

Simulation of small ruminant system productivity in the humid tropics of southwestern Nigeria



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Simulation of small ruminant system productivity in the humid tropics of southwestern Nigeria

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Summary

Evaluation of lifetime productivity of an individual animal in response to target interventions for improving the productivity of smallholder livestock systems in the humid tropics of West Africa is critical. It allows assessing long-term investment opportunities for farmers and options to minimize risk. In order to gain better understanding of the interventions for improvement of small ruminant production in southwest Nigeria, a dynamic modeling approach was used to explore the effect of feeding strategies on the lifetime productivity of the West African Dwarf (WAD) goats. Modifications were made on the current version of LIVSIM (LIVestock SIMulator), developed to simulate cattle production, to simulate sheep and goat production systems particularly for West African breeds. Sensitivity analysis for LIVSIM for a sheep and goat (LIVSIM Shoat) model for WAD goats was validated by comparing the test results with the sensitivity analysis of the PCHerd model modified for goats.

Technical soundness of the assumptions was tested on the effect of feed quality and changes in adult weight, which showed that the production parameters are very responsive input variables.

Good quality feed resulted in higher ($P<0.05$) daily growth rate of 53 g/d than 39g/d recorded in goats on moderate feed. With good quality feed, 97 kids were added to the flock after the simulation. An increase of 16.67% in adult body weight resulted in a 20.3% increased chance of early kidding on good quality feed but only 0.6% on moderate feed.

The model was tested using the common feeding practices of the smallholders' WAD goat production system in the humid tropics. Lifetime productivity parameters, namely body weight, age of the animal, age at first and last kidding, number of kids produced, weight of kid at birth, weight of kid at weaning and kidding interval were simulated for individual animals throughout their lifetime. Three scenarios were simulated based on the dominant feeding systems in the study areas: free grazing, grazing with supplementation (*Gliricidia sepium*) and the cut-and-carry feeding systems. The effect of different feeding systems was also simulated on the three generations of kids born within the simulation period of 10 years.

Goats on free grazing attained sexual maturity and kidded much later than those on grazing with supplementation and the cut-and-carry system. Simulation results for birth type indicated higher ($P<0.05$) number of quadruplet births (28 kids) recorded in the cut-and-carry feeding and in the free grazing system. In term of reproductive performance, goats on the cut-and-carry feeding system had better performance than the other systems. Kidding interval (295 days) was highest ($P<0.05$) under free grazing while does on cut-and-carry recorded the lowest ($P<0.05$) kidding intervals (195 days).

Dry matter intake of 19.55kg/DM/animal per month was recorded for animals on cut-and-carry. Dry matter faecal output (8.53kg and 8.74kg DM) were similar ($P>0.05$) under both grazing with supplementation and cut-and-carry respectively. The lowest ($P<0.05$) faecal N of 0.99g/d per animal was recorded in goats on free grazing while 3.3g/d per animal was reported under cut-and-carry management.

Supplementing the natural pasture with either browse or concentrates throughout productive life span of both the initial flock and the kids born within the simulation resulted in significant changes in all indicators of lifetime productivity. Although both supplementation with concentrates and *Gliricidia sepium* met the nutrient requirements of

goats for growth performance and reproduction, lifetime productivity was maximize using the cut-and-carry feeding system. Adoption of cut-and-carry management with concentrate supplementation will largely depend on its cost and benefit. Thus, incorporation of forage legumes in food crop to improve feed quality and quantity and the use of formulated feed ration using cheap and available feed resources as supplements in a cut-and-carry system could improve system productivity.

Introduction

The humid tropical zone of Africa covers most of the western coastal areas and the central region of the continent. This zone is characterized by high temperatures and rainfall in excess of 1500 mm, which is distributed on a bimodal basis, and high relative humidity (80-90%). The vegetation is typical tropical rainforest in the coastal areas becoming derived savanna in the northern parts (Ademosun 1988). Livestock production in the humid zone is limited to species and breeds which are trypanotolerant as the entire zone is infested at varying levels with the tsetse flies. Thus, locally produced animal protein is largely restricted to poultry meat and eggs together with the meat of dwarf goats and sheep. Although these small ruminants are mainly slaughtered on special occasions, the meat nonetheless forms a significant part of the household diet. Some pigs are kept, but ruminants have a distinct advantage over monogastric animals in being able to convert cellulose and other materials unsuitable for human consumption into products of high nutritional value (Upton 1988).

Goats are found in many different continents and climatic zones, although it is estimated that 94% of the world total live in the developing countries (FAO 1984) of which majority are found in the semi-arid and arid regions. In Nigeria, the goat population was reported to be 28 million goats in 2006 (FAO 2006) but has increased by almost 100% in 2009 to about 54 million (FAO 2010). Goats represent a valuable resource for economic development and livelihood security of the rural population in addition to having major cultural importance (Adebambo *et al.* 2011). They also serve as a source of meat, milk, leather and some other cultural occupational services, most especially among the people in the rural areas who have adopted the rearing of goats as part of their way of life (Odeyinka 2006). They are generally kept in small herds on mixed farms and provide their owners with a broad range of products and socio-economic services such as cash income (meat), security, gifts and manure for the crops (Chiejina and Behnke 2011).

Major constraints to small ruminant production in the humid zone have been identified as animal health and nutrition (Reynolds *et al.* 1988; Ahoukan 1989; Winrock 1992). The health constraints include the occurrence of regular outbreaks of *Peste des Petits Ruminants* (PPR), an epidemic disease with a high morbidity and mortality rate (Singh 2011). Furthermore, endo-parasites and ecto-parasites, and respiratory ailments are seen as constraints to animal production, not only because of their effect on mortality but also because they depress animal performance. The major nutritional constraint recognised for the humid tropics is not the quantity, but the quality of the available forage (digestibility, crude protein content) and the low nutritive value of household wastes particularly with regards to crude protein content (Hecha and Adegbola 1980).

This low level of feed quality coupled with the poor health situation has resulted in heavy mortality of goats often reaching 40% for kids up to 12 months of age (Ademosun 1993). The high mortality resulting from poor management has increased the need for the importation of live animals, often of other breeds, into the region although in some places preference is still for the local dwarf breed which commands very high prices at certain times of the year (Ademosun 1988). Interventions in health, nutrition and housing to protect the animals against inclement weather conditions can result in marked improvement in the performance of the dwarf goats in the humid tropics.

Efforts through health interventions, improved management and feed resources have been made to improve productivity of local goats in the humid tropics particularly in Nigeria through both on station and on farm experiments. Reports showed that despite the widely accepted health intervention (PPR, ecto-parasite) introduced

by projects, mortality still appears to be the major cause of variation affecting productivity, while live-weight gain appeared to be as important in determining the final output (Bosman and Ayeni 1993). Pre-weaning mortality has been associated with under-nutrition of breeding females (McDermott *et al.* 2010). In general, inadequate feed for females and young animals may be responsible for the large observed productivity gap, indicating that strategic feeding must be combined with targeted animal health interventions.

Moreover, some of the intervention projects in southwestern Nigeria reached no final conclusions simply because there were not enough data to warrant valid assessments of lifetime productivity while sustainability was another major problem. Bosman and Platteeuw (1993) concluded that to compare livestock production systems based on productivity parameters, an in-depth monitoring is needed to obtain sufficient reliable data to perform such an operation successfully. Two to three year projects may only be the bare minimum as they cover only two reproductive cycles of the animals, if parturition intervals are of normal duration.

There is therefore need to assess the long-term productivity of goat production systems and their sustainability. Parameters often used to evaluate livestock production systems are productivity, which can be interpreted as a measure of how efficiently the available resources are employed to achieve the production goals.

The objective of the study was to simulate goat production systems under different feeding systems in the smallholder livestock system of the humid tropics and assess the effects on lifetime productivity. This assessment will guide in testing the potential interventions to improve systems productivity.

Review of goat production systems in the humid tropics

The West African Dwarf (WAD) goat is a common and most important indigenous breed in the sub-humid and humid zones of West and Central Africa (DARIS 2007). In West Africa, Nigeria has the largest WAD goat population with approximately 11 million in the humid zone of eastern Nigeria (Chiejina and Behnke 2011). There are two major ecotypes: the humid zone and the savanna WAD goats, and these differ in several respects, notably their body weight, the latter being about 2-3kg heavier on average at 12 months of age (Jabbar 1998). It is estimated that at least 90% of these animals are owned by smallholder rural farmers, for whom goats represent an important asset (Peacock 2005).

The WAD goat is the indigenous hardy breed in the humid and derived Savannah zones of West Africa. They are characterized by small size, early sexual maturity, low nutrient requirement and low capital cost. These attributes in addition to their hardiness enhance their potential productivity with rapid capital turn over if well managed (Nnadi *et al.* 2007).

WAD goats are generally kept in small herds on mixed farms and provide their owners with a broad range of products and socio-economic services, such as cash income (meat), food security (milk), gifts (skin), and manure for the crops (Chiejina and Behnke 2011). Therefore, goats not only play a vital role in ensuring food security of a household (often being the only asset possessed by a poor household), but in time of emergency (e.g. crop failure, family illness or school fees) goats may be sold to provide an important source of cash (Assoku 1980). Odeyinka and Torimiro (2006) described the pivotal roles that women and children played in WAD goat husbandry. Children normally herd goats, while their day-to-day management and the care of young stock usually fall to women. Left-overs from the domestic kitchen, which are provided by the womenfolk, and cut and carry fodder/foilage, which are the responsibility of children and the men folk, are important condiment of the diet of goats in rural areas.

Important attributes of the WAD goat include its excellent adaptation to its native habitat, high fertility and high prolificacy. Their most important attributes are their resistance to the major insect-borne disease, trypanosomosis (trypanotolerance), and to gastrointestinal nematodes. These attributes have enabled the predominantly small-scale rural goat keepers in the area to successfully rear and continue to derive their sustenance from these animals without recourse to the use of trypanocides and anthelmintics, which are neither affordable nor available to most of them (Chiejina and Behnke 2011).

Advantages of keeping goats

There are other advantages associated with goats as a form of investment. First, goats are a conveniently small unit of investment with prices within the reach of most rural households. A flock of three or four does is not a huge investment. Second, the fact that goats do not compete with crops for land is an advantage especially in areas of increasing population density where there is pressure on land. Given these circumstances goats are an important means of raising farm incomes and family food supplies, without increasing pressure on land. A third advantage of

investment in goats is that access to land is not a pre-condition to raising goats because they may be fed on household scraps, crop residues and rough grazing or browse (Carew 1982).

Finally, it seems that in traditional goat keeping there are no significant economies of scale. This is an advantage in that everyone can partake in this activity and there is no strong tendency for the development of large individually owned flocks with consequent large inequalities within the village society. This egalitarian feature of goat keeping is reinforced by the widespread practice of "caretaking". In southwestern Nigeria, 54% of households surveyed were caring for "borrowed" animals (Okali 1979). Women in particular acquire stock in this way. Social norms are such that a livestock owner cannot refuse a request for a loan of breeding stock. The offspring are usually shared equally between the borrower and the lender, although risk of mortality of the doe is borne largely by the owner (Sempeho 1981). The borrower thus receives income from rearing his or her share of the offspring in return for caretaking, at little or no capital cost. In this way, breeding stock are shared and redistributed among individuals and households.

Goat management systems

Goats, in the humid tropics, are generally kept as a low-cost adjunct to arable and tree-crop production. Sellers *et al.* (1976) in a survey in southwestern Nigeria found that the average number of goats per household in the town was 3.5, while the number in the village was five. Ademosun (1987) in another survey reported a typical farm family in the zone comprises six to eight people, cultivating two to four hectares of land and owning three to five small ruminants. ILCA (1979) reported average number of goats per household in central, southeast and southwest Cote d'Ivoire as 4.5, 4.6 and 4.1, respectively. Although goat numbers per households are small, large numbers of households keep goats.

