Production strategies for integrated livestock and arable farming in Koutiala, Mali

BSc Thesis by Mirjam Breure

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Production strategies for integrated livestock and arable farming in Koutiala, Mali

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Pictures front page:
Harvested cotton (AFD, 2011)
Zébu cattle (USAID, 2011)

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Summary

Mali is one of the largest cotton producers in Africa, but the cotton sector is unstable since the late nineties as a result of decreasing cotton prices. Keeping livestock is profitable and many cotton farmers switch to livestock farming. Different integrated farming strategies are analysed to see which strategy is the most profitable. Each farming strategy involves different areas of land allocated to cotton and cowpea production. Cotton is produced for sale, cowpea for cattle feed. Also, profits for each farming strategy are analysed in case cotton and milk prices fluctuate with 15%. Strategy 2 (cattle is kept in a stable in the hot dry season and is supplemented with cowpea (3 kg $cow^{-1}d^{-1}$), cotton seed cake (2 kg $cow^{-1}d^{-1}$) and crop residues (3 kg $cow^{-1}d^{-1}$), 27% of land is allocated to cotton production, 11% to cowpea production) was most profitable, also when milk and cotton prices fluctuated. Finally it was analysed how livestock herd size changed over time for different farming strategies and how much herd size could grow before pastures were overgrazed. This was 38 years for strategy 0 and 10 years for strategy 3.

Keywords: Mali, cotton, milk, livestock production, herd size, farming strategies

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Introduction

1.1 General background Mali

Mali is situated in West-Africa and is enclosed by Algeria, Niger, Burkina Faso, Ivory Coast, Guinea, Senegal and Mauritania. Mali is divided in eight districts (Figure 1). Tombouctou, Kindal and Gao form the northern part of Mali and Mopti, Ségou, Koulikoro, Kayes and Sikasso the southern part. The capital city is Bamako, which is located in the south of Koulikoro. Bamako has 1.3 million inhabitants (number from 2000; BNETD, 2001). Malian land area is 1,241,238 km^2 (30 times larger than the Netherlands) and population size was 15.3 million heads in 2010 (World Bank, 2011). Not surprisingly, Mali is the least densely populated country in Sub-Saharan Africa (Butt *et al.,* 2006).

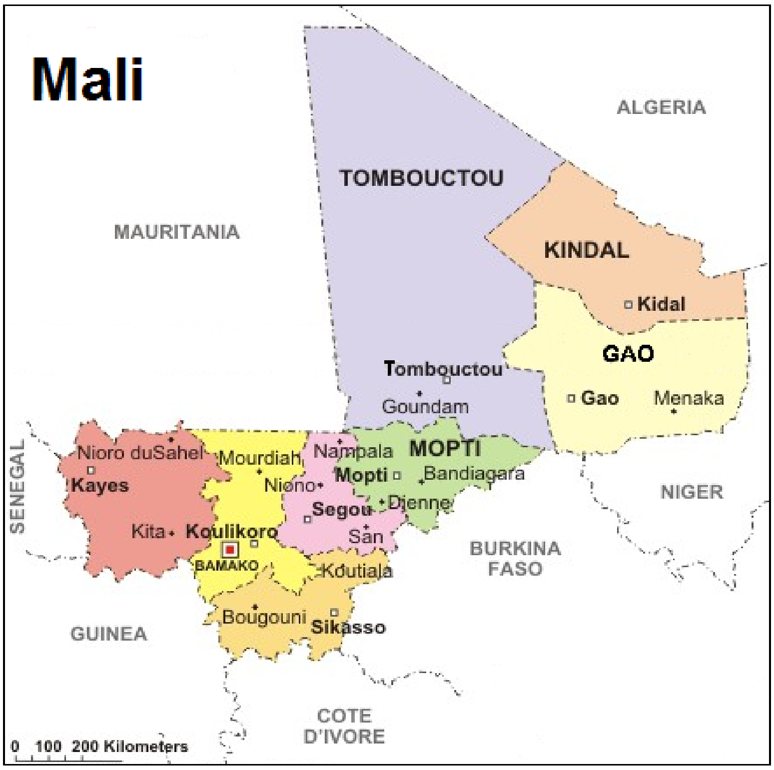

Figure 1: Map of Mali

Because of the size and location, Mali is situated in several climate zones (Bassett and Turner, 2007; Gore and Steeds, 1987):
-The Sahel zone with 200 – 400 mm annual precipitation (south Tombouctou, south Gao)
-The Sahel-Sudan zone with 400 – 600 mm annual precipitation (north Mopti, north Ségou)
-The North Sudan zone with 550 – 850 mm of annual precipitation (Mopti, Ségou, Koulikoro, Kayes)
-The South Sudan zone with 800 – 1000 mm of annual precipitation (Koulikoro, Kayes, north Sikasso)
-The Sudan-Guinean zone with 1000-1200 mm of annual precipitation (south Sikasso)
Because Tombouctou, Kindal and Gao are positioned in the Sahara desert and parts of Mopti and Ségou in the Sahel, over 60% of the area of Mali is arid or hyperarid according to FAO standards (Terrastat, 2011).

Mali has a rainy and a dry season. The dry season consists of a cold dry period (December - February) and a hot dry period (March - May). The temperatures range between 22°C in the cold dry season and 35°C in the hot dry season. The duration of the rainy season depends on the latitude. In the North Sudan zone, the rainy season starts in July and ends in October. In the North Guinean zone, the rainy season also ends in October, but starts in May (Sanogo, 2011).

1.2 Political background and development status

The French colonized Mali in 1890 and left in 1960. After 1960, a socialist economic model was adopted by the state and rural cooperatives emerged. In 1968, a military leader declared himself president but in 1991, student protests resulted in a democratic election system in Mali still used nowadays (Martin *et al.*, 2002). Although French is the official language of Mali, many other local, regional and national languages are spoken in the variety of ethnical groups (Mbodj-Pouye and Van Avenne, 2007). The Bambara is the largest minority in Mali, representing 30% of the Malians and their language is spoken most widely in Mali besides French. Another minority in Mali is the group of Fulani, also called Pheul, which is estimated to be one million people (Rietveld, 2009).

Martin *et al.* (2002) state that 1.5 – 2 million Malians emigrated to other West African countries and more industrialized nations to flee from poverty. Mali is a poorly developed country. The value of the GDP was $9,251,388,617 in 2010, which is 85 times less than the GDP of The Netherlands. The fraction of Malian inhabitants that live below the national poverty line is 47%. Adult literacy was only 26% in 2006, current life expectancy 51 years and mortality rate under five years 18% (World Bank, 2011). On the UN Human Development Index 2010, Mali is ranked 160 out of 169: Mali is one of the poorest countries in the world (UNDP, 2011). Despite the status of low income country, Mali is developing quite fast; Not only does the population size increase annually with 3% since 1993, life expectancy increased from 44 to 51 years from 1990 to 2010 and mortality under five years decreased from 25% to 18% in that same period. Furthermore, the enrolment in secondary education increased from 26% in 2006 to 42% in 2010 (World Bank, 2010). Therefore, Mali is seen as one of the most promising democracies in West Africa (Martin *et al.,* 2002).

1.3 Agriculture

Mali is, like all developing countries, characterized by a large agricultural sector. In 2010, 67% of the total population lived in rural areas. Furthermore, in 2007 the added value of agriculture was 37% of the Malian GDP (World Bank, 2011). Almost two third of Malian land area is covered by the Sahara and Sahel desert, which makes agriculture impossible. The south of Mali is more productive than the arid north. Sikasso is the most productive region, which is due to the duration of the rainy season and the annual precipitation of 800-1200 mm. Besides water limitations, agricultural production is also limited by nutrient inputs. On average 10 kg fertilizer is used per hectare, which is far below the global average of 90 kg/ha (Butt *et al.,* 2006). The most important food crops that are grown in Mali are sorghum, millet and maize. As cash crops, cotton and groundnuts are produced. Agriculture in Sikasso is focused at the two cash crops, where Kayes, Koulikoro, Ségou and Mopti are oriented on cereal production (Butt *et al.,* 2006). The following sections will explain more on livestock and cotton production in Mali.

1.4 Livestock production

Basset and Turner (2007) and Hampshire (2006) explain that the Fulani, a Malian ethnic group, are originally pastoral nomads. They travelled long distances with their cattle to find pastures and water. In the rainy season, herds were located in the green and fertile Sahel zone (central Mali). When the end of the rainy season neared, the Fulani moved their cattle to the humid savannahs in the Sudan-Guinean zone (south Mali) and consumed crop residues on the fields en route, thereby enriching the soils by leaving their manure. This annual migration is known as the transhumance. Due to droughts in ’73 and ’84 and political and economic reasons, the transhumance changed and partly disappeared: Fulani migrated more southwards to the humid areas of the Ivory Coast and Guinea and travelled shorter distances of 10 km with their cattle to nearby pastures and water.

