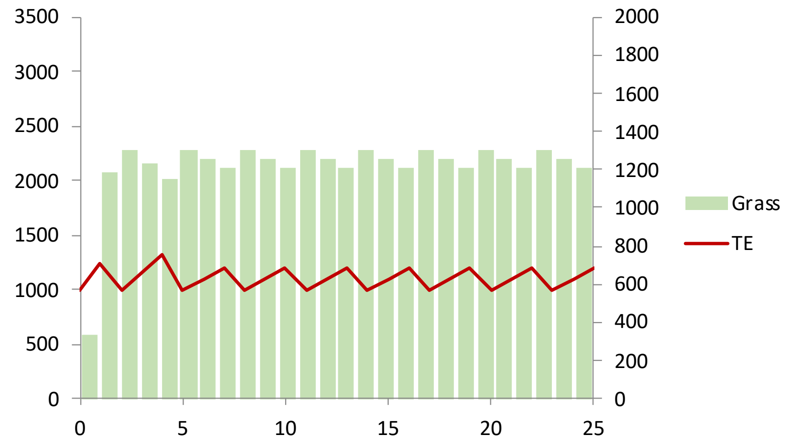
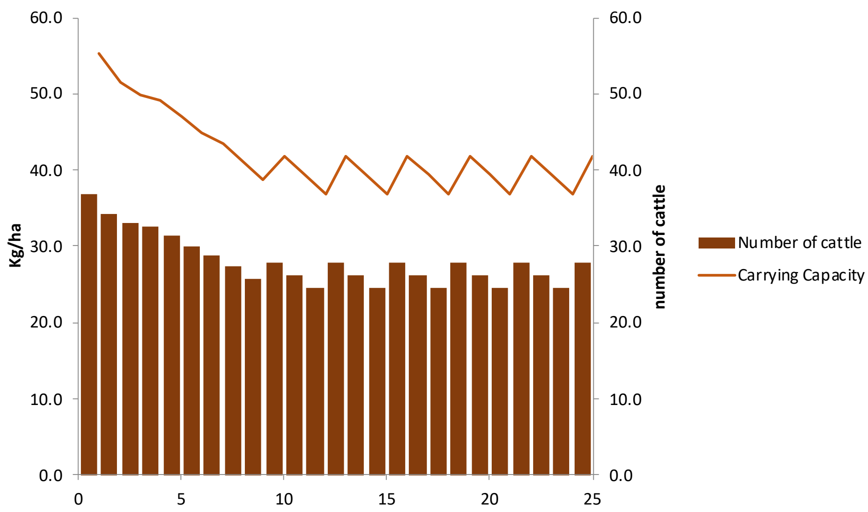


Carrying capacity (kg live weight per ha) and number of cattle stocked on 250ha

BAU1



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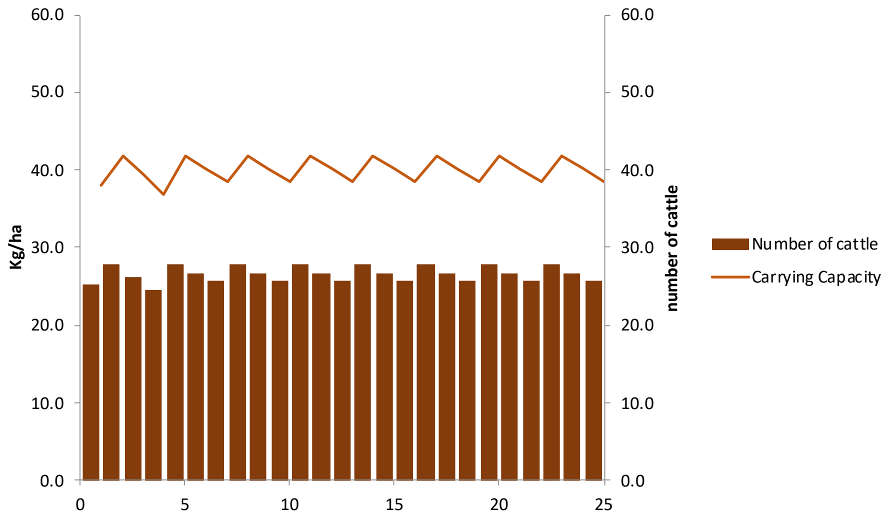
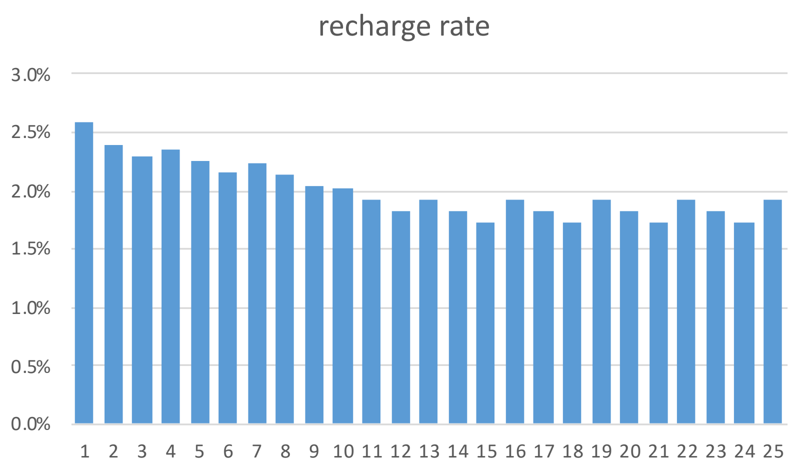
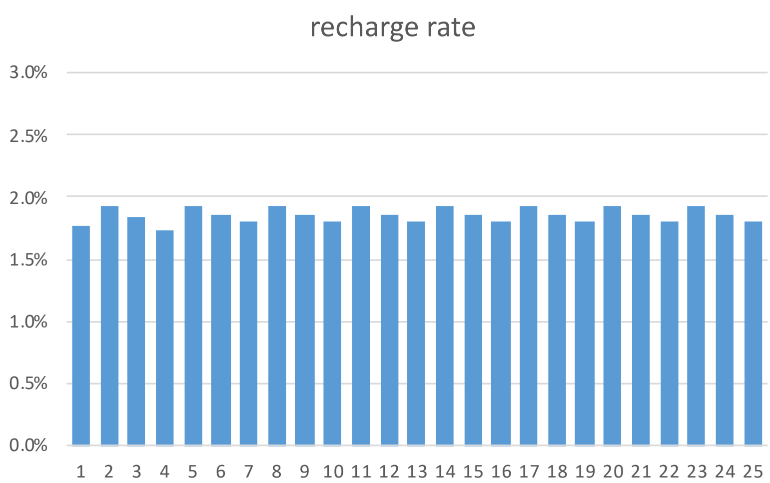