Systems of management of small ruminants vary from free-ranging in sparsely populated areas to all year confinement in densely populated areas. Recent reports revealed that free-grazing (54%) was the predominate system of rearing goats. This was followed by those who practiced the grazing with supplementation feeding system (30%). The rest (16%) being for the farmers who used the cut-and-carry feeding system (Sanusi *et al.* 2010).

The size of flock is smaller in confined than in free-roaming flocks. Labour for collection and carrying of feed, and the availability of housing space appeared to be the main constraint on animal numbers (Francis 1988). However, in some places where animals are kept near the farmsteads and there is danger of damage to crops or where, because of increasing human population and pressure on land, free ranging is no longer practical, animals are kept on tethers or in enclosures. In certain localities, the keeping of goats is prohibited to safeguard crops. Thus, where the animals are kept on the tethers or any type of confinement the use of household wastes is also supplemented with the hand-feeding of natural forages (Ademosun 1987).

Free grazing systems

Adesehinwa and Okunlola (2000) reported that free grazing, which is also called the "traditional system" is the most common system of production in southwestern Nigeria. Goats scavenge in free-roaming village flocks with no special provision of forage or housing and with minimal management. No forage crops are grown and manure is not returned to the cultivated crops, so links with crop production are slight. In this traditional system of management, little attention is paid to adequate feeding and health of the animals. Goats are sometimes, but not regularly, provided with household and kitchen wastes which could include yam, cassava and plantain peelings, the bran of maize, and other grains and pods of beans. The animals supplement this with bush grazing (Ademosun 1987). Animals receive virtually no veterinary care, and mortality rates are relatively high, though variable. In general, these animals received little attention and, as a consequence, labour costs are negligible. However, the dangers of livestock straying and damaging growing crops may be so severe as to require confinement of the animals (Upton 1988).

Generally, this system of management is cheap and less labour intensive. It is characterized by low productivity and high losses due to accidents, diseases and theft (Ajala *et al.* 2008). Feed resources under this management system are those obtained by scavenging around households through grazing and browsing on natural vegetation in natural pasture, fallow lands or along roadsides and sometimes household waste.

Free grazing with supplementation

The semi-intensive system entails a combination of limited grazing and stall feeding of goats. It is a system that typically combines grazing and the utilization of crop residues and by-products with some form of arable cropping (Devendra 1986). The extent of grazing is influenced by the area available and other considerations such as labour and time while there is usually limited stall feeding. The duration of grazing is variable, but is usually about four to six hours a day, generally in the late morning or evening. The animals are then housed and given some forage or crop residues. Very seldom are concentrates offered (Devendra 1986). The use of labour is a part-time operation and may be undertaken by unpaid family labour or by paid herders. The former often involves children and wives of the farmers. In the latter, case, it is not uncommon for the shepherd to herd the animals belonging to several farmers for grazing. The flock size is generally between one and eight animals (Devendra 1985). According to survey conducted in southwestern Nigeria in 2003, about 26% of the respondents adopted the semi-intensive system (Ajala *et al.* 2008)

Intensive system

This is a goat production system where good housing and hand-feeding is provided for the animals. This system is well established in parts of humid zone of West Africa, for example in parts of eastern Nigeria as it forbidden to allow livestock to roam freely in this area (Upton 1988). There are instances, particularly in densely populated eastern Nigeria and in the People's Republic of Benin, where more intensive methods are adopted. Goats are commonly tethered or permanently housed, feed is cut and brought to them and their manure is collected and spread on the fields to maintain fertility (Mecha 1975; Lagemann 1977; Mack *et al.* 1985). Clearly labour costs are increased under such systems, but there is no competition with cultivated crops for land since fodder and browse are obtained from fallow land or crop by-products. Ajala *et al.* (2008) reported that only 1.7% of farmers in southwest Nigeria practiced the intensive system of management. The intensive system provides the opportunity for closer control of feeding, diseases and breeding. It prevents crop damage by the animals and reduces risks of accidents. It provides the opportunity for better management, but several additional costs are involved apart from the costs of the shed itself (Upton 1988).

Feed resources under confinement systems also include feedstuffs collected from range by the farmer and fed to the animals. Household scraps, such as cassava and plantain peels and maize chaff, also provide a significant contribution to feed resources for smallholder sheep and goat production. Sometimes, farmers also provide feed concentrates or agro-industrial by-products such as wheat bran.

Feed resources in the humid tropics

In the humid zone of West Africa, herbaceous forages grow well, providing much needed nutrients in near adequate amounts for livestock. Because they mature early, quality tends to reduced significantly as plants mature. The process of early maturity leads to a rapid change in the stem to leaf ratio, in favour of the less nutritive stems. Feed constraints are therefore mainly related to quality and could be alleviated by judicious supplementation. The variety of feeds available across the ecological zones and production systems can be classified as: natural grasses and rangelands, cultivated pastures, crop residues and by-products, and browse (Atta-Krah and Reynolds 1989).

Natural pasture

The natural pastures grow on uncultivated land to which animals have access for grazing. They are found along roadsides and on fallow lands in the coastal forest belt of humid West Africa. Besides *Panicum maximum*, Atta-Krah and Reynolds (1989) described natural pastures consisting of a mixture of grasses, such as *Imperata cylindrica*, *Andropogon gayanus*, *Pennisetum spp* and *Hypparrhenia spp*. These grasses grow rapidly during the wet season, becoming fibrous and coarse, and are under-grazed because of the large amounts that become rapidly available. Their quality declines further during the dry season when they become standing hay and are subject to overgrazing. According to Smith (1991), during the period of rapid growth (wet season) these grasses contain, on average, about 25% dry matter, 10% crude protein, 6% ash, 32% crude fibre and 43% acid detergent fibre (ADF). As the dry season advances, the nutritional quality declines to the extent that crude protein can fall to as low as 2%. Consequently, these grasses cannot meet the nutrient requirements of goats for most of the year. Even during the rains they can only satisfy maintenance requirements. In a study in which rumen degradability in sheep, goats and cattle was used as a screening technique to evaluate the potential nutritive value of various feed resources (Smith *et al* 1989), supplementation with browse or crop residues was recommended. Smith (1992) suggested measures which would be effective to mitigate feed shortage in humid areas, such as the introduction of more productive pasture, fodder conservation during periods of surpluses and supplementation with crop-residues, by-products and even concentrates, where economically justifiable.

Cultivated pasture

The use of cultivated leguminous and non-leguminous pastures and fodder plants in livestock production systems for ruminants in the humid tropics has been reviewed (Murphy and Colucci 1999). These pastures show promise of providing better quality feed—and in larger amounts—to meet the nutritional requirements of the animals (Smith 1992). Leguminous pastures have the added advantage of restoring soil fertility depleted by intense cropping or grazing. Leguminous forage cover reduces soil erosion and runoff thereby conserving soil, improve organic matter content and competing with weeds (Humphreys 1995). Tropical forage legumes are rich in protein, which are usually the most limiting nutrients in tropical animal diets (Murphy and Colucci 1999). Forage legumes can be grazed, harvested and fed fresh or stored as hay or silage (Harricharan *et al* 1988). The integration of legumes into the arable cropping system in the humid tropics has been reported to increase the N content of the soil, and consequently increase grain yields in subsequent years as well as improve the performance of the animals fed the silage made from the mixture in terms of weight gain (Amole *et al.* 2013). The adoption and utilization of the technology has been slow and rather unsuccessful for a number of reasons: lack of management expertise on time of planting, and planting pattern and density (Nnadi and Haque 1986). Other limitations are the practice of communal grazing and insecure land tenure, rampant annual bush burning, and uneconomic returns (Smith 1992).

Crop residues

Crop residues have been reported by Smith (1992) as an important component of the farming system in the humid tropics of West Africa with the cultivation of various food crops (cereals, grain legumes, roots and tubers, fruits) and tree crops (cocoa, oil palm, rubber). These crops generate residues after harvest and primary on-farm processing, and/or by-products after secondary processing elsewhere. Quantitative and qualitative studies have been carried out on these feed resources in several parts of Africa, and in general the evidence is that large amounts are available for ruminant feeding. Sansoucy and Emery (1982) suggested that if all available residues were fed to livestock, each livestock unit would receive up to 3kg dry matter daily. Poor nutritional value has often been cited as the major reason for a much lower level of utilization. Many of the crop residues are highly fibrous, low in fermentable carbohydrates and nitrogen and, therefore, cannot maintain an efficient rumen ecosystem. Crop residues rarely meet the requirements for maintenance in adult ruminants (Devendra 1985), and may require upgrading by physical, chemical or even biological means to improve their value and usefulness. Such treatments may, however, be unsuitable for the majority of goat owners who are small scale and subsistence producers.

Browse

Browsets, in the form of fodder trees and shrubs, form an integral part of farming systems in humid West Africa (Atta-Krah *et al.* 1986). As their establishment and management require little effort, labour, time, technical know-how or resources, they are easy to promote and intensify as animal feed. The multipurpose nature of browsets as fuel wood, shade, food (fruits), poles, etc. as well as their potential to improve soil fertility and conservation are added benefits. In terms of utilisation as animal feed, browsets currently play an important, albeit non-strategic, role, as animals under confinement often receive one or another type of browse, from fallow lands or around homesteads. Efficient utilisation in a complementary way with grass forages and crop residues is what needs to be worked out through research, in order to exploit their potential nutritive value (Atta-Krah and Reynolds 1989).

Rumen degradability studies by Smith *et al.* (1989) and Kabaija (1985) show that many browsets degrade fairly well and rapidly supply much needed soluble carbohydrates and fermentable nitrogen to the rumen, thus enhancing forage breakdown. Many of these browsets contain high levels of essential elements, such as calcium, sodium and sulphur, as well as critical microelements, such as iron and zinc (Kabaija and Smith 1989; Devendra 1990), which have been shown to be deficient or borderline for productive purposes in many tropical grasses (Kabaija and Smith 1987). Moreover, most of the browsets remain green all year round and, if properly managed, continue to provide substantial amounts of foliage even during the dry season. Browsets, therefore, complement grasses both quantitatively and qualitatively. Several feeding and growth trials have confirmed the potential of browsets to enhance forage utilisation and improve performance (Ajayi *et al.* 2005; Asaolu *et al.* 2012; Ayuk *et al.* 2014).

Limitations to WAD goats' productivity in smallholder system

Despite the relatively high average returns from goat keeping and the other advantages already mentioned, few goats are still kept in each farmer's households. The survey report by Okali (1983) revealed some limitations listed by farmers to increasing the size of the flock: feed, need for fencing, labour, cash and disease. Long term monitoring of village flocks in southern Nigeria revealed diseases and undernourishment, particularly in the dry season when quality of feed is poor, as the main problems for improving productivity. (Jabbar *et al.* 1996).

Diseases

According to Ajala *et al.* (2008), high incidence of diseases is one of the major constraints associated with small ruminant production. The detrimental role which parasitic diseases play in livestock production has been emphasized (Lamorde 1996). Although, the incidence and intensity of pests and diseases, infestation in the ruminant farm animals may vary between the rainy and dry seasons, and across Nigeria's ecological zones, they threaten the health and productivity of the animals. According to Dipeolu (2010), livestock farmers may experience total loss of stock through death, or partial losses (through morbidity) in which the productivity of the animals becomes greatly reduced. Disease such as pneumonia, especially PPR is the major cause of death in small ruminants. Diarrhoea is mostly caused by parasitic gastroenteritis and PPR; and abortions and neonatal deaths are associated with starvation. Under village management conditions, helminthiasis can constitute a serious problem although the magnitude of the problem is often underestimated. Thus, under the traditional system, diseases and parasites have constituted the major problems which are aggravated by poor nutrition. In order to overcome these effects of pests and diseases on ruminants, it becomes essential for the livestock farmers to either prevent or control the incidence of disease.