The cattle breed Zébu (*Bos indicus*) was originally used by the Fulani because it was able to walk long distances. This breed is large for tropical cattle breeds and has a relatively good milk production. However, this breed is highly susceptible to the sleeping disease transmitted by the tsetse fly. Tsetse flies are absent in the dry, northern parts of Mali, but are present in the humid Sudan-Guinean zone (Sikasso, Ivory Coast, Guinea). In these zones, the Bambara, a Malian ethnicity which are originally agriculturalist, used the breed N'Dama (*Bos taurus*) for traction on their arable land. N'dama cattle has a small body size, but is resistant to the sleeping disease. When the Fulani migrated to more southern regions, the Bambara encountered the large Zébu cattle of the Fulani, which was more suitable for traction than their small N'Dama. The interaction between the Bambara and Fulani resulted in the cross bred Méré (Ridder, 2011). Méré cattle is resistant to the sleeping disease and has a larger body size than the N'Dama, which makes it suitable for traction. Furthermore, Méré cattle is able to walk long distances. Combined with the resistance to the sleeping disease, the Méré breed has the required characteristics to survive the Fulani transhumance (Bassett and Turner, 2007).

Former mentioned breeds have a low milk production which is due to breed characteristics, poor quality and quantity of feed and insufficient health care. N'Dama and Méré give 1-2 l $cow^{-1}d^{-1}$, Zébu gives twice that amount (Sanogo, 2011). In comparison: the breed Holstein, which is used in temperate climates, can easily produce 30 l $cow^{-1}d^{-1}$ (Roche *et al.*, 2006). Méré cattle is sometimes crossed with a Zébu to increase milk production (Bassett and Turner, 2007). Another characteristic of the Zébu and Méré breeds, is that milk let down must be stimulated by the calf. The farmer decides how much milk is available for the calf and how much milk is sold for human consumption. Calf growth is often limited by the milk availability (Coulibaly and Nialibouly, 1998). Schlecht *et al.* (1998) and Sanogo (2011) have shown that supplementing Zébu and Méré cattle during the dry (but also during the rainy) season drastically increases body weight gain, calve survival, age at death and milk yield. Age of maturity, calving interval and mortality decrease as a result of improved fodder quality.

Total amount of cattle in Mali increased from 5,092,132 heads in 1991 to 7,099,384 heads in 2002 (Ministère de l'agriculture Mali, 2004a). The development in livestock production was accompanied with a development in cotton cultivation. Development in both sectors was a positive result of integrating arable and livestock farming in households (Ba *et al.*, 2011). Despite 7 million heads of cattle, domestic milk demand cannot be met. Average annual milk consumption in Mali is estimated to be 12 kg per person; 60% of this consumption is from imported milk products (Bonfoh *et al.*, 2005).

1.5 Cotton production

Mali is one of the largest cotton producers and exporters in Africa (OECD, 2006; Butt et al, 2006). Cotton is produced in southern Mali (mainly in Koulikoro, Ségou and Sikasso). Information from the Ministère de l'agriculture (2004b) shows that the cotton production regions cover 134,518 km^2 and comprise 6345 villages with a population of 3.2 million people. The cotton sector is seen as a driving factor for development and plays a vital role in the fight against poverty. Cotton is cultivated for the production of cotton lint (used in textiles) and also for the production of cotton seed. Cotton seed has a high nutritional value and is processed to cotton seed cake, which is used as animal feed.

In 1974 the Malian Textile Development Company (CMDT) was established with the help of the French Textile Development Company (CFDT). The CFTD owned 40% of the CMDT, the other 60% was owned by the Malian government. The CMDT is responsible for the entire cotton production chain in Mali. The missions of the CMDT are:

-To give agricultural advices to cotton farmers

-To collect, market and gin cotton seed

-To produce and sale cotton lint for export and for Malian textile companies

The CMDT has a cotton monopsony; all cotton produced in Mali is bought by the CMDT. Besides the cotton sector, the CMDT invested in social projects like schools, health centres and water points (Ministère de l'agriculture Mali, 2004b). In the past, the CMDT linked cotton prices to production costs and subsidised farmers in this way to keep the cotton sector vivid (OECD, 2006). The CMDT sold cotton directly to the world market until 2004, but after the cotton price crisis from 1998 to 2001, it decided to link the cotton price to world prices. As a result, the price paid to farmers decreased with 24% in 2005 (Baquedano *et al.*, 2010). After the introduction of the new price system, the CMDT abandoned the social projects and was privatised in 2008 (OECD, 2006).

The first three decades after independence in 1960 were the 'golden age' for the cotton sector. The Malian government heavily invested in the sector and with the help of research and input credits, seed cotton yields increased from 0.4 ton ha^{-1} in the sixties to 1.3 ton ha^{-1} in the eighties (Baquedano *et al.*, 2010). Due to the devaluation of the Malian currency in 1994, the cotton sector was booming and cotton was known as the 'white gold' (Delarue, 2009). However, due to increased production costs and the collapsed cotton price as a result of US subsidies to American cotton farmers, a cotton crisis emerged in 1999 in West Africa (Vitale *et al.*, 2009). West Africa recovered from this crisis in 2002 and in 2006 a price stabilisation fund was established by the Malian government. This fund guaranteed a minimum price of 0.32$ kg^{-1} and a maximum price of 0.35$ kg^{-1} to cotton farmers in the past years since 2006 (Baquedano *et al.*, 2010; Delarue *et al.,* 2009).

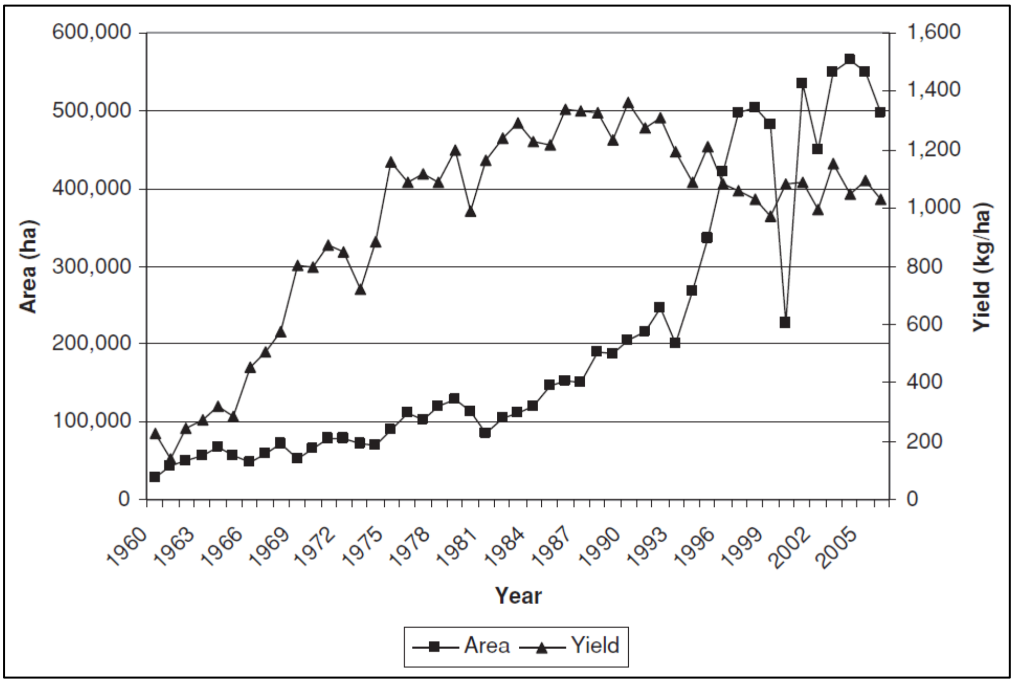

Figure 2: Cotton area (ha) and cotton yield (kg ha^{-1}) from 1960 to 2007 in Mali. (Vitale *et al.*, 2009)

As can be seen in Figure 2, cotton yields increased until the eighties as a result of research and input credits. This governmental support disappeared and cotton yields slightly declined in the early nineties. The area of cotton increased in the mid-nineties as a result of the devaluation of the CFA Franc. The annual added value of cotton was as high as 5-10% of the GDP (FAO, 2003). Due to the cotton crisis in 1999, the cotton area rapidly decreased, but recovered quickly in 2002. The international cotton market improved since 2007: US cotton production declined by 44% and exports by 26% from 2005-2008 (Baquedano *et al.*, 2010). However, Mali was not able to profit from this situation due to the instability of the CMDT. As a result, a third of the farmers abandoned the cotton sector since 2005 (Delarue, 2009) despite the price stabilisation fund. In 2003 a cotton yield of 620,000 tonnes was produced, this declined to 261,000 tonnes in 2010 (CountryStat, 2011).

1.6 Future challenges

Two major shifts in Malian agriculture occurred in the past two decades: arable farmers became livestock keepers as a result of the introduction of animal traction and the area under cotton production diminished, due to insecurities in the cotton sector. Nowadays, many farmers choose for cotton production in combination with animal husbandry to provide a more stable income. Not only does the livestock provide traction, it also produces milk, manure and meat making it an additional source of income. Besides that, milk provides a daily income instead of an annual income. Furthermore, feed supplements drastically increase livestock production, which makes animal husbandry a sector with a lot of potential.