Recharge rate

BAU1



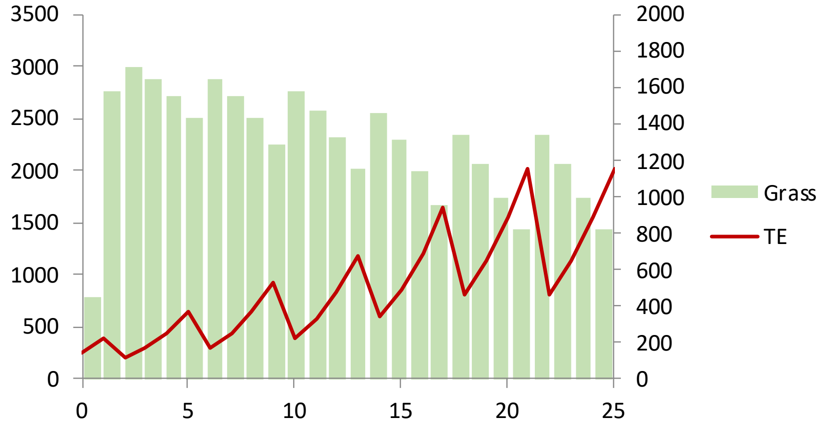
BAU2



B7. Scenario 7: Controlled fire

Bush density (TE/ha) and grass biomass (kg/ha)

BAU1



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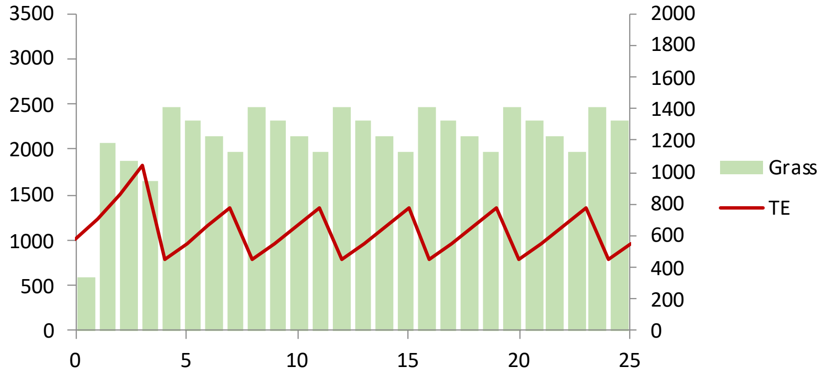
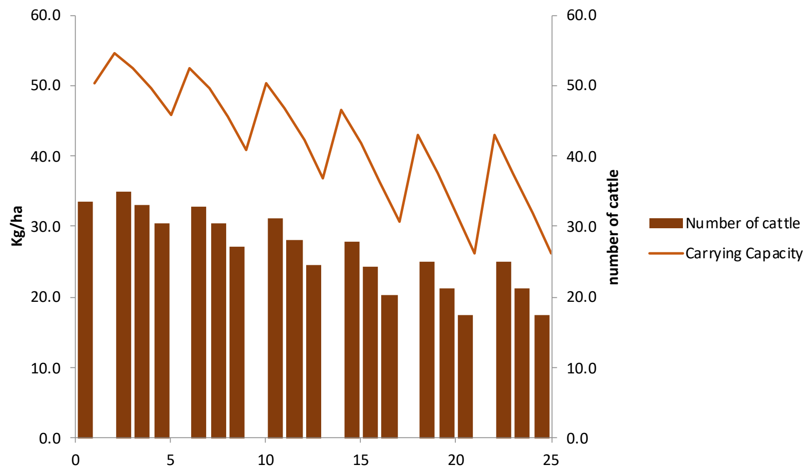
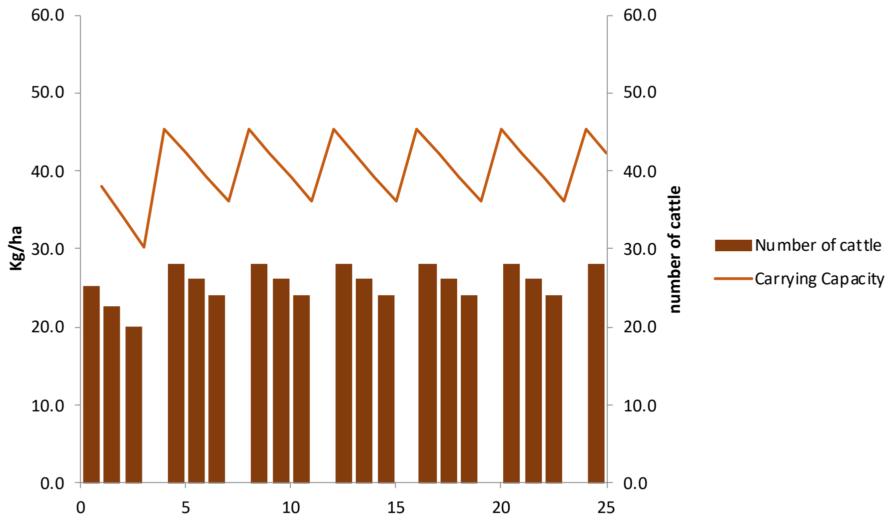


