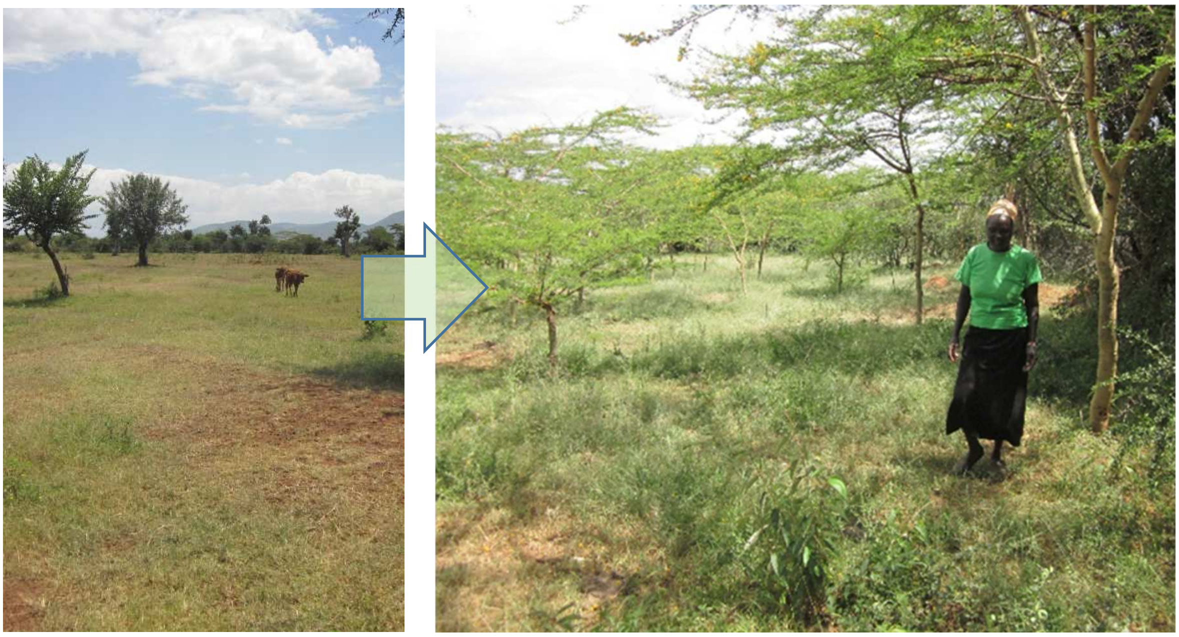
Final Report

Integrating Trees in Farming Systems in Baringo county, Kenya reduces variability of food and fodder production

Consultancy Report submitted to the FMNR-Hub, World Vision Australia



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Integrating Trees in Farming Systems in Baringo county, Kenya reduces variability of food and fodder production

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Abstract

This study aimed to quantify the benefits of practicing Farmer Managed Natural Regeneration (FMNR) in Baringo county, Kenya. In this end, farmers' testimonies of multi-annual production of crops, grass, trees, and cow-herd management were translated into 'textbook' agronomical knowledge, and analysed through an Agroforestry Systems Model.

Introducing FMNR scenarios were modelled on a virtual 10 ha (~25 acre) farm with three times 2006-2015 monthly rainfall data. In each scenario, 20% of the area was allotted to a maize-bean intercrop; while 80% was allotted to grass on which 0%, 30% and 70% FMNR was introduced in Year 1, 11 and 21 respectively. The ten-year scenarios allowed for calculating annual variations in crop and tree production, as well as monthly in-field fodder availability and the consequent cow herd size.

Modelling results suggest that annual production varies over years. In years with regular rainfall, FMNR has a slightly positive effect on open-space staple food production (from ~2,0 t to ~2,5 t), but a negative effect on below-tree grass production (from ~20 t to ~15 t), which is more or less compensated by tree fodder production (~5 t). In years with irregular rainfall, FMNR has a positive effect on staple food production (from ~0.2 to ~1.0 t/y) and yield variability goes down from 650% to (still high) 220%. Fuel wood production goes up from 0 to ~21 t/y.

Consequently, FMNR adds economic value to farm primary production. Fodder and crop production values remain more or less the same, but fuel wood production generates additional, stable value. Produced value varies from ~US$ 2,200 to $3,200/y (no FMNR), ~US$ 4,000 to $4,500/y (medium FMNR) and ~US$ 5,900 to $6,100/y (full FMNR). The net present value (at 10% discount rate) goes from ~US$ 27,000, to $35,000 to $54,000. In absence of substantial farm-level economic investments, Internal Rates of Return could not be calculated.

Annual fodder production figures hide the fact that farmers' concern is the periodic fodder shortage that in dry years results in high cow mortality. A module for month-wise calculating fodder availability shows that under the no-FMNR scenario, fodder production over seasons varies by 650%. Hence in years with a long drought, the 10 ha farm can sustain only 2 Tropical Livestock Units (TLUs). With full FMNR (with 50% canopy cover), fodder production stabilizes at a variability of 160% allowing for a stable 6 TLU on the same farm. Varying Canopy density in calculations suggests that pruning canopies back to 10-25% leads to optimum grass production for herd maintenance.

The model produces interim outcomes of canopy coverage, soil fertility, soil humidity and production trends, that can be verified through field measurements or literature research. Such work can refine the model and make its predictions more valuable for farmers' practice or for investors.

If further field verification confirms the trends that the model suggests, FMNR in Baringo (1) reduces risks for total crop failure (2) allows for more intensive cow herd management and consequent income generating activities; and (3) reduces farm-level labour to collect fuel and stock fodder for animals. As these reduce on-farm labour, with a relative high women's contribution, FMNR is likely to structurally reduce the labour burden of women and reward them better for their work.

Contents

FarmTree Services

1. Introduction: World Vision's FMNR Promotion Programme

World Vision Australia (WVA), through the FMNR-Hub (see http://fmnrhub.com.au/) promotes the concept of *Farmer Managed Natural Regeneration* (FMNR). FMNR is the *"systemic regeneration of alive underground root systems"* and serves to address "*severe and recurrent drought leading to food and water shortage"*; as well as *"food insecurity and malnutrition"*; and *"chronic or repeated disasters"* [1]. WVA and others have collected evidence of such benefits from hundreds of farmers across Sub-Saharan Africa, while tenths of detailed studies – both of individual farms and through surveys – documented more or less systematic evidence that FMNR has the claimed livelihoods and economic effects [2] [3] [4] [5]. FMNR promotors face ever more requests from donors and governments to 'prove' that FMNR promotion is worth its investment. This calls for a detailed understanding of costs and benefits of introducing FMNR on individual farms.

The above cited literature is based on methods that either rely on large surveys with stochastic methods, or on single-farm or plot studies, or on farmers' (largely qualitative) testimonies. FMNR is a technology with long-term and complex effects on farming systems; in a situation where weather varies greatly over seasons and years, and where soils, and farming practices, vary between farms. Classical field trials thus need to be carried out over many years, and need to factor in an array of agronomical and social variations. The relevance of trials might be 'overtaken' by new practices by the time that trial results become available – for example, because project objectives evaluate as a result of the development discourse. Moreover, as most studies are carried out as part of development programmes with several objectives, the effect of FMNR is difficult to single out[6]. Hence, FMNR results are not readily measurable and the technique 'risks' to be overlooked in favour of techniques with a short-term impact (such as green revolution technologies).

To overcome such difficulties, since the mid-2010s, FarmTreeServices™ (FTS, www.farmtreeservices.com) has been developing a method to quickly estimate costs and benefits of smallholder-managed Agroforestry systems. It's FarmTree®-Method combines farmers' experience, agronomic knowledge, and systems modelling, and allows to estimate agro-ecological, livelihoods, economic and environmental indicators. Simultaneously, Kabore, C. (2015) in [6], proposed a Theory of Change of FMNR based on similar thinking. FTS and WVA thus joined hands to apply this model for estimating costs and benefits of introducing FMNR at farm level. WVA selected FMNR practice of Baringo[7] county in Kenya for this purpose. This is the consultancy report of this study, that has been carried out between November 2017 and January 2018.

2. Objective, methodology and implementation of the study

2.1 Objective

The ToR of the study (see Annex 1) gives as objective ***to quantify the results of the east-African FMNR Pilot Project in [Baringo] county, Kenya***. Further, "*the costs of production, both with and without FMNR, and anticipated changes over time have to be assessed*." The ToR thus allows to assess both production and economic benefits.

[1] World Vision Kenya, 2016. Voices of Change. FMNR Newsletter.

[2] Abasse, Tougiani; Chaibou Guero; Tony Rinaudo, 2008. Community mobilisation for improved livelihoods through tree crop management in Niger. GeoJournal (2009) 74:377–389, Springer Science+Business Media B.V.

[3] ABDOULAYE, Tahirou, et Germaine IBRO, 2006. Analyse des impacts socio-economiques des investissements dans la gestion des ressources naturelles: étude de cas dans les régions de Maradi, Tahoua et Tillabéry au Niger. « Etude Sahélienne – Niger » Centre Régional d'Enseignement Spécialise En Agriculture (CRESA), Niamey et L'Université Libre D'Amsterdam

[4] Frank Place and Joachim Nyemeck Binam, 2017? Economic Impacts of Farmer-Managed Natural Regeneration in the Sahel: End-of-Project Technical Report for Free University Amsterdam and IFAD, 104 pp.

[5] Weston, Peter, and Reaksmey, Hong, undated (2012?). Social Return on Investment Report. Talensi Farmer-Managed Natural Regeneration Project in Ghana. World Vision Australia, 26 pp.