The leguminous cow pea (*Vigna unguiculata*) is a low costs crop which is able to grow on a nitrogen-poor soil. It is known for its' high protein content of 20-25%, which is twice the protein content of cereals (Dovlo *et al.,* 1976). It grows well in West-Africa and the peas are eaten by the population. The leafage can be used as green manure for other crops, but is also suitable as a high quality feed supplement for cattle. Farm area is limited, thus when cow pea is produced for fodder, it is at the expense of cotton production. In the integrated livestock and arable farming in Mali a certain farming strategy has to be applied to optimise total farm revenues. Each farming strategy is related to the distribution between cotton and cow pea area. The first research question is:
Which farming strategy for cotton and milk production has the highest revenues?

Milk and cotton prices do not stay constant, they fluctuate over time. To analyse changes in product prices, the following question is asked:
How do the annual farm revenues change, if milk and cotton prices vary?

Furthermore, it was shown in chapter 1.4 that supplementing cattle not only increases production, but also reproduction. The area of pastures is limited, meaning livestock numbers cannot grow infinitely. The following research questions are asked to analyse livestock growth:
How much can the livestock herd size of Try increase without exhausting pastures?
Within how many years is this livestock herd size reached?

2. Material and Methods

In this research, data from Sanogo (2011) is analysed to answer the research questions.

2.1 Site description

Sanogo has conducted his research in the villages Try and N'Goukan, which are located in the area of Koutiala (Sikasso district) in Mali. The characteristics of Try and N'Goukan are presented in Table 1**.** These villages are located in the South Sudan climate zone with 800 mm of rainfall per year, of which most falls in the rainy season which start in July and ends in October. Daily average temperature ranges between 22°C (cold dry period) and 35°C (hot dry period).

Table 1: Characteristics of the villages Try and N'Goukan
Data from Table 1, chapter 3 from Sanogo (2011), translated from French.

Characteristic	Try	N'Goukan
Village area (ha)	3,887	793
Cultivated area (%)	39	68
Area pastures (ha)	2000	90
Inhabitants (number)	2,251	847
Farms (number)	126	45
Average farm size (ha)	12	12
Cattle (number)	1124	726
-Cows	557	522
-Steers	567	204

In these villages, keeping livestock is the second source of income after cotton. Besides livestock and cotton, maize, millet, sorghum, peanuts, legumes and other crops are cultivated. Sanogo (2011) has classified the farms of Try and N'Goukan in 4 classes, of which the characteristics are presented in Table 2. The large farms (13% of the total number of farms) and medium farms (69%) are characterised by a large share of cotton area, which reflects their market orientation. The small farms (18%) mainly cultivate cereals for home consumption.

Table 2: Characteristics of farm classes 1 ,2, 3 and 4.
After table 1, chapter 5 from Sanogo (2011), translated from French.

Characteristic	Class 1 Large farms	Class 2 Medium farms	Class 3/4 Small farms
Family size	21	16	7
Number of labourers	20	11	3
Livestock herd size	57	15	3
Number of lactating cows	**4**	**2**	**1**
Farm size (ha)	18	11	5
Area cotton (ha)	**7**	**4**	**1.8**
Area maize (ha)	2.3	1	0.3
Area millet (ha)	4.4	3	1.6
Area sorghum (ha)	3	2	1
Area peanuts (ha)	0.5	0.6	0.2
Area leguminous crop (ha)	0.7	0.2	0
Area other crops (ha)	0.1	0.2	0.1

2.2 Treatments

Sanogo (2011) applied three different treatments (feeding strategies) in his research to see how milk production varied as a consequence of amount and type of feed consumed. The breed of cow used in this experiment is Méré, which gives 1-2 litres of milk per day. This production can increase op to 6 l $cow^{-1}d^{-1}$, depending on the feeding strategy.

The different feeding strategies are:

(0) Control strategy. Grazing the entire year on community pastures with supplements in the hot dry season, consisting of crop residues (2 kg $cow^{-1}d^{-1}$) and cereal bran (1 kg $cow^{-1}d^{-1}$).

(1) Restricted grazing. Grazing the entire year on community pastures with supplements in the hot dry season, consisting of cotton seed cake (2 kg $cow^{-1}d^{-1}$) and cowpea (2 kg $cow^{-1}d^{-1}$).

(2) Restricted kept in stable. Cattle is kept in the stable in the hot dry season and is supplemented with cowpea (3 kg $cow^{-1}d^{-1}$), cotton seed cake (2 kg $cow^{-1}d^{-1}$) and crop residues (3 kg $cow^{-1}d^{-1}$).

(3) Permanently kept in stable. Cattle is kept in the stable during the entire year and is supplemented with cowpea (3 kg $cow^{-1}d^{-1}$), cotton seed cake (2 kg $cow^{-1}d^{-1}$) and crop residues (4 kg $cow^{-1}d^{-1}$).

The grazing occurs on three types of pastures. Pasture 1 and 2 consist of different grass species (table 5, chapter 4 from Sanogo, 2011). The feed from crop land (pasture 3) is the aftermath grazing of crop residues.

To provide the cattle with cowpea, an area of land needs to be converted to cowpea cultivation. Therefore, each different feeding strategy also means a different farming strategy. In Table 3 the shares of cowpea and cotton for each farming strategy per class are given. For strategy 0, no cowpea is required, therefore no land is allocated to cowpea production. The share of cowpea is increasing from strategy 1 to strategy 3. The increasing area of cowpea is at the expense of the area allocated to cotton production.

Table 3: Share of cowpea and cotton for each farming strategy.
After table 6, chapter 5 from Sanogo (2011), translated from French.

Class	Strategy	Cowpea share (%)	Cotton share (%)
1 18 ha	0	0	39
	1	4	35
	2	11	27
	3	35	4
2 11 ha	0	0	36
	1	3	33
	2	9	27
	3	28	8
3/4 5 ha	0	0	34
	1	3	31
	2	10	24
	3	31	3

2.3 Analysis

Using a simulation model called LIVSIM, Sanogo (2011) has analysed the effects of the different strategies on mortality, body weight gain, milk production, number of calves, calving interval and live expectancy of cattle. Furthermore, he calculated the revenues from cotton and milk production for each strategy. His results are the starting point of this research. Below, the more detailed material and methods for each research question are given.

Which farming strategy for cotton and milk production has the highest revenues?
Figure 2 and table 6 (chapter 5) from Sanogo (2011) will be used to answer this research question. This analysis will be done for class 1 and 2. Class 3 and 4 are excluded from this research because the primary goal of agriculture in this class is self-sufficiency. Agriculture in class 1 and 2 is market oriented.

How do the annual farm revenues change, if milk and cotton prices vary?
Figures 2 and 3 and tables 4, 5 and 6 (chapter 5) from Sanogo (2011) will be used. This analysis will be done for class 1 and 2 for all farming strategies. Sanogo varied the milk price in his analysis with 15% at a stable cotton price. The average decrease in world cotton price from 1982 to 2009 was 13.3%. In other years there was an increase in world cotton price, on average 19.7% (calculated from Indexmundi, 2011). Therefore, in this analysis the varying milk price will be combined with a varying cotton price of 15%.

The revenues per hectare of cotton are calculated in table 4 (chapter 5) from Sanogo. The revenues of milk (per cow) per feeding strategy are calculated in table 5 (chapter 5). The data from these tables will be integrated to create a balance which shows the total revenues per feeding strategy for both classes. After this balance has been completed, the milk and cotton prices will be varied according to the scenarios described in Table 4. This balance and these calculations will be made in Microsoft Excel.

Table 4: Different scenarios for fluctuating cotton and milk prices

Scenario	Cotton price	Milk price
1	-15%	-15%
2	-15%	Equal
3	-15%	15%
4	Equal	-15%
Base scenario	Equal	Equal
5	Equal	15%
6	15%	-15%
7	15%	Equal
8	15%	15%

The total revenues for each scenario will be analysed and the research question will be answered with the help of these sub questions:
- For which farming strategy are the revenues most stable with varying milk and cotton prices?
- Does the most profitable feeding strategy change for different price scenarios?

How much can the livestock herd size of Try increase without exhausting pastures?

Within how many years is this livestock herd size reached?
Table 1 (chapter 3), tables 5 and 8 (chapter 4) and original data from Sanogo (2011) will be used.

Sanogo has determined how much fodder from pastures is consumed per TLU-[1], either by grazing or by the cut-and-carry system (table 5, chapter 4). Grazing from cropped land (pasture 3) is excluded from the feed consumption of pastures. Together with original data from Sanogo (2011) on production quantities of the pastures in Try, the carrying capacity of the pastures can be determined, meaning: the maximum number of cattle that can graze on these pastures. In this calculation, goats, sheep and other grazers are excluded. The carrying capacity will be calculated for farming strategy 0 and 3. Grazing pressure in the village N'Goukan is currently 0.1 ha TLU^{-1} (table 1, chapter 3), meaning that pastures are already being exhausted and that livestock is going on transhumance to the south during harsh periods. Therefore, the livestock of N'Goukan is excluded from the carrying capacity analysis.