Nutrition

Small ruminants suffer scarcity of feed supply and pasture quality in the humid region of West Africa, especially during the dry season when the natural vegetation is of poor nutritive value (Aye 2007). Specifically for goat production in Nigeria, Ahamefulé and Elendu (2010) identified feed shortage as a major constraint.

Even where fodder resources abound, seasonal fluctuations in nutritive value make sustainable gains in production from good management and disease control programs unrealistic (Alli-Balogun *et al.* 2003). During the rainy season, range plants grow rapidly and although their quality may be good early in the season, they mature rapidly with a resulting decline in quality. Their decline in quality impairs the productivity of ruminant livestock that depend mainly on grassland (Pamo and Pieper 1995). Often, the crude protein content of range vegetation, particularly during the dry season, is less than the critical level of 6.7% needed to maintain an efficient rumen function (NRC 2001). The growth rate and milk production of ruminants grazing tropical pastures or consuming crop residues alone are generally low and represent only about 10% of the animal's genetic potential (FAO 1997). This low productivity is due mainly to poor nutrition which lowers the resistance of animals to infectious and parasitic diseases, leading to high mortality rates among young and low fecundity in adult females (Riviere 1991). In places where the increased pressure on arable land has led to total confinement of small ruminants, the animals depend solely on feed brought to them.

Apart from grazing on natural pasture which becomes inadequate during the dry season and crop residues which is limited to the farmers harvest yield each year, small ruminants are also fed with household scraps which tends to limit their numbers according to the amount available. Experience has shown that the average household produces only enough food by-products to support three or four breeding animals. Incidentally, this may help to explain the early disposal of some young stock soon after weaning. A larger return would be obtained by carrying them through to maturity, but feed shortage may preclude this (Upton 1988). Poor quality of the available feed results in low digestibility and low voluntary intake by animals. Supplying additional protein during the dry season will increase the microbial growth and rate of fiber digestion often with increased forage intake, thereby improving nutrient absorption for enhanced animal productivity (Aregheore 2006).

Need for intensification

The demand for livestock products is rising rapidly in developing countries, mainly as a consequence of increased human population, urbanization and rapidly increasing income (Delgado *et al.* 1999). The question is whether large numbers of smallholder farmers will be able to meet the growing demand for livestock products in developing countries, or will these products be provided by other categories of producers. Staal (2001) argued that poor rural and urban people with low and slowly increasing incomes will provide much of the increasing demand for livestock products, largely from local informal and domestic markets because livestock products are not widely traded over long distances (generally 10% of livestock products are traded across borders).

According to McDermott *et al.* (2010), intensification of smallholder animal production should provide tens of millions of households with sufficient assets, skills and income to diversify out of livestock enterprises altogether. As systems intensify, there is less opportunity for free grazing and small ruminants are increasingly confined within the home compound. This will involve strategic feeding, combined with targeted animal health interventions. In peri-urban areas, fattening operations keep small ruminants enclosed and fed on concentrates and fresh fodder for finishing and sale (McDermott *et al.* 2010).

For goats to continue to play vital roles in the rural economy, the need for improved management practices has been argued (Abubakar and Yahaya 1996). The results of an experiment in Obafemi Awolowo University, Ile-Ife, Nigeria aimed at the evaluating the productivity of WAD goats fed with locally available fodder resources revealed that grazing on *Pennisetum purpureum*, *Panicum maximum*, *Stylosanthes guianensis* and *Cynodon nlemfuensis* among others was unlikely to provide adequate nutrients to permit the animals to express their optimum genetic potential in terms of productivity. Thus it was normal practice to provide supplementary concentrates of 200-500g/DM per animal per day, depending on level of productivity. When animals were zero grazed on available forages, such as *Panicum maximum*, *Gliricidia sepium* and *Leucaena leucocephala*, improved feed intake was reported although it was still necessary to supplement with concentrate feed (Ademosun *et al.* 1985).

Improvement in disease control is likely to result in an increasing flock size per farmer, and the growing human population is resulting in shorter fallows and diminishing grazing lands as crop area is expanded. It has been reported that as human population density increases, there is a decrease in farm size and crop yield/ha, but an increase in livestock numbers/farm (Lagemann 1977). These situations, therefore, imply a potential major limitation in feed availability for small ruminants in the zone. The need to increase feed supply and quality through an improvement in the production and utilization of pasture and fodder shrubs is therefore obvious (Atta-Krah and Reynolds 1987).

Evaluation of lifetime productivity of West Africa dwarf goats

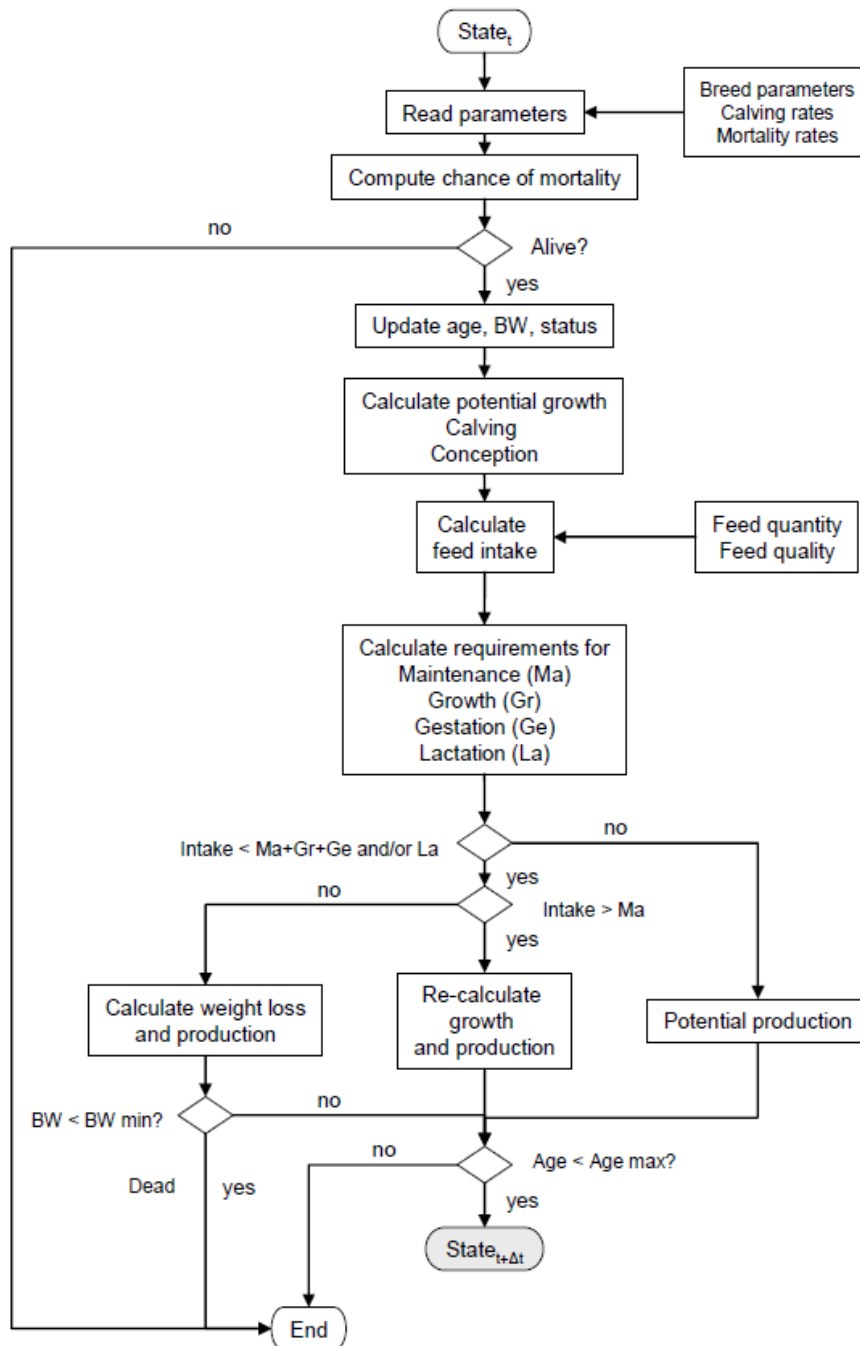
The evaluation of lifetime productivity of individual animals under an improved system has been considered more relevant in providing strategic interventions than assessment of short-term productivity, because it allows for the assessing of long-term investment opportunities for farmers that have few animals and face difficulties to spread risk (Kebreab *et al.* 2005). Ayantunde (1994) stated that studying small ruminant production systems via livestock on-farm studies (farm surveys and on-farm research) often face the problems of experimental design and data analysis, thus a simulation model is helpful to address these problems. To gain better understanding of the interventions for the improvement of small-ruminant production, various simulation models have been developed, such as the Texas A&M Sheep simulation model by Blackburn and Cartwright (1987); The the bio-economic model of small ruminant production (Gutierrez-Aleman *et al.* 1986); the sheep management model by Benjamin (1983); the PCHerd by Brouwer (1992); and LIVSIM (LIVestock SIMulator), a dynamic model based on the principles of production ecology (Van de Ven *et al.* 2003). The first requirement of a model for such a system is that it can simulate the effect of nutrition and management on production traits and, hence, productivity. Feed intake must be dealt with in such a way that its effect on reproduction and weight gain can be assessed. Furthermore, the interaction between feed intake and management, and total system productivity and its dynamics must be included. A dynamic, stochastic model is required that simulates the intensification of small ruminant production within a system (Bosman 1995).

The current version of LIVSIM was developed to simulate cattle production (Rufino *et al.* 2009). There was a need to modify and adapt the model to simulate sheep and goat production systems particularly for the West African breeds. LIVSIM Shoat (LIVestock SIMulator for Sheep and Goat) is the modified version of LIVSIM adapted for sheep and goat. Modifications were made to reproduction, energy requirements, mortality and milk production components of LIVSIM. In the reproduction component of this modified model, extra parameters were introduced, where necessary, to allow for the incidence of multiple births in small ruminants.

Model description

LIVSIM, the model used in this study, is a dynamic model based on principles of production ecology (Van de Ven *et al.* 2003). Following these principles, LIVSIM simulates the performance of individual animals in time, according to their genetic potential and feeding. Potential production is defined by mature weight, growth rate and milk yield. Figure 1 shows a flow diagram of the model. The model was written in MATLAB v.7.1 (The Math Works 2005). The integration time-step is one month. It was revised for free use, using the R package, a GNU project programming language that is open source and run within the environment of Rstudio. The basic structure is based on the concepts of the model developed by Konandreas and Anderson (1982). However, LIVSIM differs from that model in several ways. Firstly, the nutritive requirements calculations are based on AFRC (1993). Secondly, the feed intake, excreta production and the decision variables are based on the model of Conrad (1966) Potential growth is assumed to be a function of time, breed and sex. Potential growth and minimum bodyweight curves were derived by fitting a simplified Brody model (Brody 1945) to data on bodyweight and age of WAD goats found in the literature.

Figure 1. Flow diagram illustrating the structure of LIVSIM. Feed intake is compared with feed requirements for potential production. When these are not met, a set of priorities is used to partition energy and protein into lactation, gestation, growth and maintenance needs. Once production is calculated and if maximum age is not reached, and animals are not dead, a next time step (State $t + \Delta t$) is simulated.



The model has been designed to evaluate the impact of the farmer's resource allocation on animal productivity. Because flocks in such systems are usually small (two–three animals), an individual-based model offers advantages above population models. Individual-based models (IBMs) allow the explicit inclusion of relatively short-term individual variation which is useful to explore life cycles in finer detail than the age structure or stage-structure Leslie matrix models (DeAngelis and Mooij 2005). When large herds are managed in feeding groups, dividing the population into classes may be more convenient than using individual-based models (Vargas *et al.* 2001).