[6] Crawford, Anne, Sarah Shteir and Daniela Rojas Chaves, 2016. Farmer Managed Natural Regeneration Evidence Gap Analysis. Internal document, World Vision Australia.

[7] Data from Nakuru were also collected but not elaborated in this study

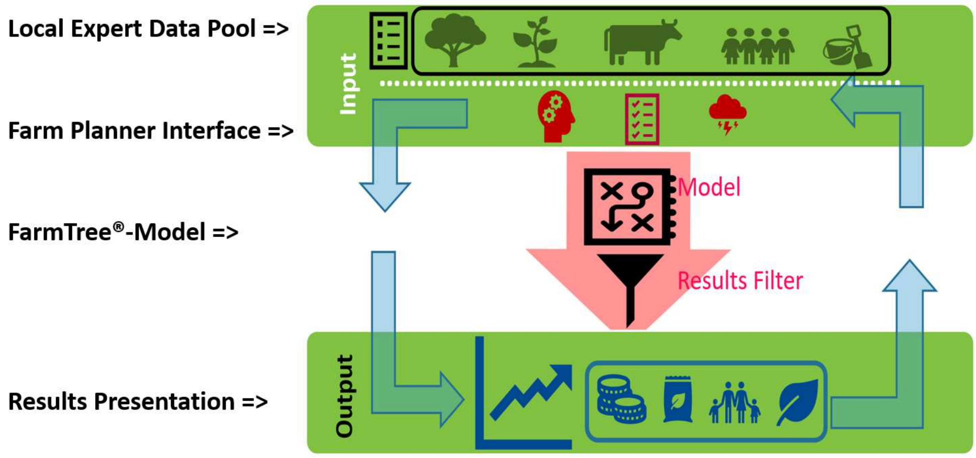
2.2 Methodology

The study team followed system modelling methodology[i] to develop an FMNR model. Such a model should help estimating indicators that are difficult to measure, such as singled-out effects of introducing FMNR, or time-series over decades for different production scenarios. For this, the study team captured local data, filled up data gaps through expert estimates, extracted cause-effect relations from farmers, or agronomists, assessed the validity of testimonies, expressed such relations in equations, and linked them up into a Baringo FMNR-model. The model needed further calibration with field observations, after which it was used to estimate the desired indicators.

Figure 1 presents the setup of the resulting FMNR-Model. The method consists of several analytical steps:

(1) **Collect and verify field data and put together a Local Expert Data Pool**, which contains quantitative data of components of agroforestry systems. All regional data that are not farm-specific are stored in such a database. They include production data of trees, crops, animals, and prices, also of inputs and labour; and weather data. Sources of data include expert farmers, local extension staff, scientific literature, and open-source data bases. Data are verified through induction or literature research.
(2) **Determine farm-specific data** and develop a data entry interface
(3) **Design a Farm System Model** that reflects the thus found constraints for production. For example, if farmers indicate that soil fertility is a major production constraint, the model has to have a mechanism by which soil fertility levels are generated, and production estimates are reduced accordingly.
(4) **Design a Results Filter**, to select the desired indicators and present them in a clear way.

Figure 1. The FMNR Model consists of (1) a Local Expert Data Pool (2) farm data entry screen (3) an FMNR systems model; that result into (4) farm projections of production, economic, livelihoods, and environmental indicators.



2.3 Applying Systems Modelling to FMNR in Baringo County

2.3.1 Developing the Local Expert Data Pool and interpreting farmers' statements

The FMNR-Model works with "Components of Agroforestry Systems" or CAFS (i.e., trees, crops, animals, inputs and human resources) and collects between 20 and 160 indicators per component (see Table 2). To collect such CAFS data, World Vision Kenya introduced the study team to FMNR-practitioners, with knowledge on the transformation from 'no' to 'medium' FMNR. Early November, 2017, WV-Australia, WV-Kenya and FTS visited three farms of FMNR practitioners in Mogotio subcounty of Baringo county, and one in Olesirwa Village, Kiambogoko ADP, Nakuru County. The study team thus collected CAFS species, and yield and price data. The team compared notes, checked them with WV-Kenya staff, and collected missing data through follow-up telephone calls. Data were collected in acres, and processed into the model in hectares. For final calculations, Kenyan

Shilling values were exchanged to US$ values at a rate of 100 KES/US$. The study team compared thus found data with data in scientific articles recording farm yields, or data found on the web (e.g., if collected yield data were inconsistent), and added some scientific data (e.g., nutritious content, maximum carbon sequestration, etc.).

Next, the study team interpreted thus collected information as common agronomical information. Table 1 gives some examples that show how farmers' information is used, adapted or even rejected.

Table 1. Farmers' statements are interpreted as agronomical knowledge to construct and to calibrate the FMNR model. Information is not used, when it cannot be understood as textbook agriculture knowledge.

Farmers' Statement	***Interpretation in the FMNR Model***
"Last year was dry and I harvested two bags of maize, but normally I harvest five to six"	The variability between low and high maize yields across years is 250 to 300%
"FMNR doubles grass yields"	True in systems where bush is opened up for grass production. Transformation from open grass to FMNR reduces space; and increases soil humidity – and doubling yields could not be confirmed.
"One acre can sustain one cow"	This statement was not used to calibrate the FMNR-model, as literature points out that high-end grass production estimates allow for around one cow per hectare; not per acre.
"When we cut trees, it doesn't rain anymore" "When we plant trees, it rains again"	We hear such statements regularly from farmers. Possibly, farmers refer to longer periods of green grass or crops in fields with trees. The study team processes such data as such.
"Last year, in the dry season, 20 of the 25 of our neighbour's cows died – while ours' survived on grass under FMNR"	Cows die in dry periods. Under FMNR, grass remains green until the next rainy season – so, in line with the farmers' observation period, for at least four months.

The team entered the data into the database format of the Local Expert Data Pool, that was linked to the FMNR-Model in MS-Excel on a PC. An extract of the Local Expert Data Pool is presented in 0.

Table 2. The Local Expert Data Pool contains values for different indicators. All in all, the for each Component of Agroforesty Systems, between 20 and 160 indicators are collected and stored in the Data Pool.

Indicator	***Use in the FMNR Model***
CAFS life cycle: economic life time, timing of production	Generate life cycles and links production to CAFS' age vis-à-vis start-up year
CAFS cultural characteristics: spacing, tolerance to intercropping, and to poor management, water and nutritional shortage	Estimate space taken by the CAFS over time and estimate CAFS response to stress
CAFS production: seasonal, yearly, end-of-lifetime products; product types and nutritional values	Estimate production and fulfilment of livelihoods needs per ha
CAFS input costs and labour needs	Estimate costs and gender-segregated labour inputs; estimate production per labour day
Production value: seasonal price fluctuations	Estimate economic value of produce
CAFS environmental effects: shading, contribution to soil fertility and structure, above and below-ground carbon sequestration	Estimate tolerance to intercropping, and contribution to soil humidity and fertility and to soil conservation and carbon sequestration

2.3.2 Developing the FMNR Scenario Planning Interface

The FMNR Model is designed so that farm data input is limited to indicators that reflect the individual farm only. Indicators that are similar across the region are already provided for in the Local Expert Data Pool. For the FMNR Scenario Planning Interface[8], required inputs are:

- Farm/Plot Size
- Tree/Crop, year of planting (for trees), and planting intensity
- Priority of Tree/Crop in case space gets scarce; and,
- Weather scenarios (1990-2016 recorded; only dry, only wet years; one dry year, one wet year)

2.3.3 Developing the FMNR systems primary production model

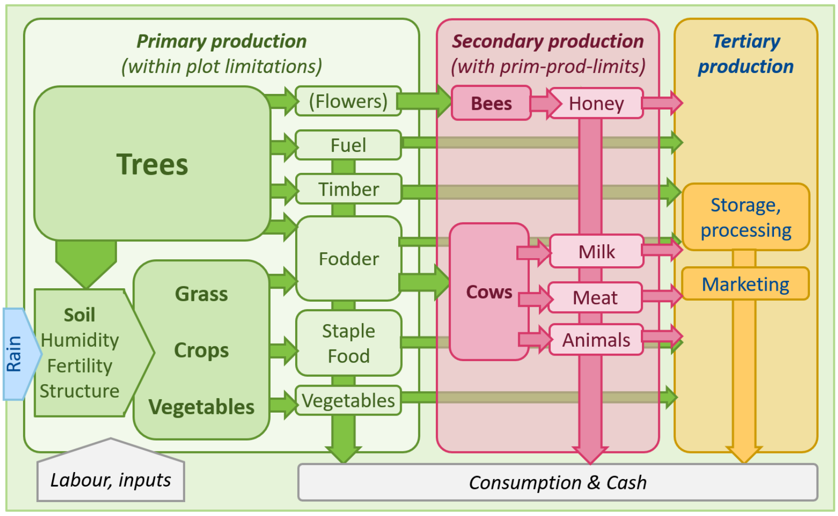
The study team's field observations, and WV-Kenya documentation[9] provide information to compose a general narrative of the results of introducing FMNR on farms in Baringo and Nakuru counties. Box 1 presents this narrative.

Box 1. A compilation of some 25 farmers' testimonies of the impact of introducing FMNR on their farm.