A model will be made to calculate livestock herd size as a function of time. This model will be made in Microsoft Excel. The variables of this model will be calculated with original data from Sanogo (2011), as well as tables 5 and 8 (chapter 4) from Sanogo (2011). It is assumed that the livestock population shows exponential growth. Livestock herd size will be calculated for the case that all offspring is added to the herd (no culling) and no livestock is bought elsewhere. This model is able to calculate within how many years the livestock herd size exceeds the carrying capacity of the pastures. This will be calculated for feeding strategies 0 and 3.

[1] TLU (Tropical Livestock Units) is a unit which expresses livestock size in relation to a common unit. 1 TLU is one head of cattle with a body weight of 250 kg or 10 sheep with a weight of 25 kg (FAO, 2011). A Zébu or Méré is 1 TLU.

3. Results

3.1 Annual farm revenues per farming strategy

Table 5 and Figure 3 show that revenues of the milk production increases from strategy 0 to strategy 3. The revenues of cotton production, show a decrease from strategy 0 to strategy 3. This causes fluctuations in the total[2] annual farm revenues. For class 1, total revenues are $876 for farming strategy 0 which increases to $924 for strategy 2 and decreases to $721 for strategy 3.
A similar trend is visible for class 2, however, farm revenues are lower due to the smaller farm size in this class. For farming strategy 2, total revenues are $402 for strategy 2.

Table 5: Total annual farm revenues per farming strategy for a milk price at farm gate of $0.38/L (After Table 6 from Chapter 5 from Sanogo (2011), translated from French)

Class	Farming strategy	Contribution of lactating cows total revenues (US$)	Contribution of cotton to total revenues (US$)	Total annual farm revenues (US$)
1 (18 ha)	0	356	521	876
	1	421	469	891
	2	557	367	924
	3	666	55	721
2 (11 ha)	0	178	168	346
	1	211	154	364
	2	278	124	402
	3	333	33	366

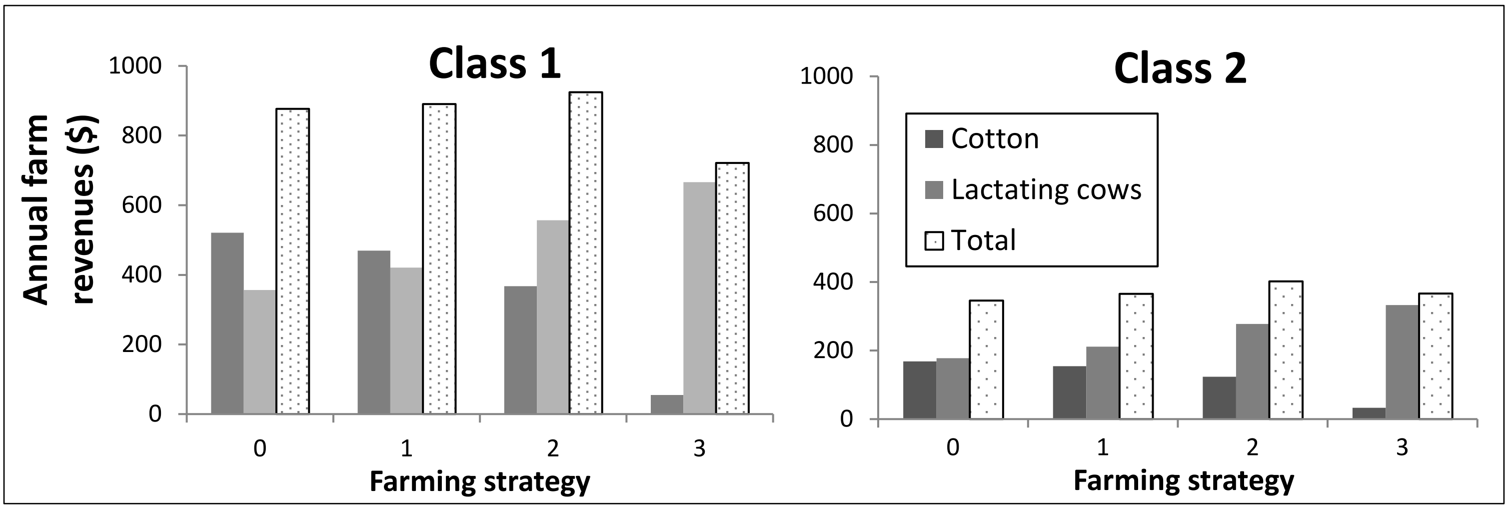

Figure 3: Total annual farm revenues per farming strategy for a milk price at farm gate of $0.38/L. (After Figure 2 from Chapter 5 from Sanogo (2011), translated from French)

[2] With 'total annual farm revenues' is meant the addition of the revenues from the lactating cows and the revenues from cotton production. In reality, besides cotton and milk, other activities also generate income, but these are excluded in this research.

3.2 Annual farm revenues in different price scenarios

After varying milk and cotton prices with 15%, total annual farm revenues are calculated. Table 6 shows that total annual farm revenues are highly variable and the most profitable farming strategy differs per price scenario. Depending on farming strategy and price fluctuations, farm revenues can be as low as $455 or as high as $1303 for class 1. For class 2 absolute variation in farm revenues is smaller; it can be as low as $138 or as high as 574.

Table 6: Total annual farm revenues (US$) per farming strategy for each price scenario. Bold numbers indicate the most profitable farming strategy in each price scenario.

Scenario	Cotton price	Milk Price	Revenues Class 1 ($) 0	1	2	3	Revenues Class 2 ($) 0	1	2	3
1	-15%	-15%	455.44	489.32	**584.40**	571.08	138.89	165.53	228.44	**273.52**
2	-15%	Stable	470.44	526.52	636.00	**683.88**	146.39	184.13	254.24	**329.92**
3	-15%	+15%	485.44	563.72	687.60	**796.68**	153.89	202.73	280.04	**386.32**
4	Stable	-15%	864.40	852.20	**872.40**	611.40	337.20	343.50	**375.90**	314.20
Base line	Stable	Stable	879.40	889.40	**924.00**	724.20	344.70	362.10	**401.70**	370.60
5	Stable	+15%	894.40	926.60	**975.60**	837.00	352.20	380.70	**427.50**	427.00
6	+15%	-15%	**1273.36**	1215.08	1160.40	651.72	**535.52**	521.48	523.37	354.88
7	+15%	Stable	**1288.36**	1252.28	1212.00	764.52	543.02	540.08	**549.17**	411.28
8	+15%	+15%	**1303.36**	1289.48	1263.60	877.32	550.52	558.68	**574.97**	467.68
Revenues		Max	1303.36	1289.48	1263.60	877.32	550.52	558.68	574.97	467.68
		Min	455.44	489.32	584.40	571.08	138.89	165.53	228.44	273.52
Revenues		Range	847.92	800.16	679.20	306.24	411.63	393.15	346.53	194.16

Farming strategy 3 has the smallest range in farm income: the difference between minimum and maximum farm revenues is $306 for class 1. Farming strategy 0 provides the least stable income, because the range is $847 for class 1. Total annual farm revenues for class 1 and 2 show a similar trend: the smallest range in farm revenues for class 2 is also strategy 3 ($194), strategy 0 has de largest range ($411).

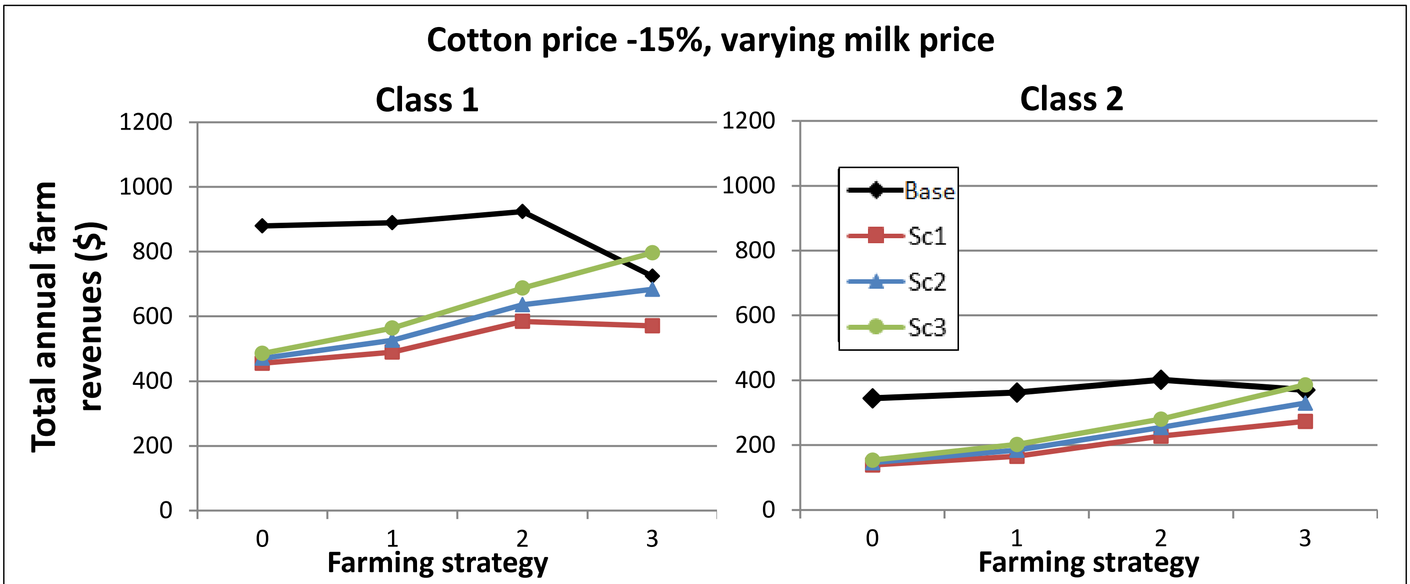

Figure 4: Total annual farm revenues ($) in case of a cotton price of -15%. (Base = stable cotton and milk price; Sc1 = milk price -15%; Sc2 = stable milk price; Sc3 = milk price +15%)