Carrying capacity (kg live weight per ha) and number of cattle stocked on 250ha

BAU1

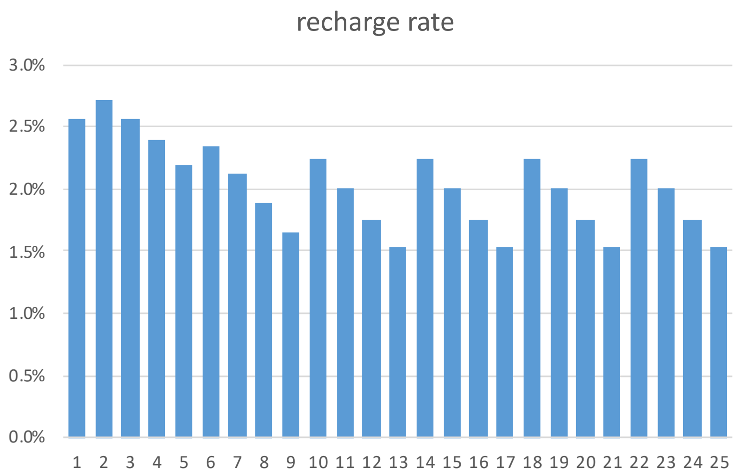


BAU2

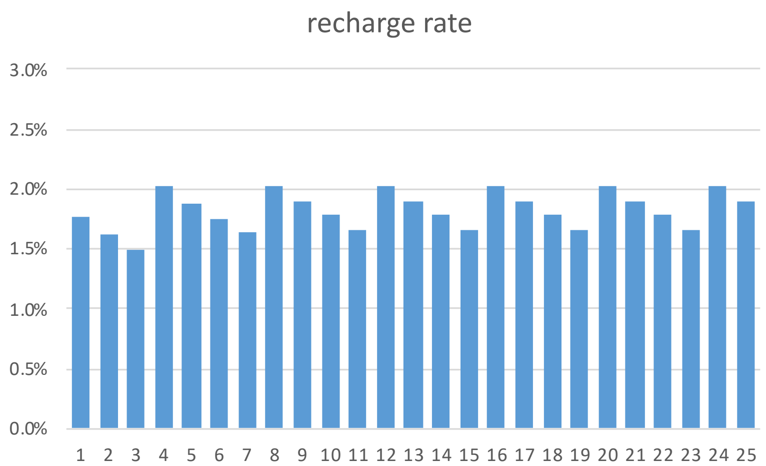


Recharge rate

BAU1



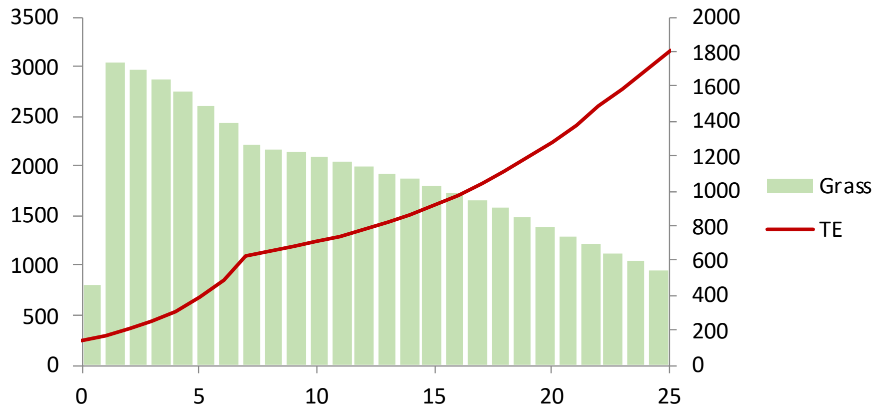
BAU2



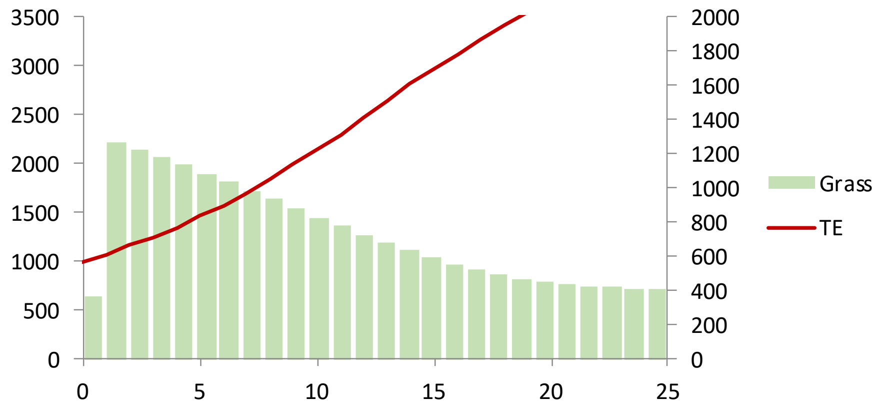
B8. Scenario 8: Goat stocking

Bush density (TE/ha) and grass biomass (kg/ha)

