Running head: Individual animal data for sustainable intensification

Optimizing management of dairy goat farms through individual animal data interpretation: a case study of smart farming in Spain

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Highlights

-A gadget which integrates individual animal data to optimize farm management is proposed.

-Productivity of 24 commercial dairy goat farms was monitored throughout 4 years.

-Unproductive periods such as delaying the first partum age and dry period were minimized.

-Milk yield and genetic progress were accelerated.

-Production seasonality was decreased.

ABSTRACT

Dairy goat production systems in developed countries are experiencing an intensification process in terms of higher farm size, electronic identification, reproductive intensification, genetic selection and milking automation. This new situation generates “big data” susceptible to be used to aid farmers during the decision making process. This case study describes how the farm management can be improved by the use of the “Eskardillo”, a tool with a smart-phone terminal which relies on three principles: i) systematic individual data recording (milking control, productivity, genetic merit, morphology, phylogeny, etc.), ii) big data processing and interpretation and iii) interactive feedback to the farmer to optimize farm management. This study evaluated the effectiveness of the Eskardillo tool by monitoring the productive parameters from 2013 to 2016 in 12 conventional Murciano-Granadina dairy goat farms which implemented the Eskardillo (ESK) in late 2014. Moreover, 12 conventional farms without Eskardillo were also monitored as control farms (CTL). Results demonstrated that ESK farms were able to better monitor the productivity and physiological stage of each animal and Eskardillo allowed selecting animals for breeding, replacement or culling according to each animal´s records. As a result, goats from ESK farms decreased their unproductive periods such as the first partum age (-30 days), and the dry period length (-20 days) without negatively affecting milk yield per lactation. This study revealed an acceleration in the milk yield in ESK farms since this innovation was implemented (+26 kg / lactation per year) in comparison to the situation before (+7.3) or in CTL farms (+6.1). Data suggested that this acceleration in milk yield in ESK farms could rely on i) a greater genetic progress as a result of a more knowledgeable selection of high merit goats, ii) the implementation of a more effective culling off strategy based on the production, reproductive and health records from each animal, and iii) the optimization of the conception timing for each animal according to its physiological stage and milk yield prospects to customize lactation length while keeping a short and constant dry period length (2 months). Moreover, this study demonstrated a decrease in the seasonality throughout the year in terms of percentage of animals in milking and milk yield allowing an increment in the production of off-season milk (+17%) since Eskardillo was applied. In conclusion, it was demonstrated that the implementation of the Eskardillo tool can be considered a useful strategy to optimize farm management and to contribute to the sustainable intensification of modern dairy goat farms.

KEYWORKDS: dairy goats; farm management; decision making; smart-farming, unproductive periods

ABREVIATIONS: CTL, control farms; DIM, days in milk; DPL, dry period length; EBV, estimated breeding value; ESK, Eskardillo farms; FPA, first partum age; SCC, somatic cell counts

1. INTRODUCTION

In the olden days flock sizes were small and dairy goat farmers could identify animals by name, remember their parentage, age and sum up other important morphological and productive features. Each animal was approached and managed as an individual given the inherent diversity among them. As a result, domestic goats have traditionally represented an important source of protein through dairy and meat production, contributing to both the food and financial security of households from less favoured rural areas (Aziz, 2010). However, in recent years the dairy goat sector has experienced a rapid intensification in developed countries (Escareño et al., 2012, Gelasakis et al., 2017) as a result of an increasing demand for goat milk and the scarcity of land for new goat producers due to the competition for other land uses (Castel et al., 2011). Over the last 20 years farms have scaled up their sizes and have incorporated highly automated processes (i.e. milking, feeding, artificial insemination, etc.) which manage the flock as a whole (Castel et al., 2011). Farmers generally work with average values per group without taking into consideration each animal´s particularity, and the inter-animal variation is perceived as an impediment to achieve economies of scale (Boyazoglu and Morand-Fehr, 2001). This intensification has contributed to an increase in the worldwide production of goat milk and goat meat by 3% and 6% per year, respectively (FAOSTAT, 2017). However, our modern society has growing demands in terms of food safety, animal health and welfare and environmental concerns (Thornton, 2010), and farmers have rising pressure for increasing productivity, economic viability, professionalization, dignity of labour and sustainability. As a result, there is a need to revisit and update the current production systems (Castel et al., 2011)