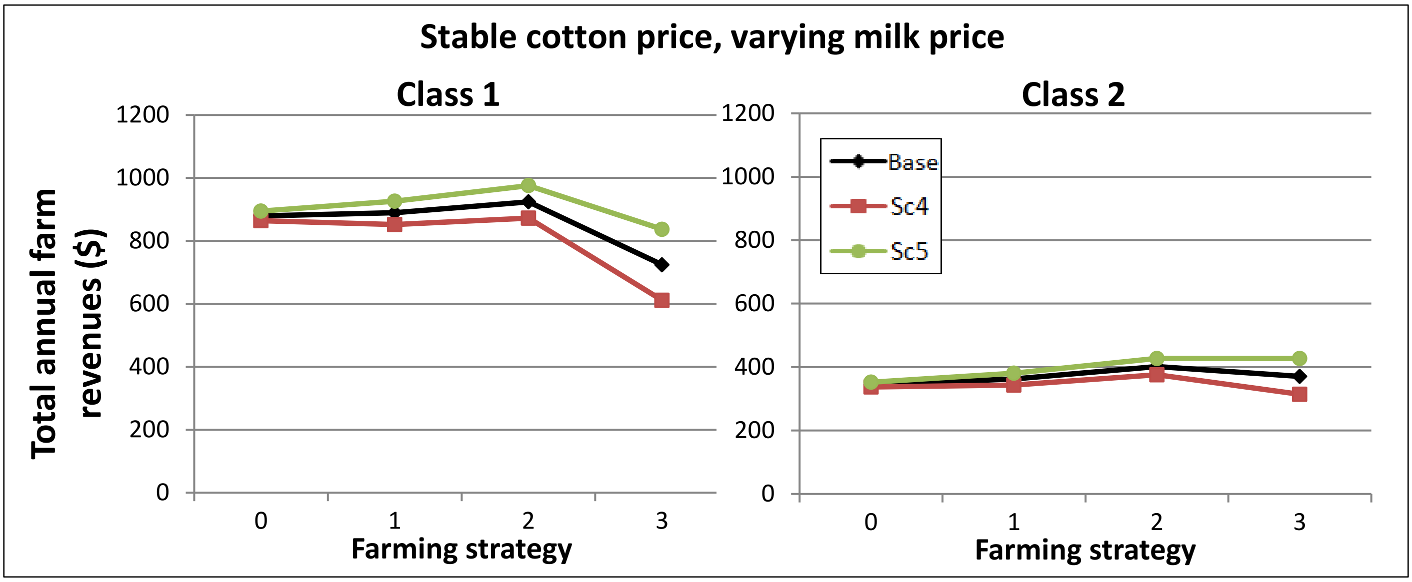

Figure 5: Total annual farm revenues ($) in case of a stable cotton price.
(Base = stable cotton and milk price; Sc4 = milk price -15%; Sc5 = milk price +15%)

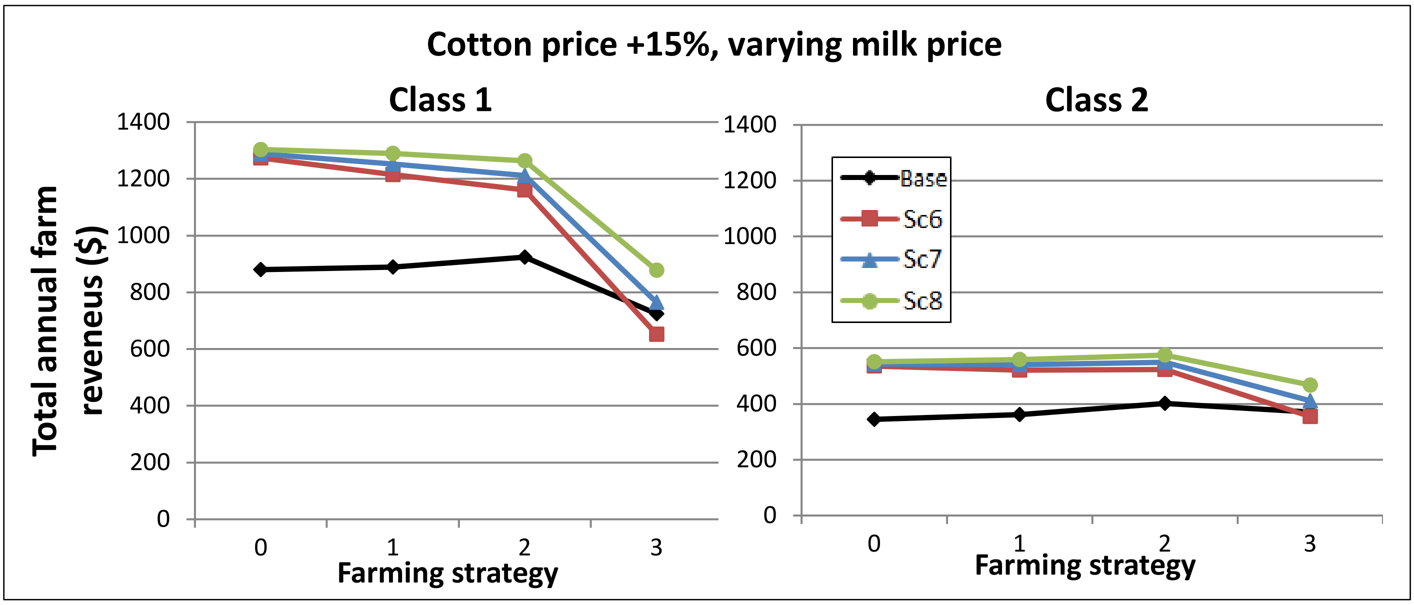

Figure 6: Total annual farm revenues ($) in case of a cotton price of +15%.
(Base = stable cotton and milk price; Sc6 = milk price -15%; Sc7 = stable milk price; Sc8 = milk price +15%)

Figure 4, Figure 5 and Figure 6 show that the difference in farm income in case cotton prices fluctuate between -15% and +15% is $817,92 (Class 1, strategy 0). This influence of cotton price fluctuations is greatest for strategy 0 and decreases with strategy 1 and 2. Strategy 3 is least influenced by the varying cotton price (income difference is $80 for Class 1). Annual farm revenues of class 2 respond similar to cotton price fluctuations as farm revenues of class 1. However, absolute revenue fluctuations are smaller as a consequence of smaller overall farm revenues.

Farm revenue fluctuations as a result of varying milk prices are small compared to fluctuations caused by varying cotton prices. The difference in farm income for class 1 in case milk prices fluctuate between -15% and +15% is $15 (strategy 0), increasing to $112 (strategy 3).
The difference in farm income for class 2 in case milk prices fluctuate between -15% and +15% is $7.50 (strategy 0), increasing to $56 (strategy 3).

3.3 Carrying capacity of pastures in Try

Feeding strategy 0

The pastures in Try together produce around 6.5 million kg dry matter (DM) per year. For feeding strategy 0, the requirements for feed from pastures are 2,568 kg DM per year per TLU. This results in a carrying capacity of little more than 2,500 TLU (Table 7).

Table 7: Calculation carrying capacity of pastures in Try for farming strategy 0. Data pasture productivity and area is from original data from Sanogo (2011). Data feed requirements from pastures is from Sanogo (2011; table 5, chapter 4).