*"**Before I practiced FMNR**, my farm was bare and rocky. We cut trees on our fields, hoping that grass would grow, or for charcoal production. Women spent 3-6 hours a day to collect firewood from the forest or snatch it from neighbour farms; or we bought additional firewood from the market. In the dry season our cows and goats starved and once in 3-5 years, drought struck and part or all of our cow herd would die. We used to work for neighbours to complement our farm production.*

*"**With FMNR**, within months, different tree species emerged and we could prune emerging shoots and use them as fuel. Women now save time by harvesting fuel wood from the farm. We sell excess fuel wood. We keep bees and sell honey. Moreover, grass production is higher, we can now feed our cows throughout the year, and sometimes sell excess fodder. Cows now give 2-3 times more milk, and we can sell excess milk. 2016 was a dry year, and our cows survived and even kept producing milk; while the neighbours – who do not practice FMNR - lost part or all of their herd. I can now expand my cow herd, and rear 2-3 times more goats."*

Figure 2. The Baringo FMNR system model is composed of primary, secondary and tertiary production processes. The present FMNR-Model covers largely primary production (green elements) and touches secondary production.



[8] The FMNR model is available from FarmTreeServices™

[9] World Vision Kenya, 2016. Voices of Change. FMNR Newsletter, p.10-21 contains some 25 farmers' testimonies of their experiences with FMNR. http://fmnrhub.com.au/wp-content/uploads/2016/09/FMNR-Voice-of-Change-Newsletter-WVK.pdf, accessed 22-1-2018

This narrative allowed to construct an FMNR-Model (Figure 2) reflecting agronomic, ecological and marketing processes.

The model distinguishes primary, secondary and tertiary production. FMNR affects the agro-ecological system through the primary production system (the 'green' system elements in the Figure). Hence this study limits to primary production within the larger agro-ecological context.

Primary production is the production of trees and crops on land. To model primary production processes, FTS incorporated the following modules in the FMNR-Model.

Farmers report both **long-term and short-term trends** about their farming systems. Table 3 shows the indicators in the model that are calculated as long or as a short term indicators. Long-term trend indicators, such as soil fertility or tree canopy coverage, are estimated at a 1-year interval. Short-term indicators, such as soil humidity, seasonal production, and prices, are estimated at a monthly interval. Internally, the model generates data for 50-year trends, even if only 30-year trends are displayed.

Table 3. The FMNR-model calculates with long-term (1-year) and short-term (1-month) trends

Long-term trends ***(modelled at a 1-year interval)***	***Short-term trends*** ***(modelled at a 1-month interval)***
Soil fertility	Top soil humidity
Soil structure	Water availability for crops and grass
Tree canopy coverage	Seasonal production – crops
Production of fuel wood and construction wood	Grass production
Carbon sequestration	Cow herd carrying capacity

Farmers report that, irrespective of season, **FMNR trees** sprout and grow. Thus the model considers deep soil (>15 cm below the surface) water availability as stable. Trees' canopies take space according to the time passed since sprouting, and intensity of pruning, thus reducing space (and yields) of grass and crops. N-fixing trees (and crops) add to soil fertility at a maximum amount set in the Expert Data Pool. Trees directly produce fuel and construction wood, for consumption and sale. Besides, trees produce (storable) fodder, and honey in-flowers, thus setting conditions for secondary production.

Farmers report that grass and crop production highly varies over the seasons and over years in bare land, and less so under FMNR. Hence the study team developed a **top soil humidity module** to explain grass and crop production in combination with FMNR coverage. Soil water is recharged based on monthly rainfall data of 1990-2016[10]. Monthly rainfall (above a threshold set at 25 mm) recharges the top soil to a maximum (set at 50 mm). Live roots improve soil structure over time so that soils can store more water and become less prone to erosion, thus stabilizing soil structure, and soil humidity. Trees, crops and grass reduce soil water evaporation by a factor related to (species-specific) canopy density. More in general, farmers did not report **soil fertility** as a major concern in the FMNR context; hence, soil fertility and structure were not taken as a constraining factor for production except for through the maximum recorded production in the Region.

Grass produces fodder as a result of available space, and of the soil condition. Maximum grass production per month is recorded in the Local Expert Data Pool. In the model, grass production is reduced according to water availability in the top soil; for example, if in a given month the top 15 cm soil contains 25 mm water, and grass 'needs' 50 mm, the model reduces grass production in that month by 50%. Similarly, the grass module reduces production when soil fertility is sub-optimal.

[10] Worldbank Group, Climate Change Knowledge Portal, 2017. Historical rainfall data for Kenya (county unspecified) http://sdwebx.worldbank.org/climateportal/index.cfm?page=downscaled_data_download&menu=historical, accessed December 10, 2017

Maximum **Crop** production in the region is also recorded in the Data Pool, and constrained by soil fertility. Soil humidity affects crop yields different than for continuous growers such as grass. Each crop growth month with a sub-optimal humidity below a settable limit (set at 80%) affects the yield. For example, if soil water availability is 80%, 100% and 50% (of 80%) in three consecutive cropping months, the model assumes a yield of (0.8*1.0*0.5=) 40% of the optimum value.

Monetary value of primary production is based on farm-gate prices. For annual and end-of-life-products (fuel wood, sometimes fodder, construction wood), the model assumes year round stable prices. Farmers indicate that dry and wet periods rather than months of the year determine prices of seasonal products, such as staple food and fodder. As FMNR tends to reduce production fluctuations, much of its added value is the availability of modest production in a time staple food or fodder is scarce. The model accounts for such price fluctuations by assessing “non-FMNR-production” and adjusting prices when production in the region is low. The price of standing grass is valued at 50% of Farm Gate Prices.

The model estimates **labour** needed for planting and management based on the acreage of the tree or crop. Labour needs for harvesting are linked to harvest levels. So far the model only calculates labour as a cost in the economic equations. The labour module will be elaborated to estimate per-labour-day costs and benefits when needed.

Farmers reported little use of **inputs** for primary production, thus external inputs were not accounted for.

Secondary production is on-farm **animal production** based on primary production – fodder and honey. The model is based on the observation that cows die after two or more months of serious deprivation of fodder.

With the available weather data, the study team carried out an analysis of fodder availability over consecutive months with **NO FMNR, MEDIUM FMNR and FULL FMNR scenarios**.

Due to time constraints, modules for honey, milk, and animal production have not yet been developed.

Tertiary production is value addition by harvesting, storage and processing of semi-finished products. Due to time constraints, a module for processing of milk and honey, meat and animals has not yet been developed. This means that the economic value of animals, and the added value of processing/storing/selling farm produce has not yet taken into account.

2.3.4 Calibrating the FMNR Model

Once the FMNR model reflects the major mechanisms by which FMNR systems arrive at producing, the model needs calibration to ensure that its outcomes reflect the costs and benefits that farmers and farm-level research reports. The model is ‘tweaked’ in two ways. First, the study team set the model settings according to ‘common sense’ values (see Table 4) valid for this particular farming system. As this exercise is about costs and benefits of FMNR in general, and not of individual farms, farm-level variables were set at 100%, i.e., not constraining production or profits.

As soil humidity was a major determinant for production failure, tweaking of soil humidity/production figures was done more accurately. The combination of grass/crop with rainfall patterns should lead to reduced production during longer time spells. The study team tweaked grass and crop water needs (in the data pool) to come to the kind of variability in with and without FMNR scenarios that farmers report. For example, farmers report that maize yields vary over 100% over years – so the model is set to generate such results based on weather variability over years.

Table 4. Screen-shot of part of the FMNR-Model's settings menu.

Farming System Settings - Sensitivity of the Model to Risks	
Sensitivity to managers' agronomic expertise	100%
Sensitivity to agronomic stress factors	100%
Sensitivity to water constraints	100%
Sensitivity to soil fertility constraints	100%
Sensitivity to managers' marketing capacity	0%
Sensitivity to marketing barriers	0%
Years farmers take to master new technologies (0-10 years)	8

Farm Settings - Agronomy	
Minimum NPK influx kg/ha /y (0-50)	25
Crop NPK Max Need kg/ha /y (0-200)	100
Soil structure / Soil fertility relative importance (%, default 60%)	60%

Farming System Settings - Variables Water availability	
Top soil (15cm) water retention if soil structure is good (25-75 mm; typically 50 mm)	50
Monthly soil water evaporation if bare (0-100%; default 80%)	80%
Monthly soil water evaporation with Crop Cover (0-100%; default 60%)	60%
Monthly soil water evaporation under tree canopy (0-100%; default 20%)	20%
Monthly rain threshold for water percolation in top soil (0-50 mm; typically 25 mm)	25
Threshold by which month-wise limited water availability affects yields of seasonal crops (typically 80%)	80%
Top soil (15cm) water retention average for the Region (for estimating general grass/fodder availability & fodder price setting) (10-75 mm; better general water retention=>higher value)	20

2.3.5 Calculation of Results for a 2.5 ha agro-sylvo-pastoral farm

The thus created FMNR Model holds endless opportunities to test farm primary production scenarios. To estimate the benefits of FMNR, the study team 'defined' a virtual Baringo farm. The farm size is 10 ha (~25 acres). The selected weather scenario is a repeated rainfall pattern of 2006-2015.

Figure 3 shows a screenshot of the crop selection, acreage, and timing. The virtual farm features a 20% maize-beans intercrop (in which 40% of space allotted to maize is available for intercropping); the remaining acreage is covered by grass for fodder. For a virtual 30-year experiment, the farm gets three different 'treatments':

- From Year 1 to Year 10, the farm has a Maize-Bean intercrop (±20% of area); remaining area is filled with grass
- In Year 11, the farmer introduces FMNR on 30% of the farm, effective of year 12.
- In year 21, the farmer brings an additional 40% of the farm[11] under FMNR, effective of year 22.

Figure 3. The entries in the Farm Planner interface for modelling the effect of increasing FMNR coverage (30% in Year 10; an additional 40% in Year 20) on a virtual Baringo farm. The salmon-rose fields can be filled in.