LIVSIM simulates a flock of individual animals which allows for detailed output on feed intake, energy balance, weight gain, optimum weight, milk yield, births, weaning and mortality. Each animal in the flock is processed independently except for ewes with suckling kids. Suckling kids secure at least a fraction of their energy intake in the form of milk from their dams, and the balance between energy demand and energy requirements is determined simultaneously for the ewe and her kid to avoid over, or undercharging, the energy costs to either of them. In terms of feed intake, the model use a statistical description of the quantity and digestibility of forage on offer, based on literature values. Quantity and quality of feed input is, therefore, user determined based on seasonal availability and quality.

All calculations are performed on a time step basis. A time step is the length of time (days) for all calculations to be performed once (size of a time step depends on users' specification). The results of one time step serve as inputs for the next time step. A series of time steps is called a simulation run. In our application of the model, a simulation run is made up of 120 time steps of 30 days length which is equivalent to 10 years. The life expectancy of goats is assumed to be three years after their reproductive lifespan which is mostly between five and seven years (Atkins 1986; Mohan *et al.* 1986; Gama *et al.* 1991). In this trial, a seven-year reproductive life span was chosen. All relevant time dependent parameters (age, live-weight, pregnancy stage, lactation stage) are updated at the end of each time step.

Flock management options, such as target number of flock, replacement age of bucks and maximum number of bucks in the flock, are user-defined. However, default values are set for weaning age of kids, which is 90 days, and lactating does are dried off after 90 days in lactation. The dams are assumed to lactate for 12 weeks, which is commonly reported for non-dairy goats (Devendra and Burns 1983; Geenty and Sykes, 1986; Snowder and Glimp 1991; Ehoche and Buvanendran 1983). Weaning of kid(s) at 90 days is also as suggested in the literature (Devendra and Burns 1983).

Parameterization of the model

LIVSIM is designed to simulate the impact of different management strategies on the long term productivity of goats. The main objective is to quantify dynamically the production of offspring of individual animals of small flocks, common in smallholder farming systems in the humid tropics. Individual animals are described with four state variables: age, bodyweight, reproductive status comprising a pregnancy index and a kidding index (Fig. 2). The pregnancy index is used to follow in time the pregnancy and its nutritive requirements and to trigger kidding. The kidding index is used to follow the lactation and its nutritive requirements in time and for triggering the next conception. Other constant variables in the model are presented in Table 1.

Figure 2. Simplified scheme of LIVSIM, where the boxes represent the different modules of the model where nutritive requirements of different for different physiological processes are compared to the actual intake of energy and protein available. MP stands for metabolisable protein.

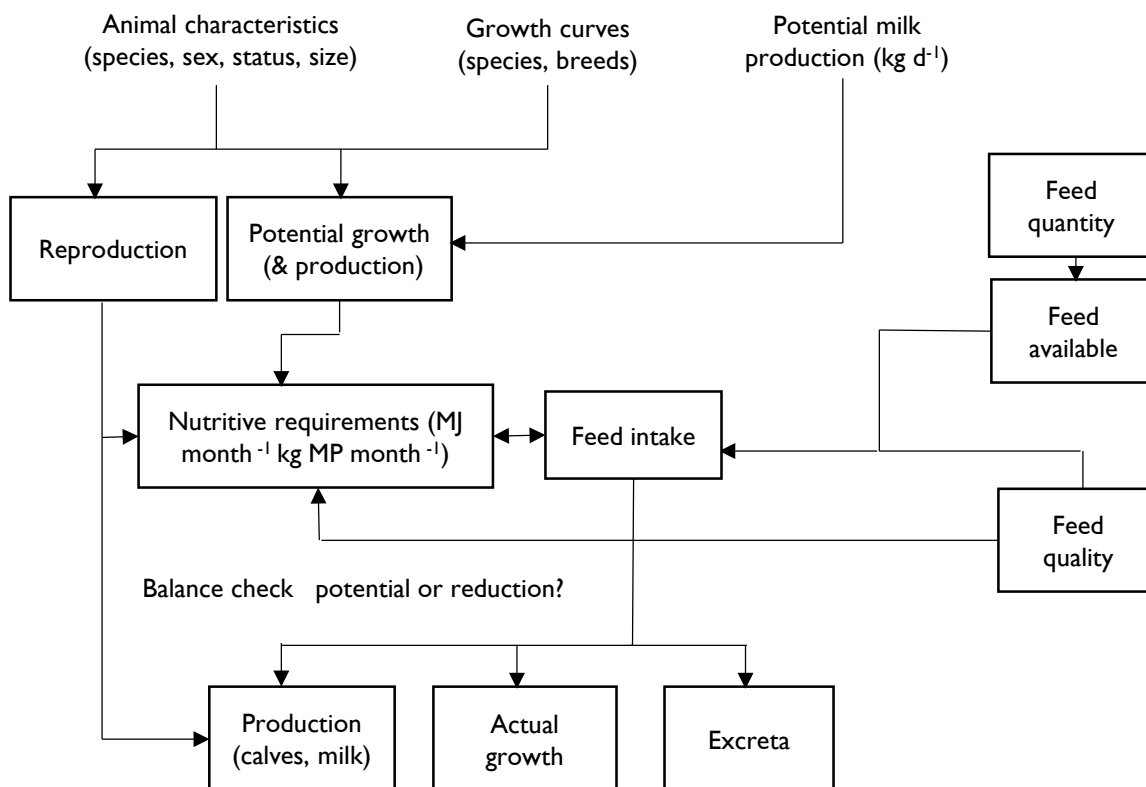


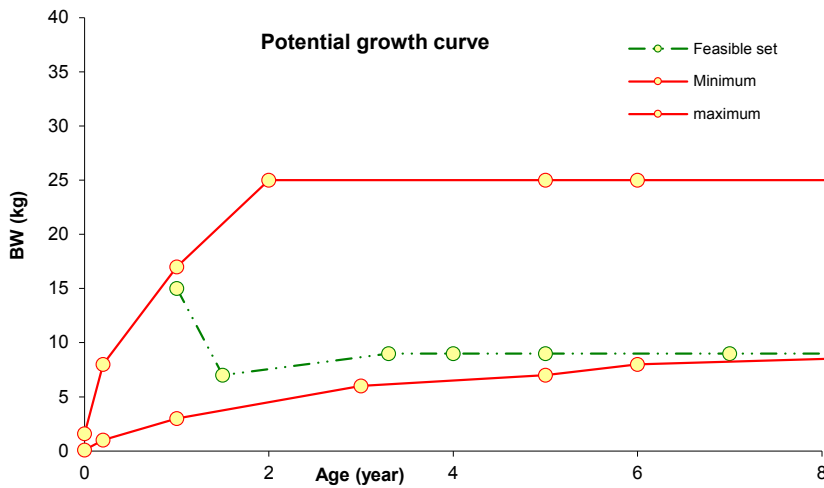
Table 1. Default values used in the model

Parameters	Parameter value	Units
Mature weight	35	kg Ayantunde 1994
Kid birth weight	1.6	kg Ikwuegbu 1993
Weaning age	90	day Ayantunde 1994
kidding rate with optimum condition	0.8	- Bosman 1995
Pregnancy length	150	day Ayantunde 1994
Postpartum length	45	day Ayantunde 1994
Milk fat (average)	35.5	g kg ⁻¹ Ayantunde 1994
Milk crude protein	32.0	g kg ⁻¹ Ayantunde 1994
Milk metabolizable energy	19.4	MJ (kg DM) ⁻¹ Ayantunde 1994
Dry period	90	days Devendra and Burns 1983
Maximum milk yield	0.4	kg d ⁻¹ Adebawale 2012
Lactation length	90	days Ayantunde 1994
Kidding probability	75	% Ayantunde 1994
Age at sexual maturity	1	year Ayantunde 1994

Growth

Potential growth is a function of age, breed and sex. Potential growth and minimum bodyweight curves are built for a goat breed fitting data on mature weight and growth rates found in the literature to a simplified Brody model (Brody 1945). The potential growth curve for female WAD goat is shown in Fig 3.

Figure 3. Potential growth curve for the WAD goat in the tropics from data on goat (Ayantunde 1994).



Maximum and minimum bodyweights are calculated by interpolation from the upper and lower boundaries shown in Figure 3.

Next, the difference (Difference Max W) between actual weight (W_t) to maximum weight (W_{max}) is calculated according to:

$$Difference\ Max\ W = W_{max, t+1} - W_t \tag{Eq. 1}$$

The actual growth per month is calculated as:

$$Actual\ growth\ t+1 = \min(AWG, Difference\ Max\ W) \tag{Eq. 2}$$

Where actual growth is the minimum of Difference Max W and the maximum growth allowed by the metabolisability of the feed (AWG) expressed in kg per month.

Reproduction

Reproductive performance of small ruminants is one of the most important measures of their productivity. Factors affecting reproductive performance are basically environmental (management and nutrition) and genetic (Urioste 1987; Devendra and McLeroy 1982; Dyrmondsson 1981; Erasmus and Fourie 1985). Reproductive performance is evaluated using a number of indicators, such as days to first conception, kidding interval and length of the productive life (disposal date minus first kidding date). Conception is simulated stochastically by using probabilities associated with bodyweight and age combinations. We used the approach of Konandreas and Anderson (1982) and data from the literature to determine a feasible age-bodyweight set when does achieve reproductive maturity.

Probabilities for conception are derived from the annual kidding rate (input to the model), this probability is a function of age. The nutrition-reproduction feedback is described through the effect of bodyweight changes on the annual conception rate. Because goats reach their maximum fertility around the middle of their reproductive life a multiplier to take into account the effect of age on the annual calving rate is used (Table 2).

Table 2. Multiplicative effect of age on the annual conception rate of goats adapted from Konandreas and Anderson (1982) for cattle and modified using data for WAD goats

Age (y)	Multiplier for the effect of age on calving rate
1	0.75
1.5	1
5	1
6	0.63
7	0.32

The monthly probability of conception is calculated in Eq. 3. Kidding rates and conception rates are assumed to be equal.

$$Prob\ conception = 1 - (1 - Annual\ kidding\ rate)^{1/12} \quad (Eq. 3)$$

Many authors reported that breeding seasons, age at sexual maturity, buck performance and time since parturition have a significant effect on conception rate (Devendra and Burns 1983; Bradford *et al.* 1986; Blackburn *et al.* 1987; Cochran *et al.* 1984; Notter and Copenhaver 1980). Breeding season is especially important for seasonal breeders, which are mostly temperate in origin. The effect of breeding season is mainly expressed via variation in day length which affects the oestrus cycle (Ayantunde 1994). The tropical breeds are mostly non-seasonal breeders. Therefore, the effect of season was not included in the model.

Age at sexual maturity refers to age at which doe-kids reach puberty, that is, the initiation of oestrus with ovulation and varies with breed, nutrition, liveweight and management practices. Pubertal age marks the starting point of reproductive cycle. Thus the doe-kids can become pregnant from this age. Considerable variations in pubertal age are reported in the literature. For Angora goats, Shelton and Groff (1984) reported a range of six to 12 months. Dahl and Hjort, (1976) reported nine months for goats. For goats, the authors advised delaying mating until an age of 18 months, depending on the availability of feeds. For tropical sheep, Combellas (1980) suggested 300 days (almost a year). Males generally reach maturity at an earlier age than the females for both sheep and goats.

In this model, age at maturity is set at 12 months which is same value Ayantunde (1994) and Bosman (1995) used in their reports. This is considered suitable for a smallholder system in view of low inputs involved although, in case of very good nutrition, the doe-kids can be pregnant at an earlier age (Dahl and Hjort 1976). Besides nutrition, Ayantunde (1994) suggested delaying mating if sexual maturity is reached early to ensure that a dam is able to accommodate the foetus without having to compete with available nutrients for her own growth.

The gestation period of goats is reported to be about 150 days with a normal range from 141 to 157 days (Peaker 1978; Shelton and Groff 1984; Devendra and McLeroy 1982). Ayantunde (1994) used a value of 150 days for the PCHerd livestock simulation of WAD goat. In this model, the default value used is 150 days.