Productivity Pasture 1	2900	kg DM ha^{-1} yr^{-1}
Productivity Pasture 2	3580	kg DM ha^{-1} yr^{-1}
Area Pasture 1	1,050	ha
Area Pasture 2	950	ha
Productivity pastures	**6,446,000**	**kg DMyr^{-1}**
Feed required Pasture 1	1,566	kg DM TLU^{-1} yr^{-1}
Feed required Pasture 2	1,001	kg DM TLU^{-1} yr^{-1}
Total	**2,568**	kg DM TLU^{-1} yr^{-1}
Carrying capacity pastures	**2,510**	**TLU**

Farming strategy 3

The productivity of the pastures stays equal, but the feed requirement from pastures per TLU decreases from 2,568 kg DM for strategy 0 to 1,440 kg DM for strategy 3 (Table 8). This results in a higher carrying capacity of 4,476 TLU for strategy 3. Sanogo (2011) does not define from which pasture the required feed for strategy 3 is harvested, therefore it is assumed that a mixture of grass from Pasture 1 and Pasture 2 is offered to the cattle.

Table 8: Calculation carrying capacity of pastures in Try for farming strategy 3. Data pasture productivity and area is from original data from Sanogo (2011). Data feed requirements from pastures is from Sanogo (2011; table 5, chapter 4).

Productivity Pasture 1	2900	kg DM ha^{-1} yr^{-1}
Productivity Pasture 2	3580	kg DM ha^{-1} yr^{-1}
Area Pasture 1	1,050	ha
Area Pasture 2	950	ha
Productivity pastures	**6,446,000**	**kg DM yr^{-1}**
Feed required Pastures	1440	kg kg DM TLU^{-1} yr^{-1}
Total	**1440**	**kg** kg DM TLU^{-1} yr^{-1}
Carrying capacity pastures	**4,476**	**TLU**

3.4 Livestock herd size model

The livestock simulator from Sanogo (2011) runs a simulation of 1000 cows and displays how many calves a cow can give birth to. To calculate population size, the model is split up in two parts. The first part consists of the population size of cows, which shows exponential growth. The second part of the model is the population size of the steers, which does not show exponential growth, for steers do not reproduce. The population size of male calves in this model is given as a function of the population size of cows. The population size of cows and of steers together is the total livestock herd size.

The model for population size is:
$x(t) = b * g^{t/c} + f * b * g^{t/c} + y(t)$
$y(t) = a - d * t$

In which:
x = livestock herd size at time t (# cattle); Herd at t=0 is assumed to consist of cattle of all ages.
t = time (year)
b = number of cows at t=0
g = growth factor in time c (# female calves cow^{-1})
c = generation time (year)
f = ratio male calves/female calves (die heb je dus op 1 staan?)

y = number of steers at time t
t = time (year)
a = number of steers at t=0
d = number of deaths per time unit (# steers yr^{-1})

The y(t) function is included in the model to correct livestock herd size for steers present at time t=0. Although they do not contribute to the growth of the population, they are present and require feed from the pastures. As time progresses, these steers will die and y(t) will become 0. y(t) cannot be a negative number and is assumed to decrease linearly.

Livestock herd size model for strategy 0
First the generation time of the population (c) will be calculated. Generation time is the average time between equal development stadia of two following generations. In practice this is calculated as the age at which the middle calve is born (Kroon *et al.*, 2009).
Original data from Sanogo (2011) shows that for strategy 0, a cow gives birth to her first calve on average at t=5.9 and has on average given birth to 3.316 calves at the end of her life. The average time between two calves is 1.59 year. The age at which the middle calve is born, can therefore be calculated as 5.9 + 1.59 * (3.316/2 -1) = 6.94. The -1 in this calculation is included to correct for the fact that at t=5.9 already 1 calve is born. Generation time (c) is 6.94 years.

Secondly, the growth factor of the population of cows (g) is calculated. Table 9 shows that 1000 cows give birth to 3316 calves of which 42.3% dies. 1269 female calves and 645 male calves survive. The growth factor of cows is 1269 female calves/1000 cows = 1.269 female calves/cow.

Try has a population of 557 cows, cow population size is therefore represented by:
$x_{cow}(t) = 557 * 1.269^{t/6.94}$

Table 9: Numbers of offspring, start population is 1000 cows. (D1- D5 = Daughter 1 - Daughter 5, S1- S5 = Son 1 - Son 5)

Cow	Occurrences (# cattle)	Fraction Dead	Survival (# cattle)	SUM
D1	814	0.4054	484	**SUM D 1269**
D2	524	0.1183	462	
D3	244	0.0533	231	
D4	75	0.0400	72	
D5	20	0.0000	20	
S1	827	0.7533	204	**SUM S 645**
S2	498	0.5301	234	
S3	233	0.4034	139	
S4	68	0.1765	56	
S5	13	0.0769	12	
Total	**3316**	**0.423**	**1914**	**1914**

Data is simulated output from Sanogo (2011), original data.

Table 9 shows that male offspring mortality is higher than female offspring mortality. Although both sexes are born in equal numbers, almost two times more female than male calves survive. The ratio of male calves/female calves (f) is 645/1269 = 0.508. The formula for steer population size is:
$x_{steer}(t) = 0.508 * 557 * 1.269^{t/6.94}$

At time t=0, Try has a population of 567 steers, which is assumed to consist of animals of all ages. The maximum age of these animals is 12 years (original data from Sanogo, 2011). The number of deaths per time unit (d) is therefore calculated as 567/12 = 47.25 steers/year. The number of steers present at t=0, at time t is:
$y(t) = 567 - 47.25t$ for t=0 to t=12.

The model to calculate livestock herd size for farming strategy 0 is:
$x(t)\ x_{cow}(t) + x_{steer}(t) + y(t) =$
$x(t) = 557 * 1.269^{t/6.94} + 0.508 * 557 * 1.269^{t/6.94} + 567 - 47.25t_{0\text{-}12} =$
$x(t) = 1.508 * 557 * 1.269^{t/6.94} + 567 - 47.25t_{0\text{-}12} =$
$x(t) = 840.11 * 1.269^{t/6.94} + 567 - 47.25t_{0\text{-}12}$

The first part of this formula suggests that at t=0 start population of the model is 840 (+567) cattle. This is not the case, because at time t=0, start population is 557 cows. However, steers are present, their number is set to 0 in the model. According to the ratio of surviving calves, at t=0 283 steers should be present. This number is the difference between the start population of 557 cows and 840 steers + cows in the model. From t=1, the formula displays the correct livestock herd size.

Livestock herd size model for strategy 3

The values of the variables of the livestock model for strategy 3 are calculated in the same way as for strategy 0. Livestock reproduction is much higher for strategy 3: a cow has on average 5.07 calves of which half is male, half is female and calve mortality is 0% for both sexes. Because the cows give birth to calves over a longer period than cows in strategy 0, generation time is larger. The livestock herd size model for farming strategy 3 is represented as:
$x(t) = 557 * 2.52^{t/7.27} + 1.013 * 557 * 2.52^{t/7.27} + 567 - 47.25t_{0\text{-}12}$
$x(t) = 2.013 * 557 * 2.52^{t/7.27} + 567 - 47.25t_{0\text{-}12}$
$x(t) = 1121.29 * 2.52^{t/7.28} + 567 - 47.25t_{0\text{-}12}$

3.5 Livestock growth and grazing pressure

The carrying capacity of the pastures is reached when:
$x(t) = 840.11 * 1.269^{t/6.94} + 567 - 47.25t_{0\text{-}12} = 2510$ (strategy 0)
$x(t) = 1121.29 * 2.52^{t/7.28} + 567 - 47.25t_{0\text{-}12} = 4476$ (strategy 3)

The carrying capacity for farming strategy 0 is reached when t = 31.88 years.
The carrying capacity for farming strategy 3 is reached when t = 10.80 years.