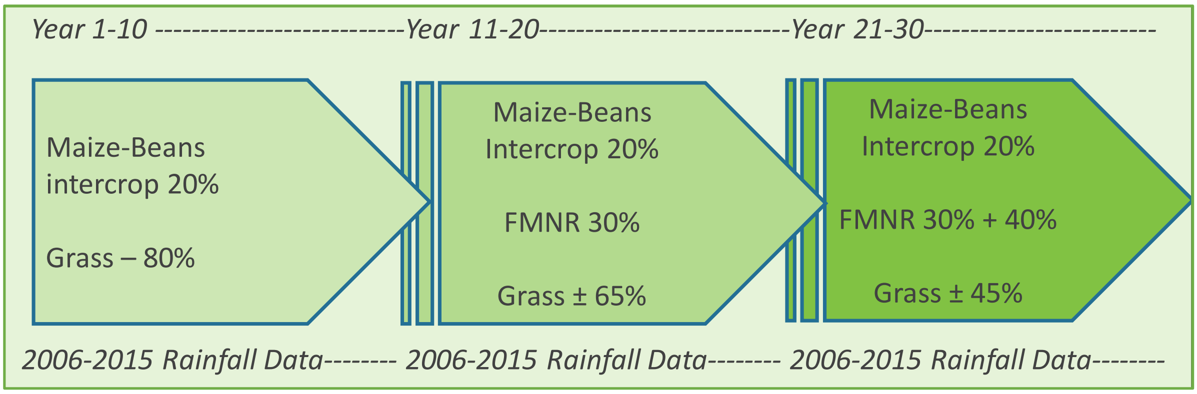
Select Tree, Crop or Tree-Crop-Mix	Tree/Crop Priority when allocating space (rank)	Planting year # from setup year (-50 to +50 years)	Select Coverage of available space (0-100%)	Feedback: Net Coverage Range (Ha)
Maize (local)	1st priority	0	20%	1.2 - 1.2 Ha
Beans (local)	2nd priority	0	10%	1 - 1 Ha
Acacia nilotica (FMNR cover 75%)	3rd priority	10	30%	0.3 - 2.3 Ha
Acacia nilotica (FMNR cover 75%)	4th priority	20	40%	0.4 - 3 Ha
Grass (traditional)	5th priority	0	100%	2.6 - 7 Ha

These virtual treatments lead to the "NO FMNR, MEDIUM FMNR and FULL FMNR scenarios (Figure 4). Please note that when FMNR practice is started, it takes 2 years to bear full effect on the system[12].

[11] The 30% Acacia in Y10, and 40% Acacia in Y20 are treated as two different cohorts, and thus the model calculates and presents their performance separately. In a later version this will be mended.

[12] Some farmers 'establish' FMNR by opening up plots with dense bushes. In that case, the process is reverse to the 'dense FMNR' scenario depicted in Figure 10-c.

Figure 4. The FMNR- Farm modelling consists of three periods with different treatments; all calculated with a repetitive period of 2006-2015 rainfall data.



To rule out the influence of rainfall variability over a 30-year period on the results, rainfall records of 2006-2015 were repeated for the respective FMNR scenarios.

The study team carried out calculations, took screenshots of the resulting graphs, and selected results relevant for the research question. Carbon, nutrition, labour and other indicators were thus not presented.

3. Results of modelling No, Medium and Full FMNR Scenarios

3.1 Results of modelling primary production with phase-wise introduction of FMNR

3.1.1 Allocating space to Agroforestry system components

The FMNR-Model starts with allocating virtual plot space to the different trees and crops according to the entry shown in Figure 3. Figure 5 shows the space the model allocates over time to the different system components. As the team ‘prioritised’ maize and beans, these crops get a stable space of 20 and 10% of available space. As maize tolerates 40% intercropping, beans hardly take space beyond the 20% of maize coverage. Remaining space is allocated to grass, until – in Year 10 - a first cohort of FMNR trees is introduced into the system. Trees are pruned back by 50%, so, even if grass coverage is reduced, it still produces in ~65% of the plot surface. When in Year 21 another FMNR cohort is introduced, the space for grass reduces even more, down to ~45%.

3.1.2 Simulating Agro-ecological indicators

After the FMNR model has calculated plot coverage, it calculates some environmental indicators that determine productivity of the different trees and crops. Figure 6 presents some agro-ecological trends in the to simulated farm. In the FMNR-model, soil structure remains positive because the dominant grass coverage (without ploughing) provides protection, and overgrazing has not been taken into account. The figure indicates that both soil fertility and soil structure are 100% of potential throughout the three scenarios. The major effects of FMNR are thus in the protection of soil humidity by a higher canopy coverage, and the consequent more regular soil humidity in times of drought.

Figure 5. The FMNR-Model allocates space to the different crops and trees over the system modelling period. Note that, as trees and crops may allow for intercropping, the total canopy coverage in the system goes beyond 100%.

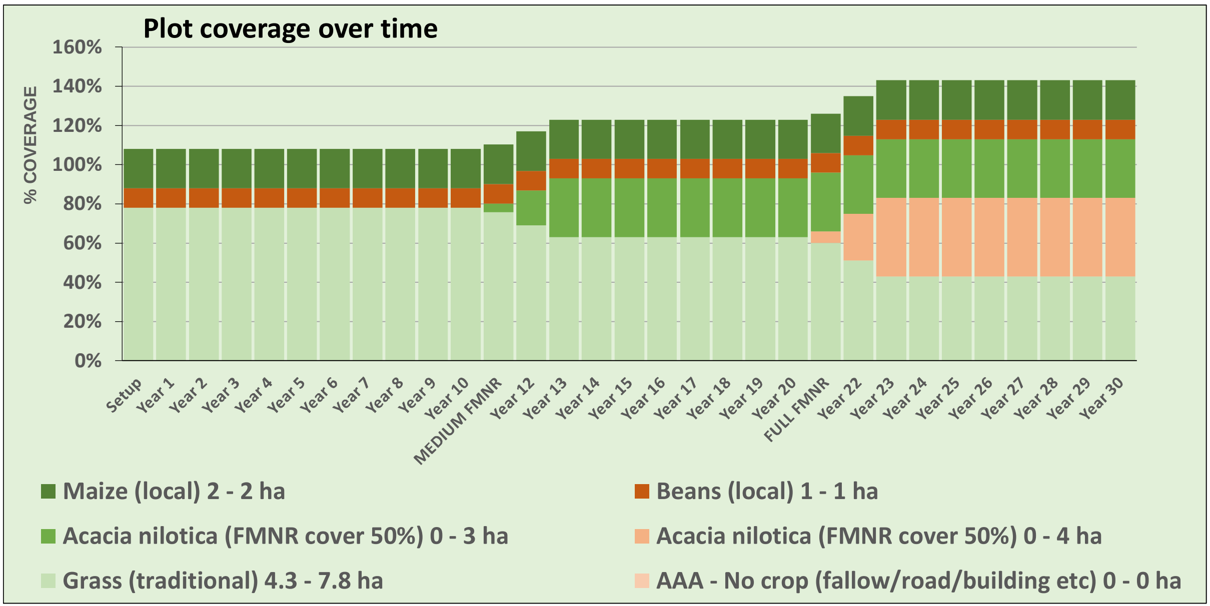
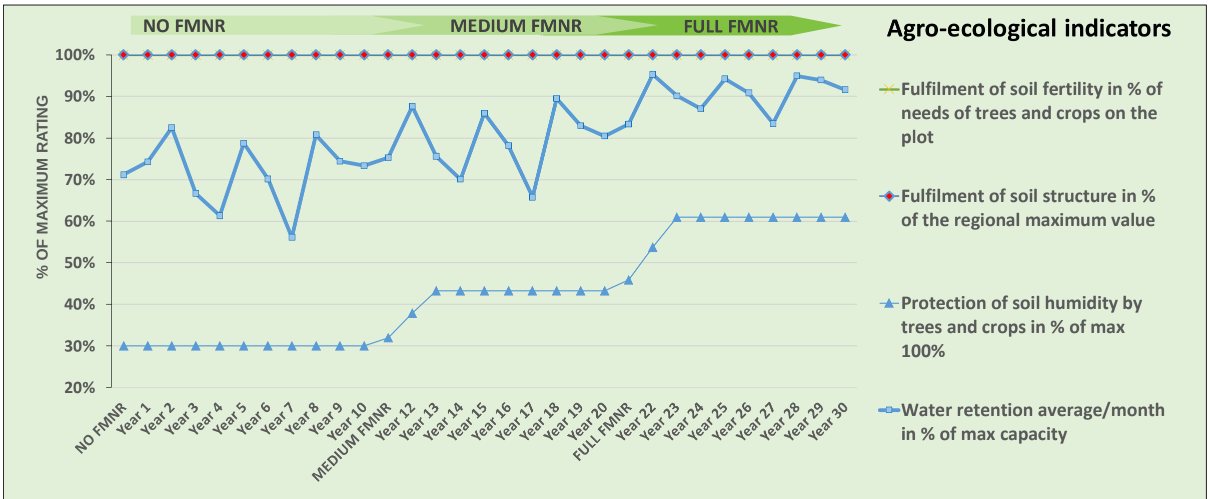


Figure 6. The FMNR-Model simulates plot-level soil structure, soil fertility, soil conservation, and soil humidity as intermediate trends that determine (among others) production trends



3.1.3 Production of Fodder, Fuel wood and Staple Food

Figure 7-a-b-c provide the production patterns of three primary product groups, viz. Fodder, Fuel Wood and Staple Food.