Kid birth weight is a breed-dependent input to the model. Lactation length and dry period are characteristics of the system under study and inputs to the model. It was assumed that kids are weaned at three months of age and that the milk allowance for kids is constant till when they are weaned.

Milk production

Milk yields are simulated by using a breed-specific potential milk yield function of lactation length modified by age and condition of the doe. Lactation length and dry period are characteristics of the system and therefore inputs to the model. The dry period is assumed to be three months. Milk production (Eq. 4) is calculated by interpolation using the potential lactation curve and correcting by age and body condition effects.

The attainable milk yield is calculated as:

$$\text{Milk yield} = \text{Potential milk yield} \times \text{age effect} \times \text{condition factor} \quad (\text{Eq. 4})$$

The energy and protein requirements for milk production have to be met by the intake of energy and protein. When feed intake does not meet the needs for potential production, the actual milk yield is calculated by iteration accounting for all the processes demanding energy and protein. Weaning age and milk allowance for kids is a characteristic of the system and therefore user-defined.

Nutritive requirements

Nutritive requirements are calculated following the energy and protein system of AFRC (1993). Metabolisable energy (ME) and metabolisable protein (MP) requirements are calculated separately for maintenance, growth, pregnancy and lactation. This structure allows application of the concepts of production ecology (Van de Ven *et al.* 2003).

The model for intake prediction was selected from the report of Ketelaars and Tolkamp (1991) for sheep and goats in the tropics.

$$IOM_f = (-42.78 + 2.3039 \times OMD_f - 0.0175 \times OMD_f^2 - 1.8872 \times N^2 + 0.2242 \times OMD_f \times N) \times 1.33$$

Where *IOM* is intake organic matter, *OMD* is organic matter digestibility and *N* is nitrogen.

When the available feed supply equals nutrient requirements, the potential production is achieved provided that there are no other limiting and reducing factors. Water requirements and reducing factors (diseases, pollutants) are not (yet) included in LIVSIM. When the nutrients provided by feed intake cannot meet the nutrient requirements for potential production, the calculated intake is used to meet the requirements of different processes according to certain rules. This is illustrated for animals in different physiological and reproductive status as case one for growing males and females, case two for pregnant females, case three for lactating females and case four for pregnant and lactating females (Ruffino *et al.* 2007). First, it is determined whether ME or MP are limiting potential production, then the physiological and reproductive status of the animal are checked. When potential production cannot be achieved, the next check is whether the nutritive requirements for maintenance can be met. This decides which routine is executed by the model: either little growth or weight loss. Through several iterations, growth and production are calculated to match the feed intake. Mortality is simulated both as a probabilistic process qualified by the age of an animal and deterministically defined by nutritional status. There is a threshold to weight loss beyond which the animal dies. This is the minimum bodyweight for a certain age calculated from the growth curve.

Feeds and feeding routine

The model contained an excel input file "input-LIVSIM_Shoat" which contain the input parameters and variables which are users determined. Feed quality and quantity are specified in the feed input file within the excel sheet.

Calculation of excreta production

LIVSIM simulates faecal dry matter production, faecal N, and urinary N faecal dry matter.

(Faecal DM) is calculated as:

$$\text{Faecal DM} = \text{DMI} \times (1 - \text{DMD}) \quad \text{Eq. 5}$$

Where DMD is dry matter digestibility which is an input to the model. Faecal N and urinary N are calculated by using the metabolizable protein (MP) system of AFRC (1993).

Mortality

Mortality is one of the most important factors affecting small ruminant production in the humid tropics. Causes of mortality are diverse, but are very often nutrition-related, age-specific, and management-dependent. In the literature, common causes are age, seasons of the year, diseases, nutritional inadequacy and sub-optimal management practices. Some of these causes are confounded, for instance, mortality due to diseases can be seasonal (Ayantunde 1994).

Mortality is based on age and body condition of the animal. The age-related mortality probability is calculated for different age range from first 15 days of the kid/lamb to 10th year. The mortality rates are from Dahl and Hjort (1976) because they are based on large data from Sudan on sheep and goats. Their results compare fairly well with reports by Singh *et al.* (1990); Mazumdar *et al.* (1980); and Mohan *et al.* (1986). In order to closely reflect the varying predisposition to death in early age of the animal, the cumulative mortality rates for the first six months reported by Dahl and Hjort (1976) were split into five ranges having the following upper ages (year): 0.042 (15 days), 0.083 (30 days), 0.167 (60 days), 0.25 (90 days), and 0.5 (180 days). These values were used in the model. Beyond 10 years, the probability of death is set at one, to prevent permanent presence of non-productive animals in the flock. Mortality rates due to causes other than under-nutrition (e.g. injuries, accidents, diseases, etc.) are input to the model.

Mortality due to under-nutrition, abortion, parturition, age and weight are described deterministically. Intake is driven by feed quality and bodyweight. Decision variables represent different management strategies related to feeding and reproduction. Mortality due to starvation is simulated using the growth routines taking the minimum bodyweight curve as threshold.

The initial composition of the flock is an input to the model. To start the simulation, a list of animal and feed characteristics needs to be provided (Table 3 and 4).

Table 3. Initial animal characteristics

Variable	Units
Sex	-
Age	Y
Initial bodyweight	kg
Reproductive status	

Feed quality parameters are adapted from AFRC (1993) and presented in Table 4.

Table 4. Feed characteristics

Variable	Units
Dry matter content	g kg ⁻¹
Metabolisable Energy (ME)	MJ kg DM ⁻¹
Crude protein (CP)	g kg DM ⁻¹
Acid Detergent Insoluble N (ADIN)	g kg DM ⁻¹
(a) fraction	
(b) fraction	
(c) fraction	
Dry matter digestibility	(DMD)

Nitrogen degradation parameters: a = proportion of water soluble N in the total N in a feed; b = proportion of potentially degradable N other than water soluble N in the total N of the feed; c = fractional rumen degradation rate per hour of the b fraction of the feed N with time (AFRC 1993).

Model validation

Sensitivity analysis

Model verification is a process of making sure that the model is doing what it is intended to do. Sensitivity analysis can be helpful in verification. An application of sensitivity analysis is described as which allows the user to estimate the degree of validity of a simulation model in absolute terms. If a model responds in an unacceptable way to changes in one or more inputs, then troubleshooting efforts can be focused to identify the source of the problem. Model validation ideally involves comparison of model results to independent observations from the system being modeled.

In a sensitivity analysis, values of parameters or inputs (or architectural features) can be changed to assess the changes in outputs or performance indices. The results of a sensitivity analysis can be used to validate a model, warn of unrealistic model behavior, point out important assumptions, help formulate model structure, simplify a model, suggest new experiments, guide future data collection efforts, suggest accuracy for calculating parameters, adjust numerical values of parameters, choose an operating point, allocate resources, detect critical criteria, suggest tolerance for manufacturing parts and identify cost drivers.

Approach

The sensitivity analysis for the LIVSIM Shoaat model for WAD goats was validated by comparing the test results with the sensitivity analysis report by Ayantunde (1994) with PCHerd model for moderate (12% CP) and good feed (19% CP).

The sensitivity of feed quality is tested using three different protein and metabolizable energy content.

Low feed quality: CP = 6% and ME = 8.8.11 MJ/kg DM

Moderate feed quality: CP = 9% and ME = 9.3 MJ/kg DM

Good feed quality: CP = 12% and ME = 11.7 MJ/kg DM

Feed quantity was assumed to be non-limiting in order to eliminate its effect. The test was performed for 10 simulation runs over a period of 10 years with starting flock size of five (four breeding does and one buck). This flock size is based on estimates commonly reported for smallholder goat husbandry systems in the tropics (FAO 1991). All other input parameters and variables were kept constant at default values. Adult weight used is 35kg, assumed for WAD goats in the humid tropics.

Results of sensitivity analysis and discussion

With low quality feed (CP 6%, ME 8.8) the flock (five starting adults and two kids born within the simulation) died out at the end of 24 months and the results were not reported. Similar result was observed in the sensitivity test of a model test (CP 6%, dry matter digestibility 55%), the flock died out at the end of fourth year (Ayantunde 2004). This implies that animals cannot be sustained on low quality forages which are characterised by the natural pasture of the southwest Nigeria. Due to their rapid growth in the wet season, these grasses become mature, fibrous and coarse, and their quality declines. Norton (2003) observed that feeds containing less than 8% crude protein content could not provide the ammonia levels required by rumen microbes for optimum activity and suggested supplementation of such forages with appropriate nutrients to achieve high levels of animal production.

Average daily growth rate on good quality feed (53g/d) was higher than the 39g/d predicted for goats on moderate feeds. Number of kids added after the simulation was higher on good quality feed than on moderate feed quality, and was comparable with the results obtained by Ayantunde (1994). For all the output variables measured in this simulation, the values for moderate feeds were consistently lower than the corresponding values for high quality feed except for kidding interval which was almost the same (moderate feed 293 days, good feed 290 days). Weaning weight were also similar under the two feeding regime (7.8kg).

Table 5. Production parameters on changing feed quality

Parameters	LIVSIM Shoaat prediction		PCHerd Predictions	
	Moderate quality feed	Good quality feed	Moderate ¹	Good ¹
Growth rate (g/d)	39± 2.13	53± 4.15	31±3.29	59±7.57
N	65	84	54	86
*Age at first kidding (yr)	1.9±0.11	1.6±0.13	NA	NA
N	54	60		
Kidding interval (days)	293±12	290±9	NA	NA
N	54	62		
Number of kids in the flock	65±4	97±2	77	112
Birth weight (kg)	1.7±0.34	2.5±0.21	1.4±0.01	1.6±0.29
N	51	75	77	112
Weaning weight (kg)	7.8±0.54	7.8±0.63	5.1±0.52	6.±0.42
N	51	87	57	89
Weight of kids at 12 months (kg)	14.6±1.66	18.2±1.46	14.3±0.41	22.3±0.79
N	45	62	54	86

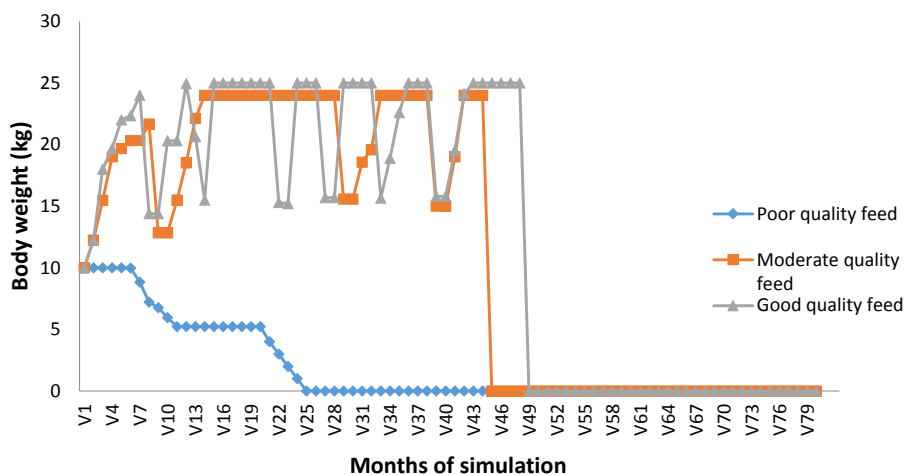
¹ Source: Ayantunde (1994) *Starting age one year included

The hypothetical crude protein and the metabolizable energy content of the moderate quality feed represent the additional household and kitchen waste occasionally available to free range animals in the traditional system in southwest Nigeria (Ademosun 1988). These kitchen wastes include cassava peels (CP of 5.5%) and yam peels (CP 7%) (Ifut 1998; Bell and Favier 1981) which are commonly eaten by free grazing animals roaming around the villages.

The CP was lower than what is required to supply adequate protein for maintenance and moderate growth (NRC 1981). Apart from the genetic limitations of the indigenous goats, heavy reliance on scavenging for food is responsible for the poor performance of the small ruminants because they are unable to meet their nutrients requirements through scavenging (Devendra 1985). Ademosun *et al.* (1988) also affirmed that unless well fertilized and harvested

young, tropical grasses alone cannot supply small ruminants with the nutrients required for a reasonable production level.