BAU1

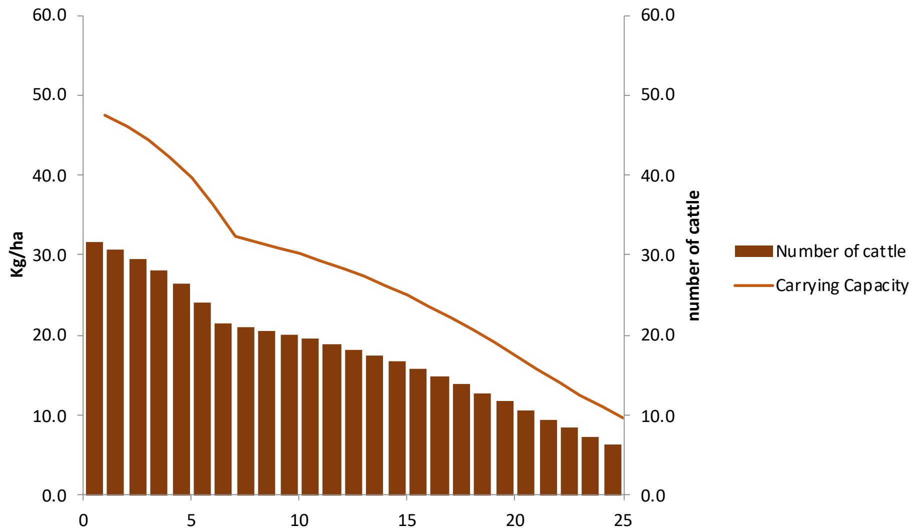


BAU2

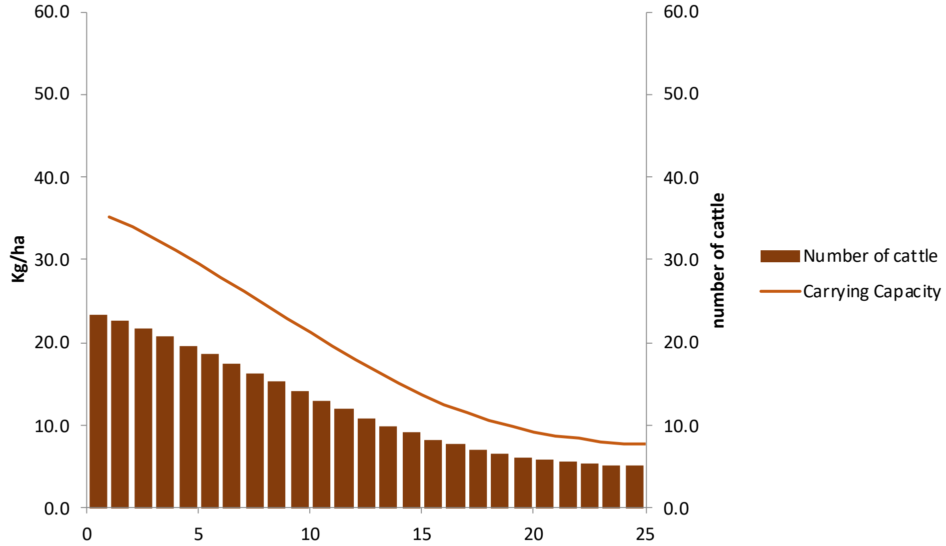


Carrying capacity (kg live weight per ha) and number of cattle stocked on 250ha

BAU1

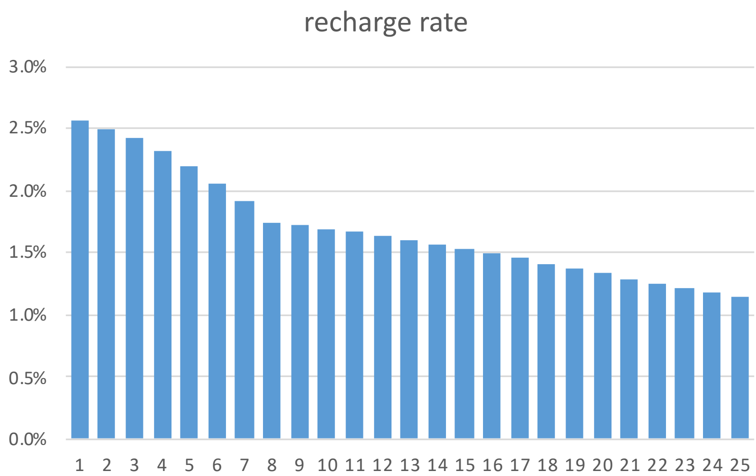


BAU2