Figure 7. Figures a, b and c display trends of production of fodder, fuel wood and staple food of the different system components.

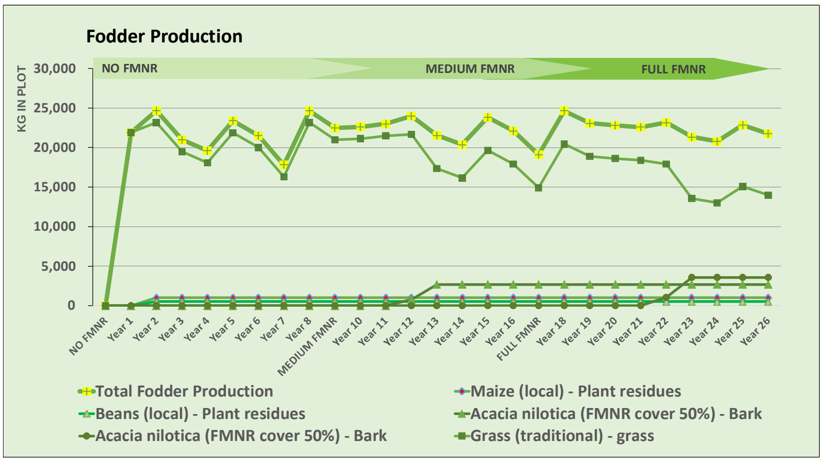


Figure 7-a shows the trend of **fodder** production during the simulation period. The annual production of grass is highest during the NO FMNR treatment. Annual grass production though goes down by 30% because trees take 50% space in the FMNR-covered area. This reduction in production is compensated by the production of bark of the FMNR-trees; and overall fodder production remains 20-25 t on the farm. Annual fodder production variability is also reduced (from 25% to 15%) but this is not a major effect.

When trying out the effect of lower canopy densities (25% of the present 50%) of the FMNR trees (virtual “extra pruning”) we saw that grass production was higher, even for FULL FMNR scenarios (not shown). This phenomenon will be further discussed in Section 4.

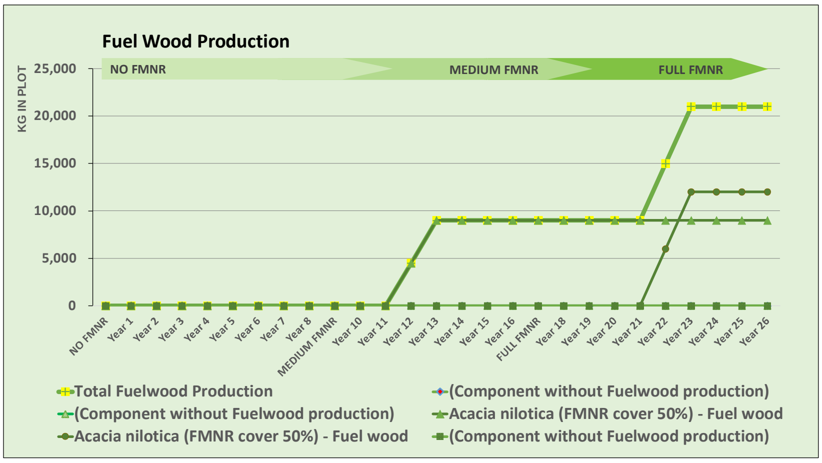
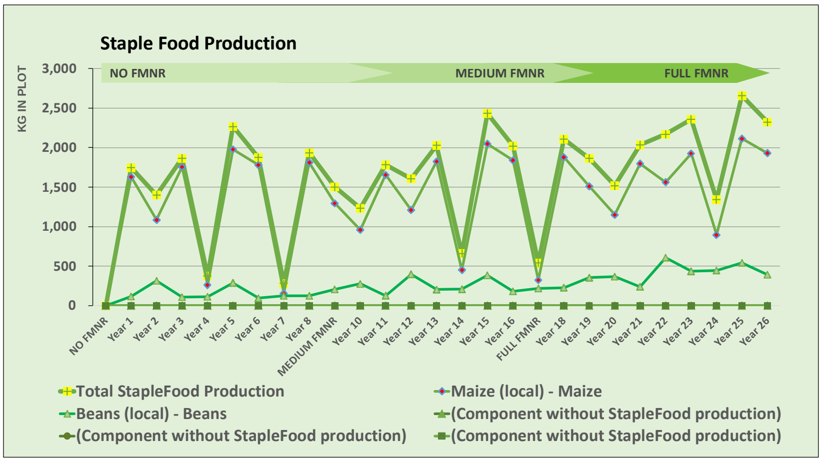


Figure 7-b shows the trend of **fuel wood** production for the three scenarios. Not surprisingly, in the NO FMNR-treatment production of fuel wood is zero. In the year following the introduction of FMNR, fuel wood production starts; and goes up to a stable 5 ton/ha. The graphs show little annual variation, because in the model, trees grow irrespective of rainfall and soil fertility.

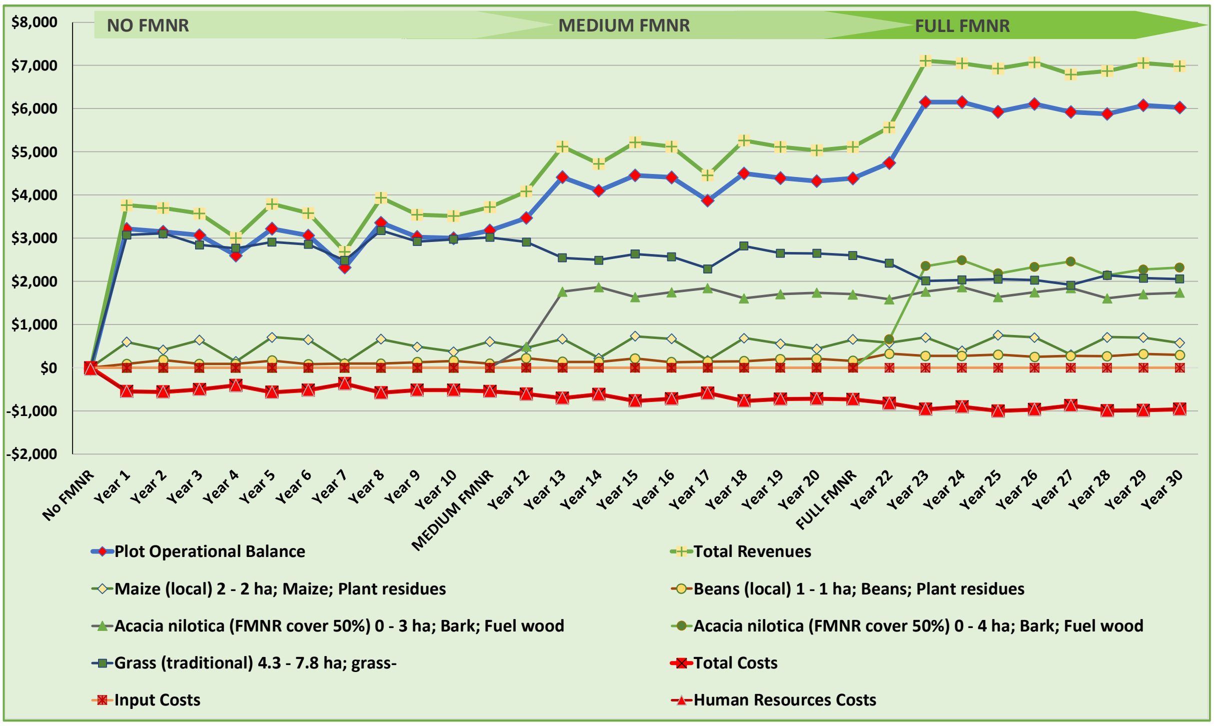


Maize and beans are **staple food** suppliers on the farm. In the model, maize and beans have priority over trees – so they don't compete with trees for space. Figure 7-c shows the trend of staple food production. In the NO FMNR treatment, production varies from ~280 to ~2,280 kg (810%); the 30% FMNR scenario between ~520-2500kg (480%) and in the 30+40% FMNR scenario ~1200-2600 kg (220%). This is a result of an improved soil water regime due to extra canopy coverage of the trees, and some green fertiliser effect. Yet, in line with farmers' testimonies, variability remains high.

3.1.4 Economic benefits of primary production

Figure 8 presents the economic results of introducing FMNR. Investments are mainly in labour, and pay back in the same year. The model does not take training costs into account. Values are as follows.

Figure 8. The economic costs (only labour) and benefits of primary production



During the entire period, the labour costs – of harvesting extra products – go up. This means that (paid) employment as a result of primary production rises. This is in line with farmers' observation that FMNR brings more productive opportunities on the farm.

During the NO FMNR scenario, farm economic value varies from US$ 2,800 to $4000. With the introduction of FMNR, trees 'take' space from the grass (at 50% of FMNR gross coverage); and in the process create a conducive agro-ecological environment. All in all the value of grass production goes slightly down. This trend is compensated by the increase of economic benefits by trees in Year 11-12, when annual production is between US$ 3,900 and $4,500 /y. The same trend continues during the following intensification of FMNR. In the "FULL FMNR" treatment, created value is stable at around US$ 7,000/year.

The resulting Net Present Values at a discount rate of 10% of the NO FMNR, MEDIUM FMMR and FULL FMNR scenarios are around US$ 27,000, US$ 35,000 and US$ 54,000 respectively. As no FMNR-related investments were included, it was not possible to calculate Internal Rates of Return.