Figure 4. Lifetime weight development of one simulated goat fed poor quality, moderate quality and good quality feed respectively.



The lifetime weight development, age at first kidding, kidding interval and parity of the simulated goats were represented in Figure 4. Age at first kidding was delayed in the goats on moderate feed and fewer kids were born within the lifetime simulation. The moderate and the good quality feed in this simulation showed similar trend with moderate and good feed reported by Ayantunde (1994) using the PCHerd simulation. Although the moderate quality feeds in this simulation meet nutritional requirements, they were sufficiently energy and protein deficient to limit the full genetic potential of the animals.

In the model, reproduction is simulated using probabilities associated with bodyweight and age combinations. Effect of changes in adult weight on reproductive parameters; age at first kidding, kidding interval and body weight development: weaning weight and weight of kids at 12 months was analysed. To establish its effect, the default value (25kg) was varied from 15kg to 40kg which corresponds to -33.33% to 50% change. Most tropical breeds of sheep and goats fall within this range (Devendra *et al.* 1983). The simulation was for a period of 10 years with starting flock size of five for two types of feed quality. The nutrient contents of the feeds are as described in subsection 4.1.1. The results are displayed in Tables 6 and 7, and Figure 5.

The influence of nutrition-reproduction through the effect of bodyweight changes on sexual maturity as indicated by age at first kidding is prominent in this model.

An increase of 16.67% in adult body weight results in a 20.3% increase in probability of early kidding on good quality feed. An increase of the same margin results in only 0.6% increase chances of early kidding on moderate feed. Weight of an animal is an important indicator of puberty or sexual maturity. Similarly a decrease of 16.67% in the adult body results in 28% fall in the number of kids in the flock on good quality feed while same margin results in 62% fall in the number of kids at the end of the simulation. This re-affirmed the fact that nutritional adequacy is related to the influence of body weight on prolificacy. Regardless of the adult weight simulated, similar changes are recorded for birth weight in both cases, except at a decrease of 33.33% where it results in 13.7% and 22.7% fall in birth weight for both good and moderate quality feed respectively. Increase in adult weight reduced kidding interval on good quality feed. Similarly, change in adult weight inversely increased kidding interval in moderate quality feed, thereby reducing the number of kids in the flock (Figure 5). With provision of good feed, reproductive performance generally improves with increasing kidding rate.

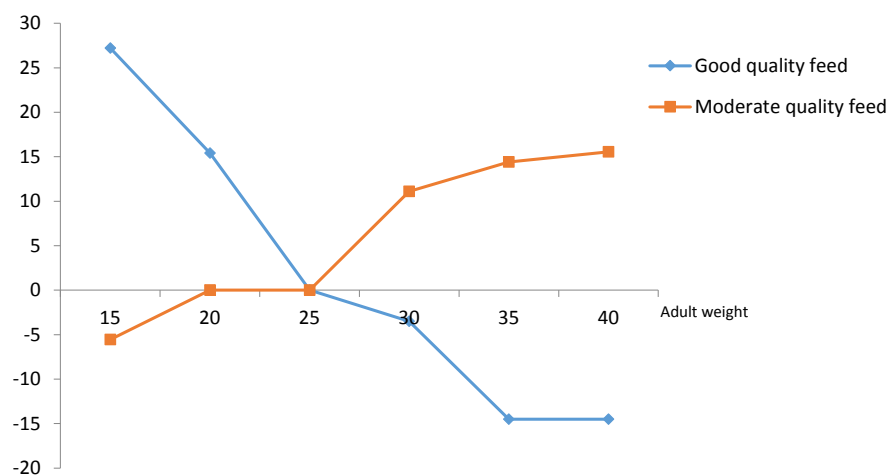
Table 6. Response of variable outputs to changes in adult body weight with moderate quality feed

Variables	15 -33.33%	20 -16.67%	25 0%	30 16.67%	35 33.33%	40 50%
Growth rate (g/d)	18 ± 1.13	28 ± 1.38	32 ± 0.43	54 ± 1.21	55 ± 0.03	58 ± 83
% change	-24.4	-56.4	0	71.7	76.1	83.5
Birth weight (kg)	1.7 ± 0.03	2.6 ± 1.62	3.8 ± 0.01	23.4 ± 0.01	2.7 ± 0.93	12 ± 0.21
% change	-22.7	-32.6	11.7	11.7	31.3	31.3
Weaning weight (kg)	7.8 ± 0.07	7.8 ± 0.07	7.8 ± 0.07	10 ± 1.03	12 ± 1.23	12 ± 0.21
% change	0	0	0	30.8	31.3	31.3
Weight of kids at 12 months (kg)	14 ± 1.03	16 ± 0.53	20 ± 0.38	22 ± 0.06	23 ± 0.01	26 ± 0.29
% change	-30.1	-17.9	0	8.54	16.7	27.9
Age at first kidding (yr)	1.9 ± 0.05	1.7 ± 0.03	270 ± 3.33	1.7 ± 0.01	1.76 ± 0.01	1.7 ± 0.02
% change	-16.9	0	0	0.60	1.66	1.8
Kidding interval (days)	255 ± 4.04	270 ± 3.33	270 ± 3.33	300 ± 3.98	309 ± 4.09	312 ± 2.13
% change	-5.56	0	0	11.1	14.4	15.56
Number of kids in the flock	129	179	0	31.8	31.8	35.5
% change	-17.2	-62.7				

Table 7. Response of variable outputs to changes in adult body weight with good quality feed

Variables	15 -33.33%	20 -16.67%	25 0%	30 16.67%	35 33.33%	40 50%
Growth rate (g/d)	22 ± 2.03	48 ± 4.21	55 ± 5.07	62 ± 2.02	67 ± 2.55	66 ± 2.26
% change	-59.3	-11.5	0	14.2	23.2	19.9
Birth weight (kg)	2.5 ± 0.1	2.6 ± 0.11	3.8 ± 0.13	3.4 ± 0.13	2.6 ± 0.01	2.6 ± 0.01
% change	-13.7	-32.6	0	11.7	31.3	31.3
Weaning weight (kg)	9.4 ± 0.21	9.2 ± 0.24	11 ± 0.21	11 ± 4.21	13 ± 2.05	15 ± 0.09
% change	-10.1	-12.9	0	0.95	20	38.1
Weight of kids at 12 months (kg)	17 ± 0.38	18 ± 0.41	18 ± 0.2	24 ± 2.35	28 ± 2.51	15 ± 0.09
% change	-13.3	-4.3	0	31.7	54.4	81.6
Age at first kidding (yr)	1.8 ± 0.12	1.8 ± 0.11	1.6 ± 0.31	1.9 ± 0.22	1.8 ± 0.38	1.9 ± 0.24
% change	-13.3	-12.6	0	20.3	15.8	20.3
Kidding interval (days)	1.8 ± 0.12	1.8 ± 0.11	1.6 ± 0.31	1.9 ± 0.22	1.8 ± 0.38	1.9 ± 0.24
% change	-13.3	-12.6	0	20.3	15.8	20.3
	290 ± 7.21	263 ± 5.58	228 ± 4.09	220 ± 2.54	195 ± 4.02	195 ± 4.02
	27.2	15.4	0	-3.5	-14.5	-14.5

Figure 5. Response of kidding interval to change in adult weight.



Simulation setup

For the simulations, a monthly time step was used for the purposes of the studies and because the model simulates discrete events by using stochastic variables. Replicated runs were used to estimate the output variables. The simulation was performed using the common feeding practice of the smallholders' goat production system in humid tropics and using the parameterisation for the WAD goat breed. Lifetime productivity parameters simulated for each production system include: body weight, age of the animal, age at first and last kidding, number of kids produced by doe, weight of kid at birth, weight of kid at weaning, and kidding interval. The effect of the treatments on indicators of lifetime productivity was evaluated with one-way analysis of variance with Statistical Analysis Systems (2008). SAS (SAS Institute 2008) was used to perform the statistical analysis using the number of runs as replicates and the differences between treatments were tested using the Duncan's Multiple Range Tests (1955). The levels of significant differences were generally taken to be at the 95% confidence interval ($P < 0.05$).

Scenario analyses

To evaluate the relative impact of different production systems on the lifetime productivity of the WAD goats, three scenarios were simulated based on the dominant feeding systems in southwest Nigeria namely free grazing, grazing with supplementation and stall feeding with cut-and-carry. The effects of different diets available in the three feeding systems were simulated. The simulation took into account the quality of available forages which are low during the four months (November–February) of dry season (Smith 1993), while other feeds were assumed to be constant in quality. Feed quantity was assumed to be non-limiting and was supply in excess in order to eliminate its effect. *Panicum maximum* was provided daily (kg/DM) at 15% body weight but reduced to 10% during dry season (November–February), while other feed were supply at 10% body weight except concentrate at 500g/day. The simulation used six animals (five mature does in their first parturition and one buck) which typify the situation of smallholder farmers in southwest Nigeria (Upton 1988). Inputs for feed quality were obtained from the literature.

Free grazing system

Major feed resources available in this extensive system of production are natural pasture which is composed mainly of different grasses and legumes. For the purpose of this simulation, *Panicum maximum* was selected as the available forage for the animals due to its dominance in natural pasture in southwest Nigeria (Olanite 2004). Cassava peels and maize bran are feed which were provided occasionally for the animals (Ademosun 1988).

Grazing with supplementation system

In this system, the animals are housed and often released for grazing and browsing of forages. In this simulation, the basic feed resource was *Panicum maximum* as the available forages during grazing. Supplementary feeds offered regularly were cassava peels and maize bran. Supplementation with browse legumes has been well researched and documented as potential feed resources for goat production which are available all year round (Smith 1992). *Gliricidia sepium* is a perennial fast-growing, highly prolific, leguminous browse plant (Sumberg 1984), which is commonly fed to goat in rural villages in southwest Nigeria (Atta-Krah *et al.* 1986).

Cut-and-carry feeding system

The simulation consists of complete zero grazing and provision of feed *ad libitum*. Feed resources are *Panicum maximum* as a cut-and-carry forage. Other feed resources are cassava peels provided *ad libitum* and commercially formulated concentrate offered at 500g/day (Chiboka *et al.* 1988; Fatoba *et al.* 2013). Concentrate composition used for

this simulation was (in per cent): maize 50.0, rice bran 30.0, brewers' dried grains 10.0, groundnut cake 7.5, dicalcium phosphate 1.5, salt 0.5, and vitamin mineral mix 0.5 (Ademosun 1998).

Table 8. Quality and quantity parameters of different feedstuffs used in the model simulations.

Feed	DM (g kg ⁻¹)	DMD (g kg ⁻¹)	ME (MJ kg DM ⁻¹)	CP (g kg DM ⁻¹)	a (kg N kg N ⁻¹)	b (kg N kg N ⁻¹)	c (kg N kg N h ⁻¹)
+Panicum maximum ¹	903	600	11.3	95.6	0.25	0.43	0.04
++Panicum maximum ¹	945	495	7.25	63	0.21	0.39	0.01
Cassava peels ²	928	719	7.67	54.4	0.43	0.44	0.11
Maize bran ³	880	750	13.5	120	0.77	0.43	0.02
Gliricidia sepium ⁴	893	650	11.3	216	0.42	0.49	0.24
*Concentrate ⁵	982	712	13.6	252	0.25+	0.64+	0.12+

DM = dry matter; DMD = dry matter digestibility; ME = metabolizable energy; CP = crude protein; a = proportion of water soluble N in the total N in a feed; b = proportion of potentially degradable N other than water soluble N in the total N of the feed; c = fractional rumen degradation rate per hour of the b fraction of the feed N with time (AFRC 1993). * 40% maximum percentage inclusion in the diet. ¹Quality and quantity from March–October; ²Quality and quantity from November–February; ¹DYNAFEED database ILRI; Ajayi *et al.* 2007; Abegunde *et al.* 2011; ²DYNAFEED database ILRI; Kalio, *et al.* 2013; Mako *et al.* 2013; Ifut 1987; Akinfemi *et al.* 2009; ³NRC 1978; Ayantunde 1994; ⁴Gusha *et al.* 2013; ⁵ Okafor *et al.* 2012; Ademosun 1998; +default values.