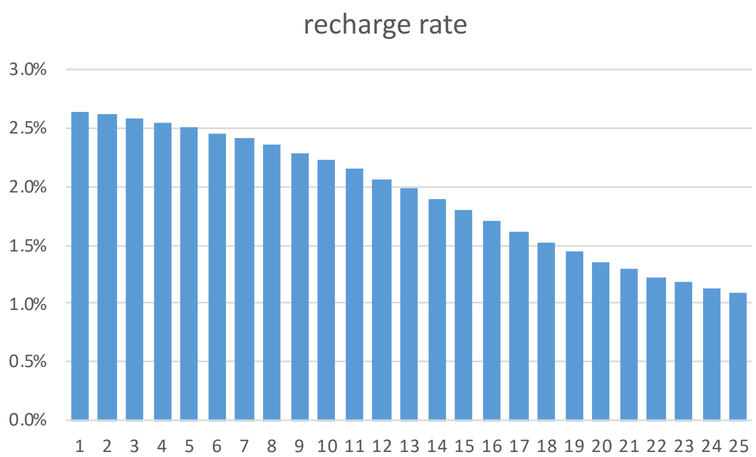


Recharge rate

BAU1



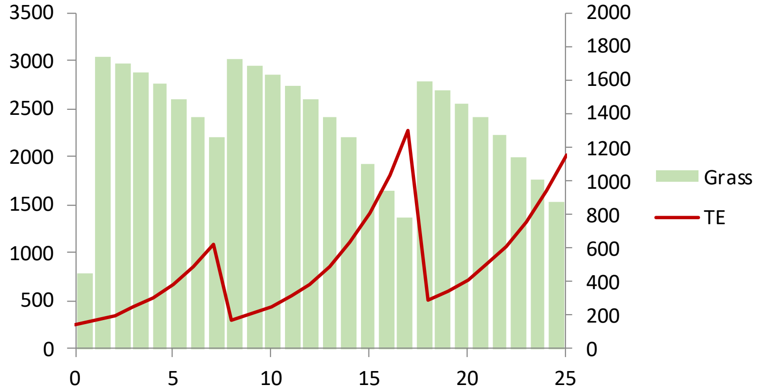
BAU2



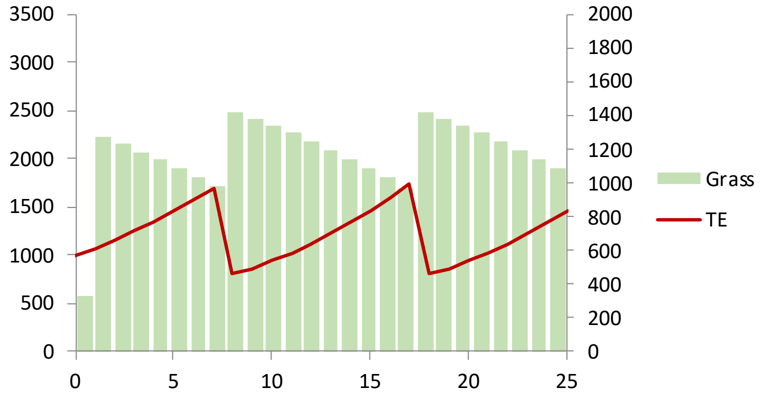
B9. Scenario 9: Combination of Fire and goat stocking

Bush density (TE/ha) and grass biomass (kg/ha)