3.2 Results of modelling secondary production: fodder availability and cow herd size

Livestock management is an essential aspect of farming in Baringo, and most of the primary production value is in the shape of fodder to maintain herds. Farmers quote improved fodder availability as a major result of FMNR. The study team made a start of an analysis of the impact of FMNR on cow herd management.

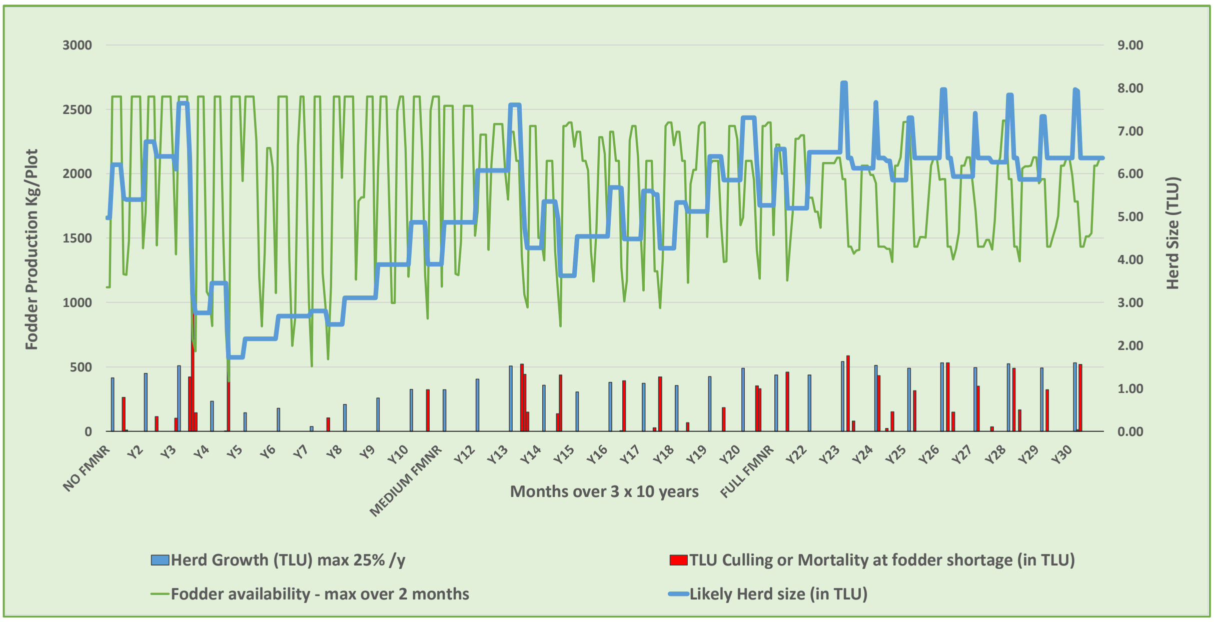
Figure 7-a shows that the total fodder production is not necessarily higher in the with-FMNR scenarios, but that production variability on a yearly basis goes down from around 25% to around 15%. Yet, farmers report that seasonal variation in production is a major constraint in herd management. In an extended dry season period, 80% losses of animals are no exception. To avoid such losses, farmers harvest grass at around 1,500 kg (300 bales) per ha and store them for feeding in the dry season[13]. This is a labourious job: farmers report up to 150 (largely women's) labour days /ha per cut (60 days per acre) for harvesting and processing hay.

It would thus save time if grass production in-the-field were more regular. To study the effect of FMNR on in-field grass availability, the study team took monthly soil humidity values, and reduced grass growth when humidity was sub-optimal (leading to grass production estimates showed in Figure 7-a). These estimates were linked to a simplified cow herd management model. Farmers state that cows will not survive deprivation of fodder for two consecutive months. Taking this into account, a herd management model was put together that works with the following equations:

1. **Fodder availability** - the FMNR Model estimates maximum on-the-field fodder production of 2 consecutive months over the three FMNR scenario periods.
2. One Tropical Livestock Unit (TLU, ~one cow) needs 225 kg dry matter per month. **Cattle culling or mortality** takes place when cows have no fodder in the field for 2 consecutive months.
3. Each month the **herd size** (in TLUs) is adjusted to the availability of in-field fodder.
4. In March, cows calve, and the **herd size** grows by 25%

[13] Farmers also reported another strategy: "cows should be fat in the wet season, so that they can survive the dry season"

Figure 9. Monthly in-field fodder availability under NO FMNR, MEDIUM FMNR and FULL FMNR scenarios, and the resulting cow herd size on the modelled farm.



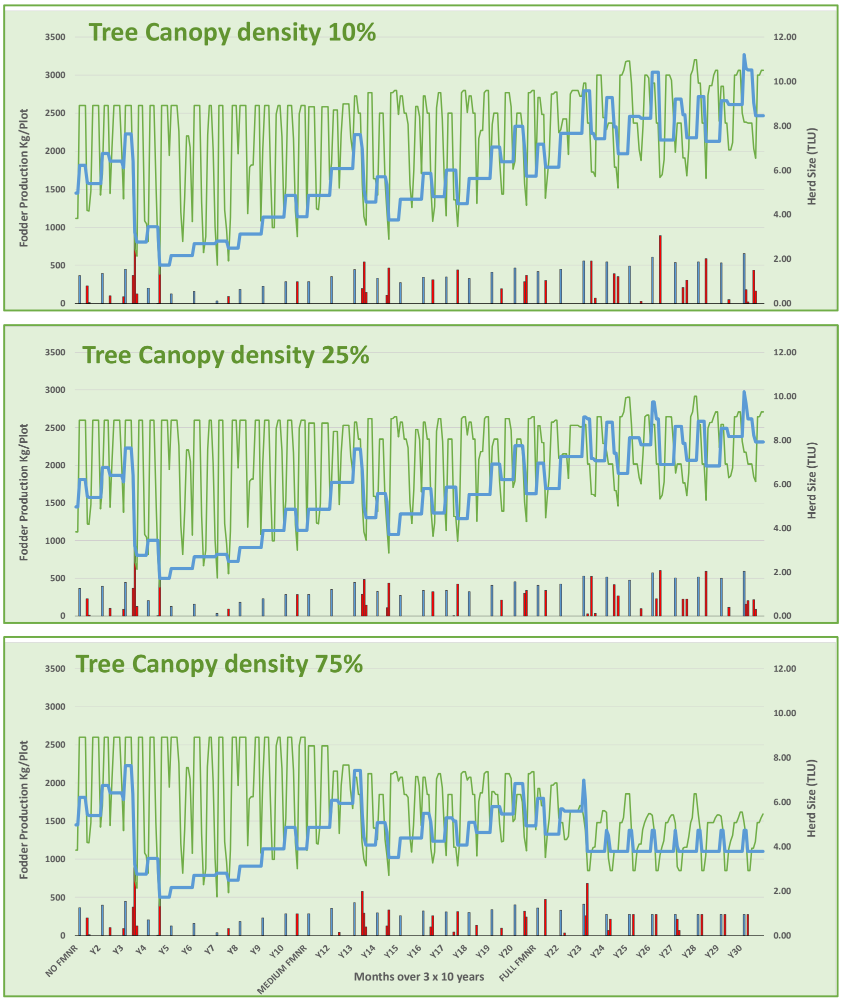


Figure 10 a,b and c. The effect of intensive, intermediate and low pruning of FMNR trees on fodder production and the consequent cow herd size on the farm.

The result of this model is depicted in Figure 9. The figure shows that under the NO FMNR scenario, two-monthly fodder availability varies from 400 to 2,600 kg (>550% variability). Under a MEDIUM FMNR scenario the variability is 800 to 2,400 kg (300%); while under the FULL FMNR scenario variability is 1,400 to 2,400 kg (160%).

This variability of fodder availability has serious consequences for the potential herd size. In the 2009/2010 rainfall scenario (Y4/5), in the NO FMNR scenario, the herd size goes down to below 2 TLU. With FMNR establishing (Y14/15), the herd size goes down to just below 4 TLU under the same 2009/2010 stress level. In Y24/Y25, when full FMNR is firmly established, every single year herd growth and mortality are in balance at 6 TLU.

This means that, even if in the with FMNR scenarios year-wise in-field fodder production goes down, the farm's cow herd carrying capacity more than doubles. Please note that in this equation, fodder stocks (in terms of hey, bark and staple crop residues) have not yet been taken into account. A major labour investment of farmers was the harvesting and stocking of grass, to overcome shortage of fodder in the dry season. As this was mainly a women's job, in-field grass availability reduces such a labour burden on women.

The canopy cover – i.e., the intensity of pruning – has quite an influence on the fodder production and hence the carrying cow herd capacity of the farm. Figure 10 shows how a setting of different pruning intensities allow for a smaller or bigger cow herd on the farm. Strikingly, intensive pruning allows for more animals on the farm, with an optimum between 10 and 25% crown coverage.

4. Conclusion and Discussion

4.1 Limitations of the Study

This study features both limitations of the method, and limitations of its application.

The **method** Systems Modelling is a powerful technique, but it is not magic. Constructing the model implies finding out major relations that lead to results, and expressing those in a set of equations. The model thus feeds back data, and the 'thrash-in, thrash-out' principle dictates that bad quality data lead to invalid estimates. As much as the study team tried to get valid data, sometimes variables had to be estimated. Collected data and results need thorough cross-checking with available studies of farm-level production in the area. At the same time, the process of constructing the model allows for learning and setting priorities for research for further understanding of the FMNR-system, that can feed back into the FMNR-model.