Results of simulated feeding system scenarios

Performance parameters of the starting flock simulated for each production system include body weight after one year, age of the animal, weight of kid at birth, and weight of kid at weaning. The production parameters of the initial flock from the three feeding systems are presented in Table 9. The average weight after one year (24.8kg) of goats in the cut-and-carry feeding system was significantly ($P<0.05$) higher than in other systems. Average daily gain was same in both cut-and-carry and free grazing with supplement system, but higher than in the free grazing system ($P<0.05$). Goats on free grazing attained puberty and kidded later (12 months after the start of simulation) than those on grazing with supplementation and cut-and-carry (10 months and 9 months, respectively). Change in body weight mass after parturition and throughout lactation was similar, irrespective of the feeding systems. However, weight recovery was significantly higher in the cut-and-carry feeding system.

The weight development of the initial flock at 13 months of the simulation are shown in Figure 6. Early weight development and attainment for optimum weight was observed in both supplementation and cut-and-carry, but kidding was earlier under the cut-and carry system.

The simulation results indicated higher ($P<0.05$) birth weight (2.1kg) in both grazing with supplementation and cut-and-carry feeding system than the free grazing system (Table 9). Supplementation either with concentrate feed or Gliricidia had a significant effect on the weaning weight of kids. Pre-weaning mortality (28%) was higher ($P<0.05$) in the free grazing feeding system than in other groups.

Total dry matter intake and faecal output were simulated in time steps of 30 days (Table 9). Animals on cut-and-carry had the highest ($P<0.05$) dry matter intake of 19.6kg DM/animal per month. Values obtained for the dry matter faecal output (8.5kg and 8.7kg DM) were similar ($P>0.05$) in both grazing with supplementation and cut-and-carry respectively. The lowest ($P<0.05$) faecal N of 1g/d per animal was recorded in goats on free grazing, while 3.2g/d per animal was predicted under cut-and-carry system.

Reproductive performance of the initial flock in the model were: age at first and last kidding, lifetime number of kids produced, and kidding interval (Table 10). The results indicated that goats on the cut-and-carry feeding system kidded at 10 months into the simulation. This was significantly ($P<0.05$) lower than 11 months and 13 months into the simulation recorded in goats on grazing with supplementation and free grazing respectively. The simulated kidding interval (295 days) was highest ($P<0.05$) in free grazing, while does on cut-and-carry recorded the lowest ($P<0.05$) kidding interval (195 days).

Table 9. Production parameter, dry matter intake and faecal output of starting flock under different feeding systems

Parameters	Free grazing	Grazing plus supplementary	Cut-and-carry	±SEM
*Number of reproductive female	5	5	5	-
*Age (year)	1	1	1	-
*Initial weight (kg)	10	10	10	-
Weight at 24th month (kg)	18.8 ^c	22.2 ^b	24.8 ^a	2.3
Growth rate (g/d)	9.2 ^b	18.99 ^a	25.2 ^a	7.1
Weight loss during lactation (kg)	8.8	9.1	9.23	1.6
Weight gain after lactation (kg)				
By first month after lactation	1.7 ^c	3.5 ^b	5.8 ^a	1.0
By second month after lactation	6 ^b	7.4 ^b	10.5.0 ^a	1.1
By third month after lactation	7.9 ^c	11 ^b	15. ^a	2.8
Pre-weaning mortality (%)	28.2 ^a	12.8. ^b	2.1 ^c	5.9
Post weaning mortality (%)	4.2 ^a	3.9 ^b	2.8 ^c	0.1
Birth weight (kg)	1.78 ^b	2.1 ^a	2.1 ^a	0.03
Weaning weight at 90 days (kg)	7.2 ^c	7.9 ^b	10.5 ^a	0.08
Total dry matter intake (kg/month/animal)	14 ^c	19.9 ^b	19.6 ^a	0.2
Total faecal dry matter output(kg/month/animal)	6 ^b	8.5 ^a	8.7 ^a	0.9
Faecal N (g/d/animal)	1	2 ^b	3.2 ^a	

a,b,c. means with similar letter within same row are statistically similar at 5% * Input factors.

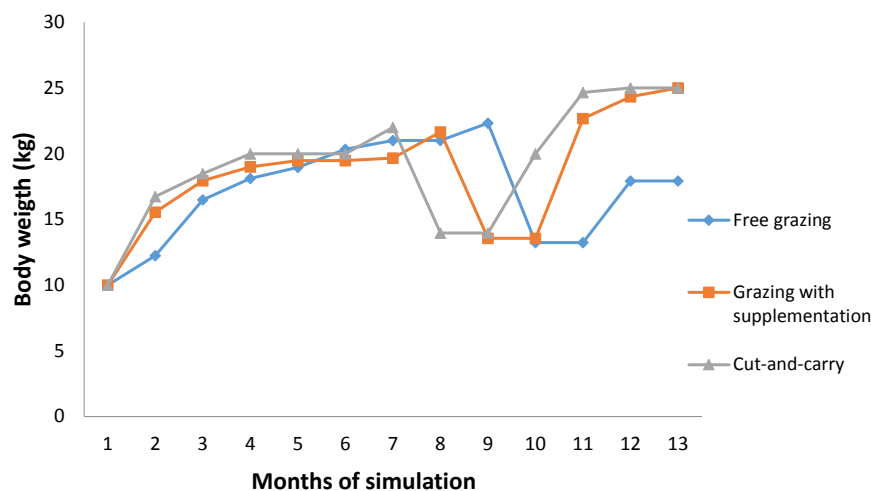
Table 10. Reproductive performance of the initial flock under different feeding systems

Parameters	Free grazing	Grazing plus supplementary	Cut-and-carry	±SEM
*Age at first kidding (yr)	2.0 ^a	1.8 ^b	1.7 ^b	0.3
Age at last kidding (yr)	2.4 ^c	4.7 ^b	5 ^a	0.03
Kidding interval (days)	290 ^c	254 ^b	195 ^a	48
Number of kid in the flock after 12 months	0.8 ^b	1.5 ^a	1.5 ^a	0.11
Number of kids in lifetime	2 ^b	6.5 ^a	6.5 ^a	0.33

starting age 1 year included

a,b,c. means with similar letter within same row are statistically similar at 5%

Figure 6. Weight development of one initial goat on the free grazing feeding system, grazing plus supplementation and cut-and-carry feeding system until the 13th month of the simulation.



The effect of the feeding system on the types of birth was simulated and the result presented in Table 11. Sexes of kids were not recorded. The genetic potential of the WAD goats for multiple births cannot be over-emphasized. Simulation results for birth type indicated higher multiple births in the cut-and-carry feeding system than free grazing system. Goats on grazing with supplementation predicted more ($P<0.05$) single births (56 kids) than in the other systems, while a higher ($P<0.05$) number of quadruplet births (28 kids) were predicted in the cut-and-carry feeding system. Among other reasons, the feed quality contributed to higher multiple births in the cut-and-carry system.

Table 11. Breakdown of kids born during the simulation under different feeding systems

Parameters	Free grazing	Grazing plus supplementation	Cut-and-carry	\pm SEM
Flock productive years	8.5 ^b	10 ^a	10 ^a	1.08
Number of kids/productive years	79 ^c	113 ^b	137 ^a	9
Single	34 ^b	56 ^a	37 ^b	4.6
Twins	26 ^c	32 ^b	57 ^a	3.7
Triplets	15 ^a	9 ^b	15 ^a	3.9
Quadruplet	4 ^b	16 ^c	28 ^a	1.01

a,b,c. means with similar letter within same row are statistically similar at 5%.

The effect of different feeding systems was simulated on the three generations of kids born within the simulation period of 10 years (Table 12). The productivity value of three generations of kid born within the simulation period was evaluated in terms of their birth and weaning weights and their reproductive performance in terms of age at first kidding and kidding interval.

Kids born within the cut-and-carry feeding system had similar ($P>0.05$) birth weight from generation to generation. These weights were higher ($P<0.05$) than those from the free grazing system. Pre-weaning growth rate increased in all the feeding system from first generation of kids to the third generation and was significantly higher in kids from the cut-and-carry system. Age at first kidding is an indication of sexual maturity. Feeding systems had effect ($P<0.05$) on the reproductive maturity of the second and third generation of kids in the simulation. Comparing free grazing and cut-and-carry feed system, sexual maturity was delayed (up to 21 and 22 months) in the second and the third generation of kids respectively under the free grazing feeding systems.

Table 12. Performance of kids born in different feeding systems

Parameters	Free grazing	Grazing plus supplementary	Cut-and-carry	±SEM
Birth weight (kg)				
First generation kids	1.8 ^b	2.1 ^a	2.1 ^a	0.34
Second generation kids	2.4 ^b	3.1 ^{ab}	3.4 ^a	1.0
Third generation kids	2.4 ^b	3.4 ^a	3.4 ^a	0.6
Pre-weaning growth rate (g d ⁻¹)				
First generation kids	18.9 ^c	35.4 ^b	43.9 ^a	4.3
Second generation kids	25.6 ^c	36.2 ^b	40.1 ^a	2.2
Third generation kids	30.8 ^c	37 ^b	59.1 ^a	12.4
Weaning weight (kg)				
First generation kids	7.2 ^c	7.9 ^b	10.5 ^a	0.6
Second generation kids	7.8 ^b	8.9 ^a	8.2 ^a	0.7
Third generation kids	7.7 ^b	9.2 ^{ab}	9.8 ^a	1.5
Age at first kidding (months)				
First generation kid	18.4	18.6	18.4	8.9
Second generation kid	21.2 ^a	17.6 ^b	12.8 ^c	4.0
Third generation kid	22.6 ^a	16.4 ^b	13.6 ^c	5.89
Average productive years of kids (yr)	4.6 ^b	5.2 ^a	5.4 ^a	

a,b,c. means with similar letter within same row are statistically similar at 5%.

The growth development of kids born within the simulation is presented by the growth curve over the 13 months of the simulation (Figure 7). The difference in post-weaning growth rate was evident until 13 months of the simulation with effect on the body weight at the end of the first year.

The reproductive performance of the kids, as shown in Figure 8, indicated a delay in sexual maturity, longer kidding interval and low number of kids in goats on free grazing (three) within five years. In comparison with free grazing, grazing with supplementation and cut-and-carry had early kidding, which resulted into more number of kids within five years. The figure indicated shortest kidding interval in does on cut-and-carry feeding system.

Figure 7. Twelve month's growth curve of kids on free grazing feeding system, grazing plus supplementation and cut-and-carry feeding system.