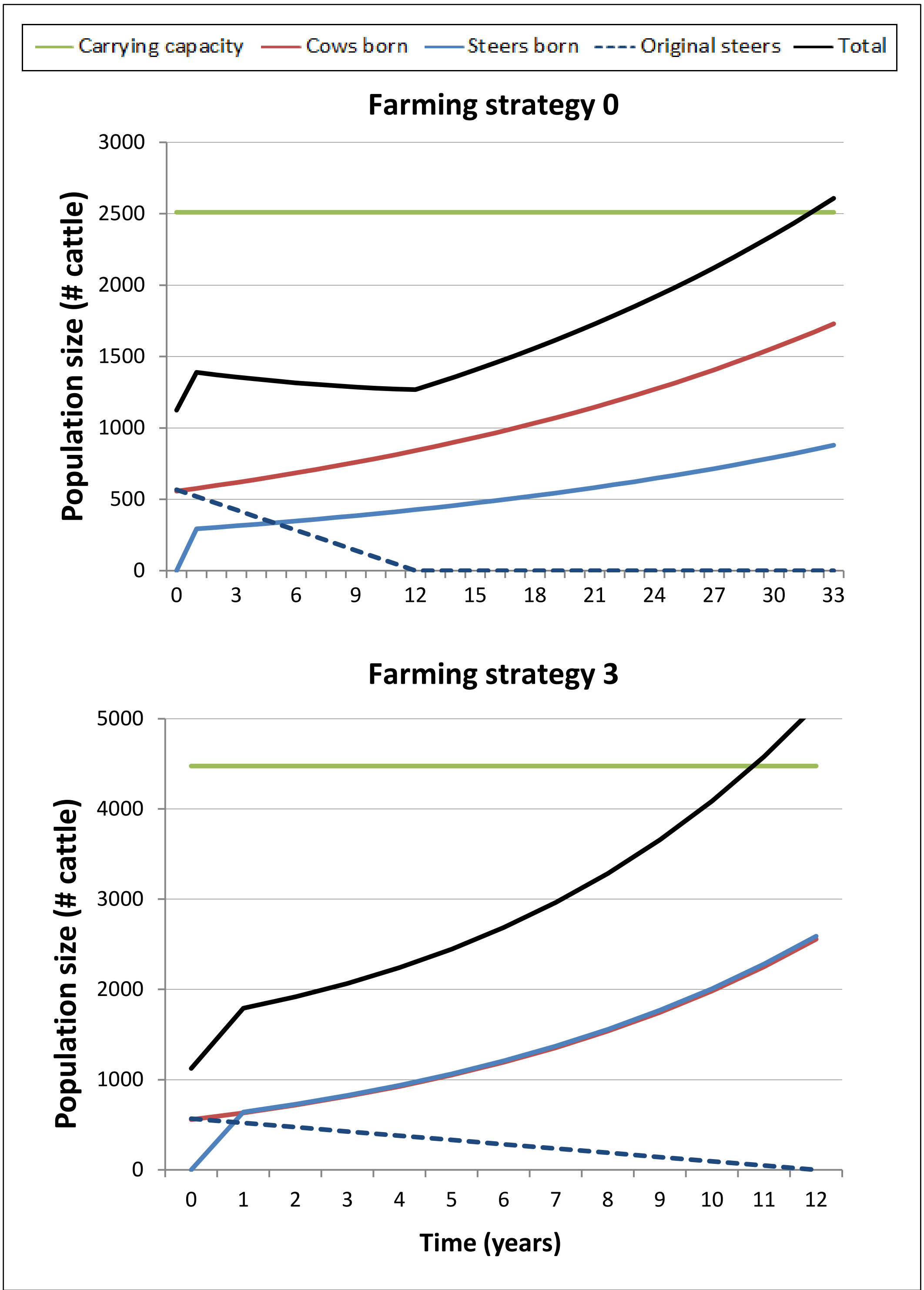

Figure 7: Livestock herd size as a function of time for farming strategy 0 and 3.

Figure 7 shows livestock herd size and carrying capacity of the pastures. If farming strategy 0 is applied, after 32 years the carrying capacity of 2510 TLU is reached. With farming strategy 3, carrying capacity is reached within 11 years, despite the higher carrying capacity of 4476 TLU. The differences between the two farming strategies in livestock growth are clearly visible; not only is the growth rate of the livestock much higher for farming strategy 3, also the distribution of the sexes of surviving calves is equal. Farming strategy 0 on the contrary, has a unequal distribution: male calve mortality is almost three times higher than female calve mortality.

The decrease of total livestock herd size for strategy 0 from t=0 to t=12 is due to the number of dying original males. The growth of the population does not compensate this loss.

The kink in graphs of both farming strategies is due to the discrepancy between simulated number of steers at t=0 and the set number of steers.

4. Discussion and Conclusions

4.1 Discussion

Which farming strategy for cotton and milk production has the highest revenues?
Table 5: Total annual farm revenues per farming strategy for a milk price at farm gate of $0.38/L (After Table 6 from Chapter 5 from Sanogo (2011), translated from French) and Figure 3 show that for both class 1 and 2 farming strategy 2 has the highest total annual farm revenues, which are $924 and $402 respectively. Although strategy 3 in class 1 has the lowest total revenues, for class 2 this is not the case. This is due to the lower cotton revenues per hectare for class 2 (see Box 1). This explains why strategy 0 and 1 have lower total revenues than strategy 3 in class 2; they include a larger area of cotton. Farmers are recommended to apply farming strategy 2 for optimal farm revenues. For class 1 this means that an area of 5 hectare is allocated to cotton production and 2 hectares is allocated to cowpea production to feed 4 (Table 2) lactating cows.
For class 2 this means that 2.9 hectares of cotton are cultivated and 1.6 hectares is allocated to cowpea production to feed 2 (Table 2) lactating cows.

How do the annual farm revenues change, if milk and cotton prices vary?
- For which feeding strategy are the revenues most stable with varying milk and cotton prices?
- Does the most profitable feeding strategy change for different scenarios?
Total annual farm revenues are highly variable, due to the fluctuations of both milk and cotton revenues**.** Table 6, Figure 4, Figure 5 and Figure 6 clearly show that total annual farm revenues are most dependent on cotton prices: the maximum difference in farm income when cotton prices fluctuate between -15% and +15% is $817,92 (Class 1, strategy 0). In comparison, the maximum difference in farm income in case milk prices fluctuate between -15% and +15% is $112.80 (class 1, strategy 3). Therefore, the strategy with the smallest area of cotton provides the most stable income if milk and cotton prices fluctuate. For both class 1 and 2 this is strategy 3 (only 4% of the farm area of class 1 is allocated to cotton production in this strategy, for class 2 this is 8% (Table 1)).

Because total annual farm revenues are largely dependent on cotton prices, the most profitable strategy changes for different price scenarios. In general for class 1, if cotton prices decrease with 15%, it is more profitable to change towards a strategy with a large share of cowpea area and a small share of cotton area (strategy 3). If cotton prices increase with 15%, the strategy with the largest share of cotton is most profitable. The most profitable scenario is therefore dependent on the cotton price. For class 1, strategy 2 is in 4 out of 9 scenarios the most profitable.

Class 2 shows a different picture. Because the production (and therefore revenues) per hectare of cotton are lower than for class 1 (see Box 1), total revenues are less dependent on cotton prices. When cotton prices decrease with 15%, strategy 3 is most profitable, like in class 1. However, in contrary to class 1, if cotton prices increase with 15%, strategy 0 (with the largest area of cotton) is not the most profitable, it is only most profitable in combination with a decreased milk price. Although revenue differences between the strategies are very small, strategy 2 is even with a high cotton price the most profitable farming strategy. For class 2, farming strategy 2 is in 5 out of 9 scenarios most profitable, therefore this strategy is recommended.

To define which farming strategy should be used, a consideration has to be made. On the one side there is a lot of risk, but in return revenues can be very high. On the other side, there is a stable income, but relatively low revenues. Assuming that all price decreases occur as much as price increases, the control scenario should represent the average of all scenarios. In this case, farming strategy 2 should be most profitable on the long term, for both class 1 and 2.
Further research should clarify if price increases indeed occur as much as decreases.

Box 1: Intermezzo

Why are cotton revenues lower in class 2 than in class 1?

During the analysis, cotton revenues appear to be much lower in class 2 than in class 1, which is due to the smaller area allocated to cotton production. But there is more: cotton revenues for class 1 are $74 per hectare, for class 2 only $43, although production costs are lower for class 2 (table 4, chapter 5 from Sanogo, 2011). The large difference in revenues is caused by a difference in production. Farmer from class 2 produce 975 kg cotton ha^{-1}, but farmers from class 1 can produce up to 1100 kg cotton ha^{-1}. Table 4 from chapter 5 from Sanogo (2011) shows something else: in class 1, more than twice the amount of manure used in class 2 is applied on a hectare of cotton. Table 2 shows that class 1 and class 2 farms have on average 57 and 15 heads of cattle respectively. The number of livestock limits the amount of organic manure which can be applied to the cotton fields. Probably, the smaller livestock of class 2 is the cause of the lower cotton production. This is plausible, for agriculture in Mali is often limited by nutrients (chapter 1.3).

How much can the livestock herd size of Try increase without exhausting pastures?
Within how many years is this this livestock herd size reached?

The carrying capacity of the pastures is almost 2000 TLU higher for farming strategy 3 than for strategy 0, due to the lower feed requirements from the pastures. With a population size of 1124 TLU, livestock can grow 1386 TLU for strategy 0 and 3352 TLU for strategy 3. Different farming strategies have a large effect on generation time, reproduction rate and calve survival. Therefore, despite the higher carrying capacity for strategy 3, pastures are overgrazed within 11 years. When strategy 0 is applied, after 32 years the pastures will be overgrazed. However, not the total amount of grass produced by the pastures is consumed by the herds, for cattle is selective. In West-Africa, 30-50% of the grasslands dry matter production is consumed by cattle (Ayantunde *et al.*, 1999). decreasing the carrying capacity of the pastures by more than half. This means that in reality, pastures are exhausted much faster than in the model. However, when changing the carrying capacity to 30% and 50% of the original value, it appeared that pastures are exhausted within 0 to 4 years (depending on the strategy). The value of the carrying capacity heavily depends on the selectivity of the cattle, furthermore, herds sometimes graze at pastures belonging to other villages; therefore it is hard to make an accurate estimation of the number of cattle that can be fed from the pastures.