The **implementation** of the study implied a five-days field visit, having 4-6 hour interviews with three farming families in Baringo and one in Nakuru; followed by some 50 days of systematising and model development. In Baringo, cow rearing both for milk and animal production is an essential component of the agroforestry system, that is yet to be captured in a model. And, as farmers spent a good part of their time managing animals, calculations on farm-level production-per-labour input, and production-versus-household-needs are yet to be done. Production of local herbs and medicines are locally important but have not yet been taken into account in the model.

4.2 Conclusion

The FMNR Model is based on farmers' narratives and general agronomical know-how. Application of the model in Baringo county suggests that FMNR has the following effects:

- In wet years, yields of **food crops** remain more or less stable under FMNR. In dry years, FMNR reduces the risk for total yield loss; even if yield variability remains high.
- Obviously, FMNR results in higher **fuel wood** production, which reduces the work load for women and allows farmers to sell surplus.
- **Annual fodder production** remains stable in with and without FMNR scenarios.

- **Monthly fodder production** stabilises in with-FMNR scenarios, even with low tree densities. This allows farmers to manage their herd as per their farm's preferences rather than as a result of weather events; thus allows for intensification of herd management.
- **Economic value** of tree and crop based production both gets more stable, and more or less doubles when fully introducing FMNR on the farm. Revenues of crops remain the same, but fuel wood allows for an additional, stable revenue stream.

This makes FMNR a technology that generates resilience for animal-based production systems in Baringo county.

4.3 Discussion

In sub-Saharan Africa FMNR is practiced by millions of farmers. The FMNR-Hub and colleague organisations are promoting the technique claiming that it increases yields of crops, based on field observations and plenty of farmers' narratives. Both anecdotal, GIS and surveys' evidence support the thesis that FMNR can address livelihoods security and landscape restauration. Yet, field studies providing solid evidence are scarce, limited to specific systems, and sometimes provide conflicting results. Moreover, economic benefits are rarely convincing for farmers, or farmers' organisations, let alone for Governments or impact investors. Therefore, besides support for FMNR as a mechanism for farm and landscape restauration, there is also skepticism about FMNR in the development domain.

This study aimed to develop a method to fill the information gap between convinced practitioners and skeptical development actors. The method consists of the steps: collect farmers' testimonies; interpret and validate them in agronomical knowledge terms; summarise this information in a FMNR-Model; calculate and validate FMNR scenarios and present them. Such a model thus generates 'best informed' hypotheses about the performance of FMNR systems. Assumptions can be verified, and model outcomes can be rejected, refined or confirmed with field-experience or follow-up research.

In this study, the FMNR-model is applied to an FMNR system in Baringo, Kenya. The above conclusion shows that economic performance stabilises and increase with FMNR application. Yet the study also resulted in some counterintuitive results. For example, the claim that FMNR *'increases staple food yields'* needs unpacking. In the model, with FMNR, staple food yields indeed increase; but more importantly, total yield failures are avoided. Similarly, total grass (fodder) production is *lower* with regular FMNR, but *with* FMNR, production is spread better over the year, so grass is available when it is badly needed, and hence allows for productive cow herd management rather than dealing with disaster.

Such outcomes noted down from Famers' testimonies ("*FMNR saved our cows last season*") are difficult to believe – but with the FMNR-model, are backed up with plausible agronomic mechanisms. This thus turns farmers' observation in sharable information based on which investors such as donors, but also farmers, or credit institutions, can decide to invest in farm or landscape restauration.

Having said that, the above developed FMNR model is far from complete. The model does not yet cover the complete Baringo farming system: cow herd management, household needs and surpluses, and processing and marketing modules, are yet to be developed. Moreover, the model needs testing, and refining.

At the same time, now that a first FMNR-Model has been constructed, we can continue calculating FMNR-scenarios, both in Baringo based on the present Local Expert Data, or – for other regions – on data to-be-collected. Such calculations can find application in project formulation (ex-ante impact assessment), project monitoring and learning; and even in farm or landscape planning. Sharing the method with field-level experts allows them to direct the development of the Model so that they can use it in their daily practice.

5. Acknowledgements

The study team – Dr Judith Sinja and Dr Frank van Schoubroeck - thank World Vision Kenya staff Geoffry Yator Rerimoi, Mr Victor Omonde, and others who assisted to identify and find highly motivated FMNR-farmers. FMNR-practitioners Mrs Nancy Kemboi of Lombogishu Village, Mr Justin Komen and his wife Scholastica, Mr Wilson Borin, and Mr Elijah Oyaro and his wife Mrs Spora, Olesirwa Village, Nakuru, kindly shared their experiences with introducing FMNR on their farm and gently provided local data. World-Vision Kenya drivers assisted to transport the study team to the different farms. Dr Karl Hughes and Dr Judith Oduol of ICRAF provided feedback on the first draft of the study results.

After the field visit, the World Vision Australia team warmly supported the study team with encouragement and documentation. FMNR-Hub staff Tony Rinaudo helped the team to get in contact with the wider debate; and Mrs Anne Crowford shared documentation and survey data. The team warmheartedly thanks Mrs Alice Muller for her perseverance to get the contract through, the weekly contact, and all encouragement along the way.

6. Abbreviations

CAFS	Component of Agroforestry Systems (i.e., tree, crop, animal, input, labour)
FMNR	Farmer Managed Natural Regeneration
FTS	FarmTreeServices™
LEDP	Local Expert Data Pool
N	Nitrogen
TLU	Tropical Livestock Unit
WV-A	World Vision Australia
WV-K	World Vision Kenya

Annex 1. Terms of Reference for the study

Objective of the study thus is ***to quantify the results of the east-African FMNR Pilot Project in Nakuru county, Kenya***.

Impacts of FMNR that should be included in such an assessment are:

- income from consumption and/or the sale of timber and non-timber products derived from trees and shrubs managed with FMNR,
- income from consumption and/or the sale of products produced as a result of beneficial association with FMNR (such as food crops, honey, livestock etc.),
- the value of products used at a household level that are sourced from farmer regenerated trees, shrubs or associated production system.
- changes in labour requirements and rates of return/benefit distribution.

To assess the value of these impacts at a household scale, the costs of production, both with and without FMNR, and anticipated changes over time have to be assessed. This assessment should also include a comparison to the business as usual scenario of 'no FMNR' as well as variations such as low density FMNR and high density FMNR etc. The study should show anticipated benefits of FMNR over time, for example at year 2, 5, 10, 20, 50. The consultant is free to choose relevant results as to clarify the benefits of FMNR.

Annex 2. Rainfall in Data used for modelling

Table 5. 2008-2015 monthly rainfall in mm/month, as used for modelling soil humidity

	2008	2009	2010	2011	2012	2013	2014	2015
Jan	33	37	45	26	10	45	23	28
Feb	25	32	45	31	15	23	31	25
Mar	120	24	93	82	17	154	62	53
Apr	85	111	99	72	111	149	70	146
May	68	78	71	91	77	70	73	98
Jun	33	34	52	31	28	27	41	50
Jul	22	26	28	20	33	27	28	28
Aug	30	22	30	32	27	58	33	26
Sep	33	24	24	38	22	46	38	38
Oct	87	126	52	66	48	44	71	72
Nov	110	69	60	116	103	87	108	153
Dec	22	78	47	47	98	66	51	70