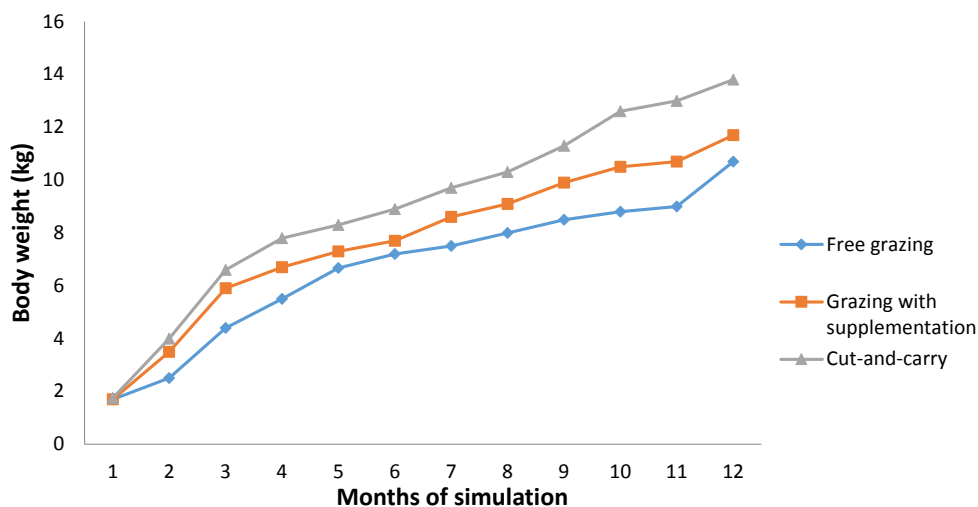
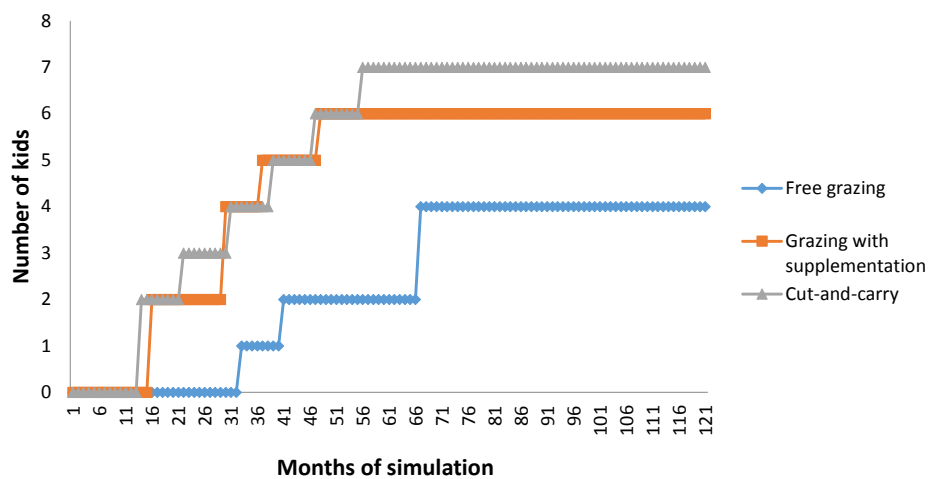


Figure 8. Lifetime reproductive performance of kids free grazing feeding system, grazing plus supplementation and cut-and-carry feeding system respectively.



Discussion

The main aim of this feed-driven model is to investigate the productivity of small ruminant flocks. It simulates the performance of the individual animal within the flock so that effects of changes in feed intake or herd dynamics on production traits and hence productivity can be assessed. Because most of the fixed parameters can be set by the user, the model is very flexible and can easily be tuned to production characteristics distinct from the default values.

The performance of our model is reasonable as a number of independent datasets were used to calibrate the different modules of LIVSIM. The model captures the effect of better quality diets on productivity indicators in a realistic way. Vital information on reproductive performance (weight at birth, weaning weight, proportion of multiple births), and weight at different ages are provided on individual animals. Many of these parameters could not be easily evaluated in field situation in view of practical problems with experimental design, data collection and analysis. The model also allows for testing numerous options (nutritional, reproductive and management) which could have required high financial resources, time and personnel commitment for experimentation.

The suitability of LIVSIM Shoaat to simulate the career of a small ruminant under different conditions can be judged from results of the sensitivity analysis and the operational validation. The operational validation of our simulation showed that goats required supplementation with protein and energy source at particularly pre-weaning, pre-partum and post-partum to promote lifetime productivity in terms of early sexual maturity, higher birth weight and shorter kidding interval. The result of the simulation revealed lower daily weight gain and late sexual maturity in goat on free grazing. As an important factor in determining life time productivity, delaying sexual maturity for a long time decreases lifetime production (Mruttu 2001). Supplementing free grazing WAD goat with protein and energy source either locally available feed resource or concentrate, will promote early maturity as showed in the result.

Change in body weight mass after parturition in the simulated goats was due to milk secretion for offspring. Such changes are generally drastic in malnourished lactating females and negatively influence the resumption of oestrus and ovarian activities (Durotoye and Oyewale 2000; Gubartalla 2002). Our simulation showed that earlier weight recovery, an indication of the quality of feed offered during this period is possible using cut-and-carry feeding system. This confirmed empirical studies that nutrition has a significant influence on body mass changes at different period of gestation and in the pre weaning period (Oyeyemi and Akusu 2002).

The simulation indicated higher pre-weaning mortality in the free grazing feed system than in other groups. Pre-weaning mortality of about 40% has also been recorded under the extensive system and it is higher than any other system (RIM 1991). The author attributed pre-weaning mortality to a number of causes: poor milk production by the dam, poor management and disease and poor mothering ability. Since the latter are not included in this simulation, poor milk production as a result of low quality of feed intake could be the main cause of pre-weaning mortality in this simulation.

Our simulation indicated prolong kidding interval as in the case of does on free grazing. This had been explained to be associated with inadequate nutrition which delays the occurrence of postpartum oestrus (Dadi *et al.* 2008). Also the interval could be affected by change in the quality and quantity of forages, which occurs during dry season of the year as was simulated in this model, as the natural forages are the main sources of goats' diet. With irregular or prolonged

kidding intervals, the goal of having three parturitions in two years becomes increasingly difficult to achieve. This was reflected in the lower number of lifetime kids in free grazing system. This is because kidding interval has to be less than 190 days for the twice a year kidding to be possible, and it has been proved that nutrition and early weaning are the primary factors responsible for shorter kidding intervals in the ruminants (Diskin et al. 2001). The simulation confirmed the potentials of browse legume inclusion in the WAD goats' diet to enhance higher conception rate, improves kidding interval, early weaning, hence improved productivity, as reported by Nouala et al. 2006; Pamo et al. 2006.

Our simulations identified different best-fit strategies as it combines feed resources and management systems together. Based on the results, our simulation provides two major areas of intervention to improve system productivity in a smallholder crop-livestock system as common in humid tropics of West Africa. The first best-fit strategy is the integration of protein-rich forage legume into arable crops as a better option to improve livestock feed quality of beside supplementation with browse legume. The effect of forage legume inclusion in animal feed to improve CP intake, stimulate dry matter (DM) intake of animals consuming cereals alone, increase rate of passage of digesta and utilization has been studied (Topps 1992). Other authors described the influenced of forage legumes inclusion in livestock feed on the digestibility of roughages, on nutrient utilization and animal performance (Leng 1990; Manyuchi 1994; Devendra 1995; Topps 1995).

Integration of forage legume also contributes to soil fertility and consequently crop production through the immediate transfer of N from the legume directly to the associated crop. Secondly, through residual effects in which N fixed by the legumes is available after senescence of legume residue to an associated sequentially crop. Evaluation of forage legumes incorporation with maize in southwest Nigeria showed that sowing *Lablab purpureus* two weeks after planting maize effectively controlled weeds, maximized maize yield by increased the shelling percentage and weight of 1000 maize grains (Amole et al. 2013).

Furthermore, lots of residues are generated from cropping and from households in southern Nigeria, however, its large-scale utilization is uncommon (Onwuka 1997). The common residues were those from cassava, maize, sorghum, rice, yam and cowpea. These were used to varying extents but, in some cases, burnt or left unutilized on the field. Seventy per cent of the cassava tuber peels were used as livestock feed. (Onwuka 1997). Very little effort was made to carry stovers of maize, rice and sorghum for animal feeding due to the distance between farms and homesteads.

The nutritional potentials of some residues need to be emphasized to farmers to encourage their further utilization in livestock feeding. Forage legume integration with arable crops also holds the capacity to enhance the quantity and quality of the crop residues. Amole et al. (2013) reported that the mixture of maize stover and *lablab* silage (70:30) produced feed ration with CP contents of 23% and increased daily weight gain of calves during the dry season. Formulation of ration using available feed resources—crop residues from forage-crop integrated plots, crop by-products, and browse plants—will limit the amount of concentrate use to strategic periods where availability and cost of concentrates are, however, major limiting factors facing smallholder livestock farmers. Other report maintained that the additional income from supplementation of concentrates does not justify the additional cost accompanied with it for these goats (Getahun et al. 2006).

Other intervention arising from the results of the simulation is confinement and supplementation with high energy and protein feed particularly pre and post- parturition and during pre-weaning in kids. Our simulation result showed that cut-and-carry feeding system leads to early maturity, short parturition interval, and increased rate of weight recovery after kidding, which increased the lifetime productivity of WAD goats and flock size, consequently, improved productivity. Market prices are determined by body weight; therefore, early attainment of market weight will increase farmers' income, and greater flock size is advantageous where there are no market constraints.

According to the results of this simulation, cut-and-carry feeding system also produced higher dry matter faecal output and faecal N. Livestock represents a means of gathering nutrients from the surroundings or from farmland which can become additions to the farm when manure is deposited during confinement. Powell et al. (1996) stated that nutrient recycling is critical to maintain the productivity of the land and to maximise the benefits from nutrient inputs in most

African farming systems. Although, there are trade-offs between increasing animal productivity, and income from livestock and sustaining crop production through cycling nutrients from animal manure (Rufino 2008). The appropriate means of efficient recycling of nutrient and minimizing the resources in smallholder crop-livestock system in humid tropics of West Africa will be that the residues are fed to animals and the faecal are returned to the farm. Nutrient recycling is slightly more complicated when livestock are not confined because nutrients will be ingested and excreted throughout the day some on-farm, and some off-farm. Its management and efficient utilization in terms of minimizing losses during collection and handling has been discussed (Rufino 2008).

It should be noted that because of the substantial nutrient removal from soil by the various crops in the form of grains and tubers (Giller *et al.* 1991), it requires among other things, inorganic fertilizers to keep pace with this loss and to raise agricultural productivity. Apart from the well-known health and environmental hazards associated with prolonged and heavy use of inorganic fertilizers, their availability and affordability by livestock producers have also been major constraints to their use (Oad *et al.* 2004). In Southwest Nigeria, large quantities of animal manures are generated daily from the high volume of animal production activities on varying scales (Osuhor *et al.* 2002). Increasing soil organic matter through manure application may serve both restoration of soils and mitigation of the effects of climate change through reduced vulnerability to erratic rainfall. The use of organic manures generally ensures effective and efficient management of soil by providing nutrients in correct quantity and proportion in environmentally beneficial forms (Gruhn *et al.* 2000). Farmyard manure can also improve nutrient and water use efficiency, as well as yields of common crops in the humidtropics of SSA (Juo and Kang 1989).

Our simulation emphasises the need to look for opportunities for small step improvements in lifetime productivity through resource management and strategic feeding regimes using available resource. This entails feeding residues formulated ration as supplement to basal feed in a cut-and-carry feeding system to improve system productivity in the humid tropics zones.

Conclusions and recommendations

LIVSIM Shoat simulation model provides detailed information that may be otherwise difficult to obtain through field studies. It could be used for ex-ante testing and comparing of different management options and simulating productivity across many different seasons and agro-ecological conditions, as well as the identification of system-component productivity gaps. In the light of the hypothesis of the humitropics strategic research theme, the simulation model could be used to evaluate the impact of well-managed integrated crop-livestock systems in other to provide opportunities to increase income, to improve productivity through improved nutrient cycling, and to recover resource integrity, as feed resources become more available.

LIVSIM Shoat is still in a developing phase. Raw data from real life scenarios are still needed to confirm further the sensitivity of the model. It is considered important to do the cost–benefit analysis of each system. Furthermore, based on the identified interventions, on-farm experimentation of the interventions is high recommended in full cooperation with all stakeholders. In other to obtain information on the sustainability of specific interventions and combinations of interventions, long-term monitoring sites should be established. The performance of best-bet formulated ration that minimize trade-offs between system productivity and other ecosystem services should also be evaluated. These insights are key in scaling up interventions that enhance sustainable intensification in livestock systems.

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