The variables of the livestock herd size model are based on simulations of one generation of cattle. To see whether the values of the variables of this model are truthful for more than one generation, livestock dynamics should be analysed for a longer period. Furthermore, in this analysis, cattle of Try is seen as one livestock population. In reality, the amount of 1124 TLU is spread over 126 individual farms (Table 1), which could cause a discrepancy in simulated values and true values of the variables generation time, reproduction rate and calve survival.

When the livestock herd size model was formulated, exponential growth was assumed. In reality, when a certain carrying capacity exists, population growth will slow down when the carrying capacity is approached. In this logistic growth model, a carrying capacity will never be reached in reality (Kroon *et al.,* 2009). However, the livestock model in which exponential growth is assumed does give a good indication within how many years the carrying capacities of the pastures are reached.

For strategy 0, there is a remarkable difference in male calve and female calve mortality. This is due to differences in diets for male and female calves (Sanogo, 2011).

4.2 Further research

During the analysis and discussion phase of this research, many different questions emerged which are recommended for further research.
First, total annual farm revenues were calculated. However, milk and cotton prices used for this calculation are variable, therefore farm revenues were calculated for different price scenarios (chapter 3.2). Further research could find out what the likelihood for each of these price changes is. It is plausible that milk production is going to increase when the incomes from cotton production remain unstable or keep on decreasing. Research could be performed to analyse what happens to milk prices when national or local milk production will increase. In this way it could be investigated whether there is a connection between cotton and milk prices.

In box 1, is was assumed that cotton production in class 2 is limited by manure application, which results in lower cotton yields per hectare than for class 1. It could be investigated if cotton production in class 1 is also limited by manure application. Furthermore, research could find out whether the costs of increasing manure application are compensated by the increase in cotton yield.

In the livestock herd size model, it was assumed that feed from pastures was the limiting factor for herd growth. However, if livestock herd size increases, the required amount of cotton seed cake, cow pea, crop residues and cereal bran also increases. The main type of feed in feeding strategy 0 is grass from pastures. When feeding strategy 3 is applied, each cows daily requires 3 kg cowpea, 2 kg cotton seed cake and 4 kg crop residues. Therefore, the production of cowpea, crops and cotton has to increase when livestock herd size increases. It could be investigated if the production of former mentioned crops limits herd growth more than pastures for the different feeding strategies.

Sanogo (2011) has introduced 3 feeding strategies to increase livestock production and performances in Mali. Further research could investigate which consecutive production steps could increase livestock production and performs better than feeding strategy 3.

Finally, Sanogo (2011) has analysed the quantities of disposable manure for each feeding strategy. Further research could find out how manure quality (e.g. nutrient concentrations, dry matter content etc.) changes for different feeding strategies.

4.3 Conclusions

Farming strategy 2 is most profitable for class 1 and 2 and, provided cotton and milk price decreases occur as often as increases, this is also on the long term the most profitable strategy.

The higher the quality of feed provided to the cows, the better cow performance is: reproduction rate, number of calves and calve survival will increase drastically with improved feed quality. This causes a faster increase in livestock herd size for strategy 3 than for strategy 0, which results in exhausting the pastures in a shorter time period. This period is 32 years for strategy 0 and 11 years for strategy 3.

References

AFD (2011) Agence Française de Développement. Website, visited on 19-10-11: http://www.afd.fr/Jahia/site/afd/lang/en/pid/1169

Ayantunde AA, Hiernaux P, Fernández-Rivera S, Van Keulen H, Udo HMJ (1999) Selective grazing by cattle on spatially and seasonally heterogeneous rangeland in Sahel. *Journal of Arid Environments* 42: 261–279

Ba A, Lesnoff M, Poccard-Chapuis R, Moulin C-H (2011) Demographic dynamics and off-take of cattle herds in southern Mali. *Tropical Animal Health and Production* 43: 1101–1109

Baquedano FG, Sanders JH, Vitale J (2010) Increasing incomes of Malian cotton farmers: Is elimination of US subsidies the only solution? *Agricultural Systems* 103: 418–432

Bassett TJ, Turner MD (2007) Sudden shift or migratory drift? Fulbe herd movements to the Sudano-Guinean region of West Africa. *Human Ecology* 35:33–49

Bonfoh B, Zinsstaga J, Farah Z, Simbé CF, Alfaroukh IO, Aebi R, Badertscher R, Collomb M, Meyer J, Rehberger B (2005) Raw milk composition of Malian Zebu cows (*Bos indicus*) raised under traditional system. *Journal of Feed Composition and Analysis* 18: 29–38

BNETD (2001) Bureau National D'Etudes Techniques et de Developpement, Côte D'Ivoire. Bamako, Mali: City Development Strategy Report

Butt TA, McCarl BA, Kergna AO (2006) Policies for reducing agricultural sector vulnerability to climate change in Mali. *Climate Policy* 5: 583–598

Coulibaly M, Nialibouly O (1998) Effect of suckling regime on calf growth, milk production and offtake of Zébu cattle in Mali. *Tropical Animal Health and Production* 30: 179-89

CountryStat (2011) Statistical information about feed and agriculture. Subdivision from the Feed and Agricultural Organisation. Website, visited on 28-10-11: http://countrystat.org/mli

Delarue J, Mesple-Somps S, Naudet J-D, Robilliard A-S (2009) The Sikasso Paradoxe: Cotton and Poverty in Mali. DIAL: Développement Institutions & Analyses de Long terme.

Dovlo FE, Williams CE, Zoaka L (1976) Cowpeas: Home Preparation and Use in West Africa. International Development Center, Ottawa, Canada.

FAO (2003) Economic and Social Development Department. Fact Sheets: Input for the WTO Ministerial Meeting in Cancún., Chapter 12.

FAO (2011) Information on Tropical Livestock Units. Website, visited on 03-11-11: http://www.fao.org/ag/againfo/programmes/en/lead/toolbox/Mixed1/TLU.htm

Gore JE and Steeds D (1987) Desertification in the Sahelian and Sudanian zones of West Africa. *World Bank Technical Paper No. 61*.

Hampshire K (2006) Flexibility in Domestic Organization and Seasonal Migration among the Fulani of Northern Burkina Faso. *Journal of the International African Institute* 76(3) 402-426

Indexmundi (2011) Monthly world cotton prices, data from 1981 to present. Website, visited on 21-09-11: http://www.indexmundi.com/commodities/?commodity=cotton&months=360

Kroon JCJM, Brunsting AMH, Kammenga JE, Takken W, Veenendaal E (2009) Ecologie: leerwijzer, werkcolleges, practicum en PGO-projecten. Wageningen UR, Chair group Natuurbeheer en Plantenecologie.

Martin P, Martin S, Weil P (2002) Best practice options: Mali. *International migration 40*(3): 87-101

Mbodj-Pouye A, Van Avenne CD (2007) Analyzing multilingual narratives through peasants' notebooks from mali mixing French and Bambara. *Langage et Societe* 120(2): 99-127

Ministère de l'agriculture, de l'élevage et de la pêche du Mali (2004a) Secrétariat-General, Politique nationale de développement de l'élevage, Cadre d'orientation politique, Adopté par le conseil des ministres du 14 janvier 2004

Ministère de l'agriculture Mali (2004b) Presentation of the CMDT. Website, visited on 28-10-11: http://www.maliagriculture.org/services_tech/cmdt/page-cmdt.html

OECD (2006) Organization for Economic Cooperation and Development. Policy Insights no. 30.

Ridder, N de (2011) Plant Production Systems Group, Wageningen University. Oral information provided, based on experience.

Rietveld A (2009) Livelihood strategies in a globalizing world: Analysis of farmers' strategies in Southern Mali with emphasis on milk production. Thesis report, Wageningen University

Roche JR, Berry DP, Kolver ES (2006) Holstein-Friesian strain and feed effects on milk production, body weight, and body condition score profiles in grazing dairy cows. *Journal of Dairy Science* 89(9): 3532-3543

Sanogo OM (2011) Le lait, de l'or blanc? Amélioration de la productivité des exploitations mixtes cultures-élevage à travers une meilleure gestion et alimentation des vaches laitières dans la zone de Koutiala, Mali. Thesis, Wageningen University, Wageningen, NL. 158 p

Schlecht E, Sangare M, Susenbethce A, Becker K (1999) Supplementation of Zébu cattle grazing Sahelian pasture II. Development of body mass and empty body composition. *Journal of Agricultural Science* 133: 83-95

Terrastat (2011) Land and water development division from the Feed and Agriculture Organisation. Data on deserts and dryland areas. Website, visited on 20-10-11: www.fao.org/ag/agl/agll/terrastat/

UNDP (2011) United Nations Development Program. Human Development Index 2010.

USAID (2011) United States Agency for International Development. Website, visited on 19-10-11: http://www.usaid.gov/ml/en/AEG/Livestock.html

Vitale JD, Djourra H, Sidibé A (2009) Estimating the supply response of cotton and cereal crops in smallholder production systems : recent evidence from Mali. *Agricultural Economics* 40: 519-533

World Bank (2011) Website, visited on 20-10-11: www.worldbank.org