BAU1

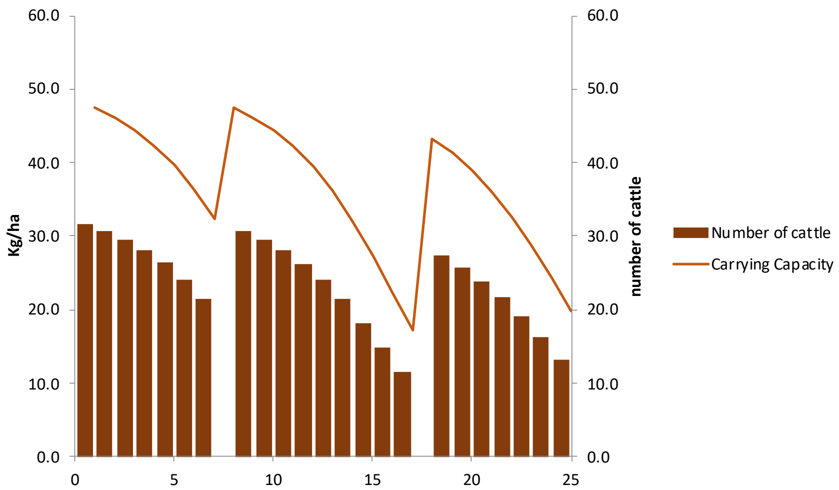


BAU2

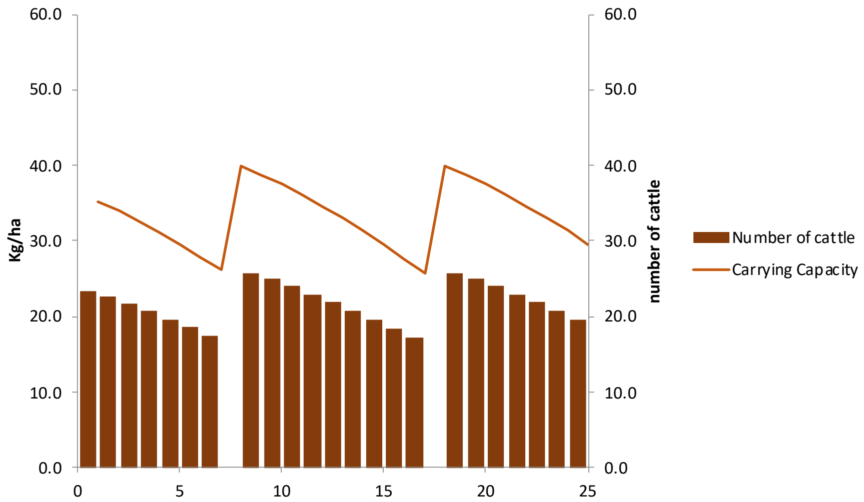


Carrying capacity (kg live weight per ha) and number of cattle stocked on 250ha

BAU1

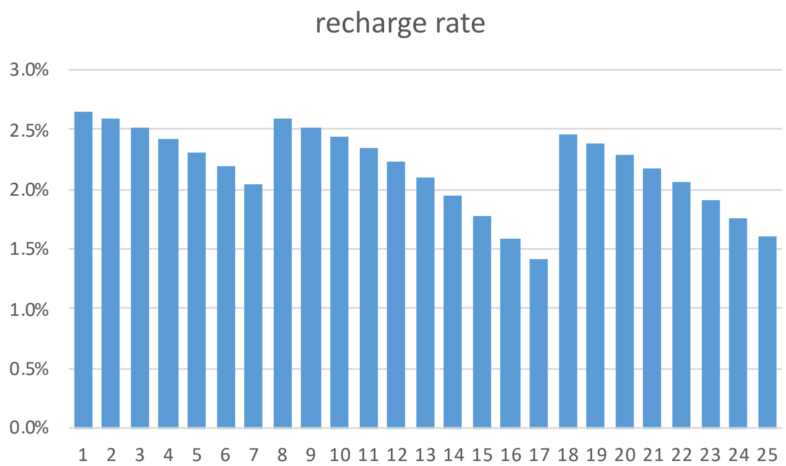


BAU2

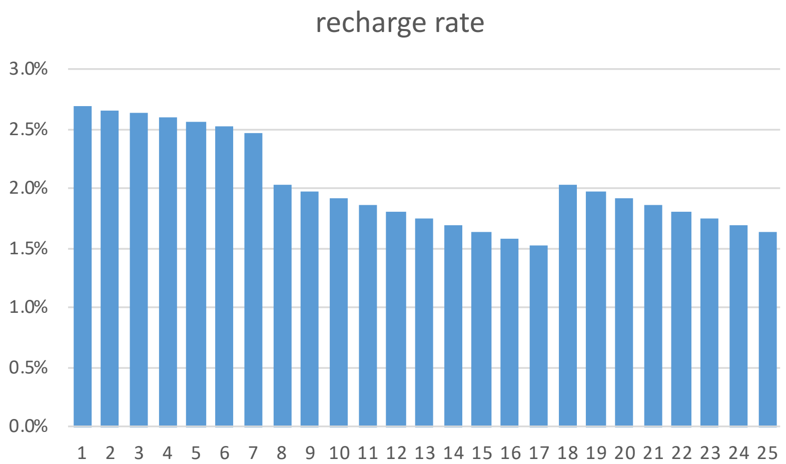


Recharge rate

BAU1



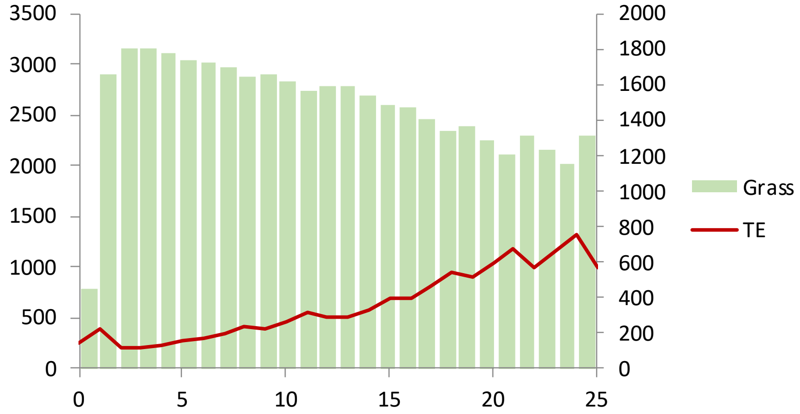
BAU2



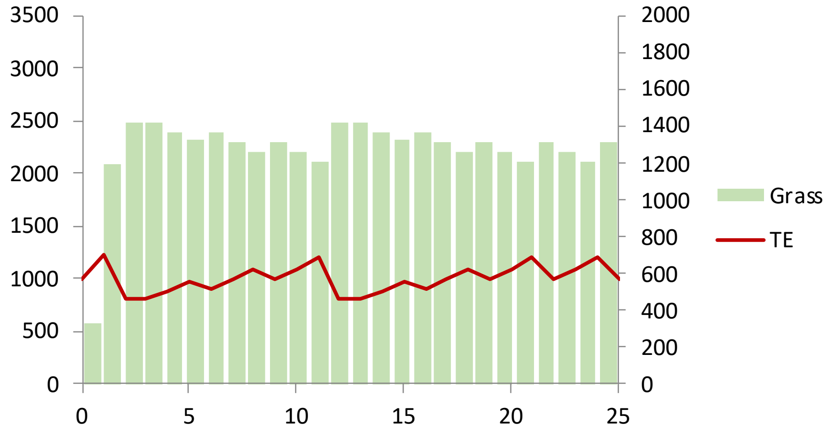
B10. Scenario 10: Combination of Fire and foliar applied chemical

Bush density (TE/ha) and grass biomass (kg/ha)