Annex 3. The Local Expert Data Pool

Name Agroforestry System Component	Culture Characteristics	Tolerance to Stress	Shade, water need	Max C-sequestration & N-fixation	Products, production, prices	Origin of Data	Remarks
AAA - No crop (fallow/road/building etc)	100% canopy density;	Tolerance to: drought - 100%; to poor soil 100%; to poor management 100%	Tolerance for intercropping 0%; water need~10mm/month			Data collected for FMNR-Hub World Vision and collected from WV-Kenya, Baringo , Kenya, around Nov-2017	
Acacia nilotica (FMNR - for grass intercrop)	pl dist 4 x 4 m; 50% canopy density; life span 50 y Life cycle of 50Y, opt prod after Y2	Tolerance to: drought - 100%; to poor soil 75%; to poor management 75%	Tolerance for intercropping 50%; water need~40mm/month	C-sequ max 10 tCO2e/Ha. N-fix max 50 Kg/Ha	Seasonal Product: Bark@300kg/Ha; Price/unit US$ 0.55 - 0.88 (Human Nutr Value: none) - Yearround Product: Fuel wood max prod 6 Trailer of 500Kg; reaching max production in Year 2	Data collected for WV-Kenya and collected from Nancy Kambol, Justin Komen, Baringo, Kenya, around 43009	Identification by FMNR-Hub Alice Muller
Beans (local)	100% canopy density;	Tolerance to: drought - 60%; to poor soil 50%; to poor management 75%	Tolerance for intercropping 0%; water need~60mm/month	N-fix max 50 Kg/Ha	Seasonal Product: Beans@8bag of 90 kg/Ha; Price/unit US$ 44.04 - 66.06 (Human Nutr Value: Carbohydrates 55%; Fat 2.5%; Plant Protein 22%; -.) - Yearround Product: Plant residues max prod 500 kg	Data collected for WV-Kenya and collected from Nancy Kambol, Justin, Nakuru, Kenya, around Oct-2018	Approximate record based on interviews with Mrs Nancy Kombol, Mr Justin, etc
Bush, mixed (Baringo, on-farm, unmanaged, some grass)	pl dist 2 x 2 m; 100% canopy density; life span 100 y Life cycle of 100Y, opt prod after Y2	Tolerance to: drought - 100%; to poor soil 100%; to poor management 100%	Tolerance for intercropping 0%; water need~35mm/month	C-sequ max 15 tCO2e/Ha. N-fix max 10 Kg/Ha	Seasonal Product: Grazing grass@1500kg/Ha; Price/unit US$ 0.55 - 0.55 (Human Nutr Value: none) - Yearround Product: Fuel wood max prod 3 Trailer of 500Kg; reaching max production in Year 2	Data collected for WV-Kenya and collected from 0, Nakuru, Kenya, around Oct-2017	Approximate record based on interviews with Mrs Nancy Kombol
Eucalyptus (pole production 5-y cycle)	pl dist 2 x 3 m; 100% canopy density; life span 5 y Life cycle of 5Y, opt prod after Y4	Tolerance to: drought - 90%; to poor soil 50%; to poor management 75%	Tolerance for intercropping 0%; water need~30mm/month	C-sequ max 20 tCO2e/Ha.	- Yearround Product: Fuel wood max prod 3 Trailer of 500Kg; reaching max production in Year 3 - End-of-life-Product: Poles@1667 Piece/Ha, with a value of US$ 9174	Data collected for World Vision FMNR Hub and collected from Elija Oyaro, Nakuru, Kenya, around Oct-2017	Price of poles is non-linear. So far not modelled; we create different CASF records for different coppice intervals. It is assumed that 75% of biomass=>poles; 25%=>fuel wood.
FMNR Mixed Trees (8 species for intercrop)	pl dist 4 x 4 m; 25% canopy density; life span 50 y Life cycle of 50Y, opt prod after Y3	Tolerance to: drought - 100%; to poor soil 100%; to poor management 75%	Tolerance for intercropping 75%; water need~20mm/month	C-sequ max 10 tCO2e/Ha. N-fix max 20 Kg/Ha	Seasonal Product: Fodder@40kg/Ha; Price/unit US$ 2.75 - 2.75 (Human Nutr Value: none)	Data collected for WV-Kenya and collected from Elija Oyaro, Nakuru, Kenya, around 43009	Faidherbia Croton, Leleshwa, Watal, Mukinyai, Moreoamotua, Ulea. Collected from Nakuru with World Vision.
Grass (Improved, Rhodes; 3-y cycle with ploughing)	100% canopy density; life span 3 y Life cycle of 3Y, opt prod after Y1	Tolerance to: drought - 100%; to poor soil 75%; to poor management 75%	Tolerance for intercropping 0%; water need~60mm/month		Seasonal Product: grass@8000kg/Ha; Price/unit US$ 0.28 - 0.44; in-field price 50% of Farm Gate Price (Human Nutr Value: none)	Data collected for WV-Kenya and collected from Kambol, Nakuru, Kenya, around Oct-2017	Approximate record based on interviews with Mrs Nancy Kombol, Mr Justin, etc
Grass (traditional)	100% canopy density;	Tolerance to: drought - 0%; to poor soil 50%; to poor management 75%	Tolerance for intercropping 0%; water need~60mm/month		Seasonal Product: grass@4000kg/Ha; Price/unit US$ 0.28 - 0.44; in-field price 50% of Farm Gate Price (Human Nutr Value: none)	Data collected for WV-Kenya and collected from Kambol, Nakuru, Kenya, around Oct-2017	Approximate record based on interviews with Mrs Nancy Kombol, Mr Justin, etc

(continues next page)

Name Agroforestry System Component	Culture Characteristics	Tolerance to Stress	Shade, water need	Max C-sequestration & N-fixation	Products, production, prices	Origin of Data	Remarks
Grevillea (Coppice 10-y cycle)	pl dist 2 x 3 m; 80% canopy density; life span 10 y Life cycle of 10Y, opt prod after Y8	Tolerance to: drought - 90%; to poor soil 75%; to poor management 75%	Tolerance for intercropping 20%; water need~50mm/month	C-sequ max 20 tCO2e/Ha.	- Yearround Product: Fuel wood max prod 7 Trailer of 500Kg; reaching max production in Year 3 - End-of-life-Product: Poles@1667 Piece/Ha, with a value of Euro 45872	Data collected for World Vision FMNR Hub and collected from Elija Oyaro, Nakuru, Kenya, around Oct-2017	Price of poles is non-linear: 3y-old pole => KES 300; 10-y old pole: KES 3000. In terms of price/kg: KES 23 & 44 resp. So far not modelled; we need different CASF records for different coppice intervals. It is assumed that 60% of biomass=>poles; 40%=>fuel wood.
Grevillea (Coppice 4-y cycle)	pl dist 2 x 3 m; 60% canopy density; life span 4 y Life cycle of 4Y, opt prod after Y8	Tolerance to: drought - 90%; to poor soil 75%; to poor management 75%	Tolerance for intercropping 40%; water need~50mm/month	C-sequ max 20 tCO2e/Ha.	- Yearround Product: Fuel wood max prod 7 Trailer of 500Kg; reaching max production in Year 3 - End-of-life-Product: Poles@1667 Piece/Ha, with a value of Euro 4587	Data collected for World Vision FMNR Hub and collected from Elija Oyaro, Nakuru, Kenya, around Oct-2017	Price of poles is non-linear: 3y-old pole => KES 300; 10-y old pole: KES 3000. In terms of price/kg: KES 23 & 44 resp. So far not modelled; we need different CASF records for different coppice intervals. It is assumed that 60% of biomass=>poles; 40%=>fuel wood.
Grevillea (Coppice 6-y cycle)	pl dist 2 x 3 m; 60% canopy density; life span 4 y Life cycle of 4Y, opt prod after Y8	Tolerance to: drought - 90%; to poor soil 75%; to poor management 75%	Tolerance for intercropping 40%; water need~35mm/month	C-sequ max 30 tCO2e/Ha.	- Yearround Product: Fuel wood max prod 7 Trailer of 500Kg; reaching max production in Year 3 - End-of-life-Product: Poles@1667 Pole/Ha, with a value of Euro 10703	Data collected for World Vision FMNR Hub and collected from Elija Oyaro, Nakuru, Kenya, around may-2016	Price of poles is non-linear: 3y-old pole => KES 300; 10-y old pole: KES 3000. In terms of price/kg: KES 23 & 44 resp. It is assumed that 60% of biomass=>poles; 40%=>fuel wood.
Maize (local)	60% canopy density;	Tolerance to: drought - 60%; to poor soil 75%; to poor management 50%	Tolerance for intercropping 40%; water need~80mm/month		Seasonal Product: Maize@12bag of 90 kg/Ha; Price/unit Euro 27.52 - 41.28 (Human Nutr Value: Carbohydrates 69%; Fat 3%; Plant Protein 8%; -.) - Yearround Product: Plant residues max prod 500 kg	Data collected for WV-Kenya and collected from 0, Nakuru, Kenya, around Oct-2017	Approximate record based on interviews with Mrs Nancy Kombol, Mr Justin, etc
Mandarin	pl dist 8 x 8 m; 80% canopy density; life span 15 y Life cycle of 15Y, opt prod after Y10	Tolerance to: drought - 70%; to poor soil 50%; to poor management 75%	Tolerance for intercropping 20%; water need~50mm/month	C-sequ max 12 tCO2e/Ha.	Seasonal Product: Fruits@5000kg/Ha; Price/unit Euro 0.64 - 0.97 (Human Nutr Value: none)	Data collected for Experna and collected from SY-AFD, Casamance, Senegal, around Oct-2016	
Melia (Coppice 4-y cycle)	pl dist 3 x 3 m; 80% canopy density; life span 4 y Life cycle of 4Y, opt prod after Y5	Tolerance to: drought - 90%; to poor soil 75%; to poor management 75%	Tolerance for intercropping 20%; water need~50mm/month	C-sequ max 20 tCO2e/Ha.	- Yearround Product: Fuel wood max prod 7 Trailer of 500Kg; reaching max production in Year 3 - End-of-life-Product: Poles@1111 Piece/Ha, with a value of Euro 3058	Data collected for World Vision FMNR Hub and collected from Alex Oduor, Nakuru, Kenya, around Oct-2017	Prices & volumes derived from Grevillea + ICRAF documentation
Mixed vegetables (local)	60% canopy density;	Tolerance to: drought - 40%; to poor soil 25%; to poor management 25%	Tolerance for intercropping 40%; water need~80mm/month		Seasonal Product: Vegetables@6000kg/Ha; Price/unit Euro 0.46 - 0.46 (Human Nutr Value: Carbohydrates 10%; Fat 1%; Plant Protein 1%; -.)	Data collected for WV-Kenya and collected from 0, Nakuru, Kenya, around Oct-2017	Approximate record based on interviews with Mrs Nancy Kombol, Mr Justin, etc
Sorghum (local)	80% canopy density;	Tolerance to: drought - 70%; to poor soil 75%; to poor management 50%	Tolerance for intercropping 20%; water need~45mm/month		Seasonal Product: Sorghum@12bag of 90 kg/Ha; Price/unit Euro 32.11 - 32.11 (Human Nutr Value: Carbohydrates 74%; Fat 3%; Plant Protein 11%; -.) - Yearround Product: Plant residues max prod 500 kg	Data collected for WV-Kenya and collected from Justin, Nakuru, Kenya, around Oct-2017	Approximate record based on interviews with Mrs Nancy Kombol, Mr Justin, etc

Annex 4. References

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[i] See https://en.wikipedia.org/wiki/System_dynamics : The steps involved in a simulation are (1) Define the problem boundary; (2) Identify the most important stocks and flows that change these stock levels; (3) Identify sources of information that impact the flows; (4) Identify the main feedback loops; (5) Draw a causal loop diagram that links the stocks, flows and sources of information; (6) Write the equations that determine the flows (7) Estimate the parameters and initial conditions. These can be estimated using statistical methods, expert opinion, market research data or other relevant sources of information; (8) Simulate the model and analyse results.