BAU1

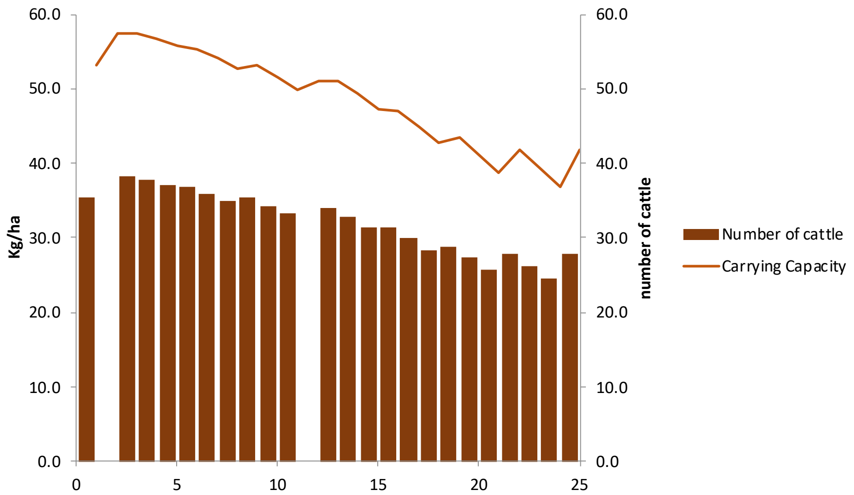


BAU2

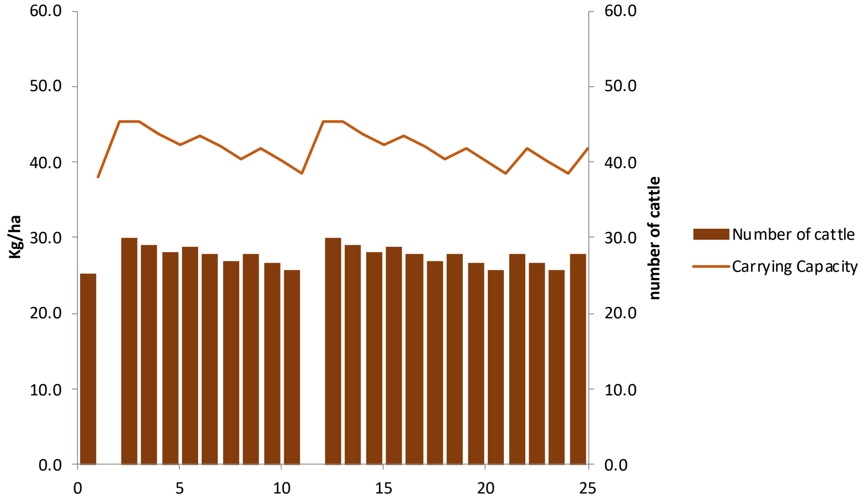


Carrying capacity (kg live weight per ha) and number of cattle stocked on 250ha

BAU1

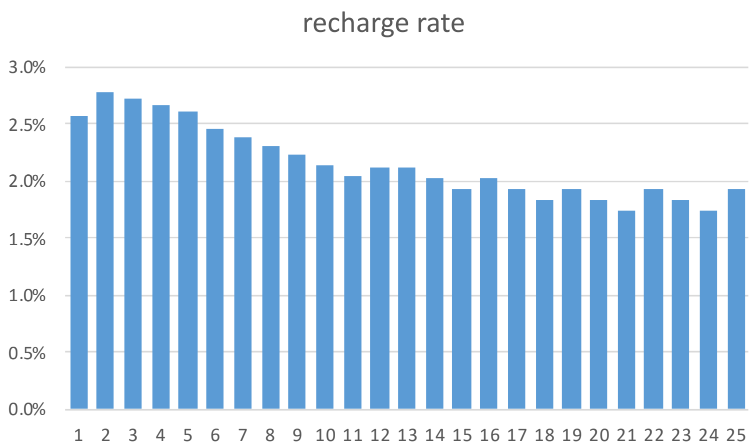


BAU2

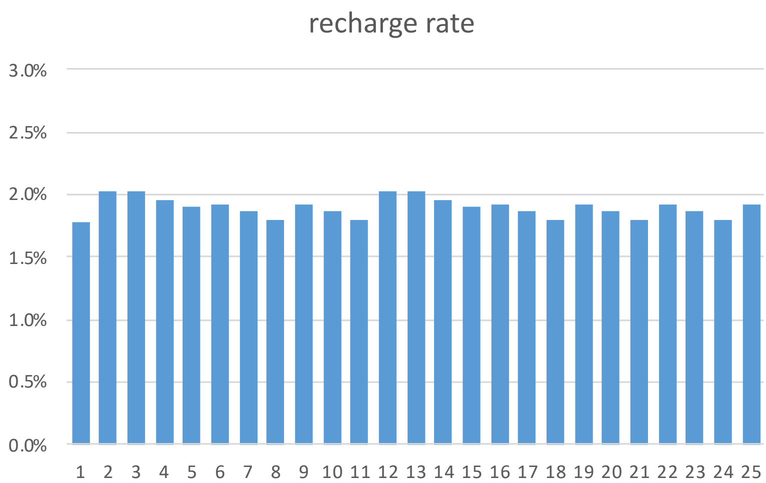


Recharge rate

BAU1



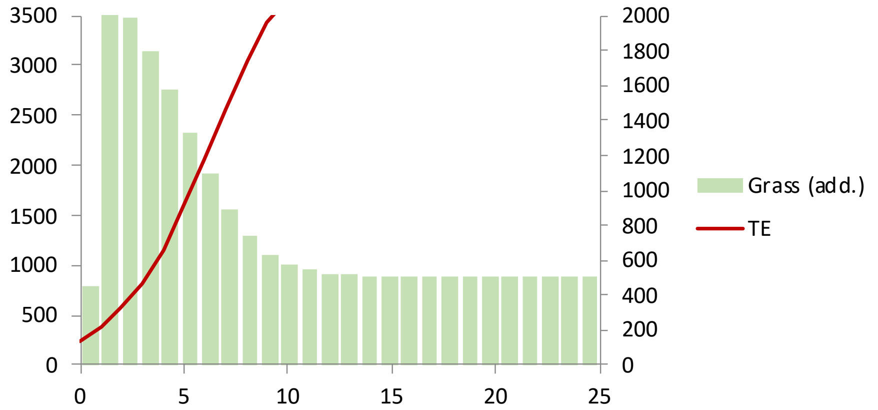
BAU2



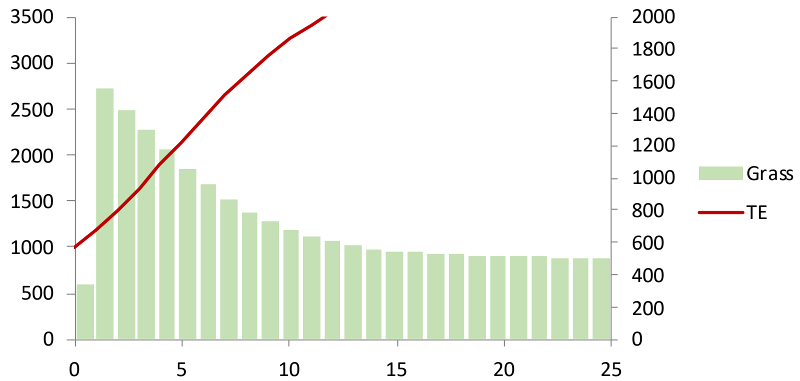
B11. Scenario 11: Brush Packing and reseeding

Bush density (TE/ha) and grass biomass (kg/ha)

BAU1

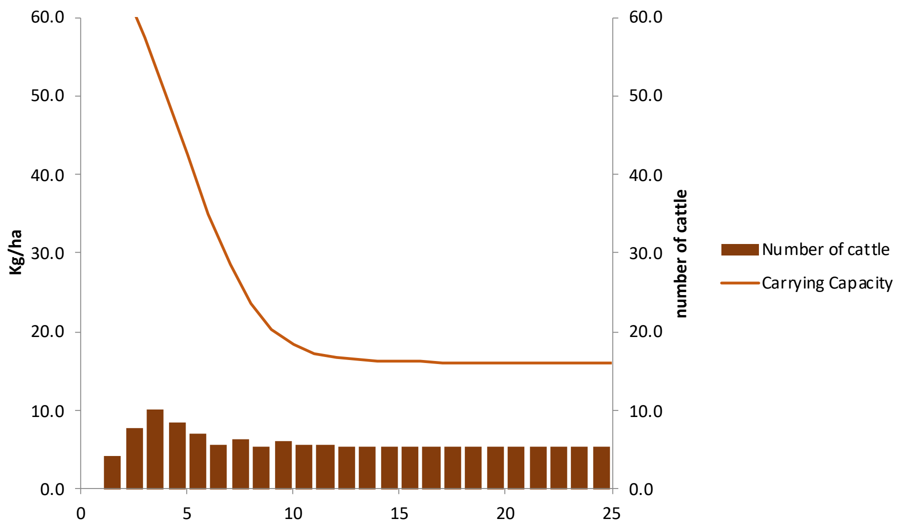


BAU2

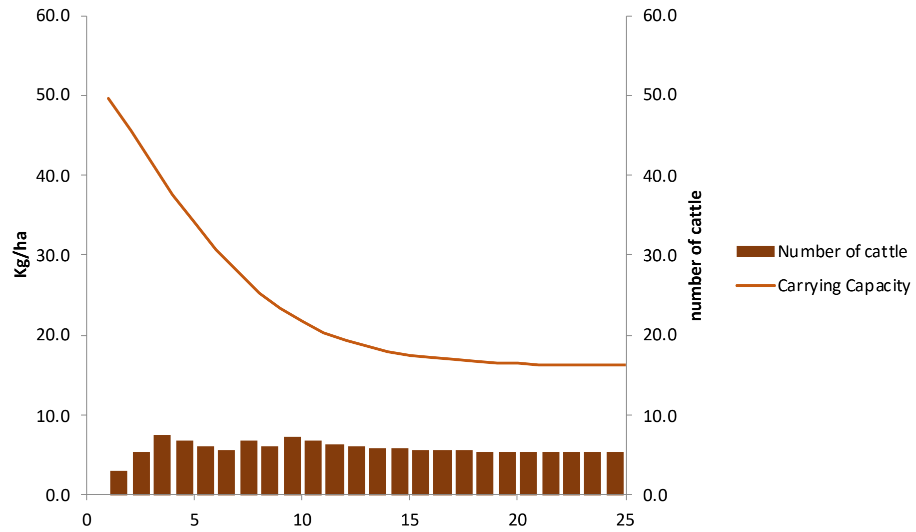


Carrying capacity (kg live weight per ha) and number of cattle stocked on 250ha

BAU1

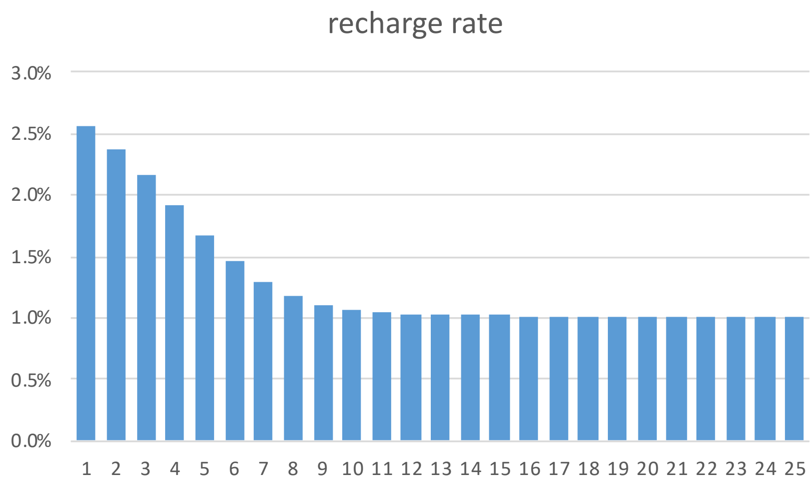


BAU2



Recharge rate

BAU1



BAU2