The application of Precision Livestock Farming (PLF), which relies on the use of forward-thinking technologies to optimize the productivity of each individual animal by taking advantage of the inter-animal variability, could represent a step-forward to address these new demands (Wathes et al., 2008). To date, most of the PLF concepts applied to ruminants have mainly focused on very specific aspects of dairy cows such as implementation of automatic milking robots (John et al., 2016), oestrus detection (Mottram, 2016) and prevention of health problems (Bull et al., 1996). In the dairy goat sector it has been proved that the analysis of technical economic data can help to improve farm profitability (Ruiz et al., 2008), however little progress in terms of successful implementation of new technologies to optimize farm management has occurred so far. Perhaps the peculiarities of this sector, such as low net margin per animal, absence of individual milking robots and frequent utilization of grazing-based systems, have limited the implementation of PLF concepts (Wathes et al., 2008). However this sector is rapidly changing in developed countries, now the electronic identification of dairy goats is compulsory in the EU and many modern farms are experiencing intensification processes which generate "big data" susceptible of being analysed and interpreted (Wathes et al., 2008). This new scenario could facilitate the implementation of PLF-concepts as a strategy for optimizing farm management (Wolfert et al., 2017).

Cabrandalucía Federation, which comprises the main goat breeding associations in the Andalusian region (Spain) and represents over 50% of the national dairy goat production, has recently implemented a new concept of smart farming based on the use of "Eskardillo", a tool which incorporates PLF-like principles based on the integration of individual animal data to optimize decision making through a smart phone-based terminal. The aim of this study was to describe the basics of the Eskardillo tool and to evaluate its effectiveness by monitoring the shift in the productive indicators after this innovation was implemented in 12 conventional dairy goat farms (ESK). A similar number of control farms (CTL, without the innovation) were monitored as reference to better describe the progress of conventional dairy goat farms using the same production system. It was hypothesized that the implementation of a smart-farming strategy could help to optimize farm management in the current context of the dairy goat sector.

2. MATERIAL AND METHODS

2.1. Description of the tool

'Eskardillo' means "hoe to remove weed" because it allows to easily identify poor performing animals. This tool was first developed by Cabrandalucía federation and a software developer (Diseño software Kerkus S.L, Malaga, Spain) as a result of farmers´ need to optimize farm management (Figure 1). Eskardillo itself is an Android smartphone-based terminal which incorporates various elements: 1) an electronic chip reader to identify animals *in situ*, 2) a barcode reader to identify tubes with biological samples (milk, blood) or drugs used, 3) a digital camera to take pictures of for post-mortem certificates, 4) keyboard for data input, 5) a Wi-Fi connection for data transfer, 6) a mobile-phone SIM card to store data, 7) a touchscreen to navigate through the different pages and 8) software for data interpretation. However, Eskardillo tool relies on three principles (Figure 1): 1) systematic on-farm individual data recording as described in Table 1 together with remote data acquisition as a result of the milk control, morphologic evaluation and genetic selection program, ii) data storage, processing and interpretation by a supercomputer placed at Cabrandalucía headquarters (Granada, Spain), and 3) interactive feedback of processed data to the farmer to optimize farm management. The data-driven managing decisions can be performed using either a laptop-based software or the Eskardillo smart-phone terminal (Diseño software Kerkus S.L, Malaga, Spain).

(Figure 1 here)

The main data inputs and outputs of the Eskardillo tool are summarized in Table 1. Briefly, inputs were divided into those entered using the Eskardillo terminal and those acquired remotely from Cabrandalucía. Among the data which must be manually imputed by the farmer are those acquired at the time of birth (e.g. date of birth, sex, type of partum and ID) and those during the productive live (collar colour/location, sanitary treatment, artificial insemination, date and reason of culling/death). While the breeding association upload all relevant data regarding productivity, breeding value and reproductive tests. Thus, only those farms which are within the breeding program and milk control scheme, which implies monthly measurement of milk yield and milk components for each individual goat by certified controller staff, can effectively implement the Eskardillo. The morphology score was also determined by an officially certified referee at the end of the first based on the scoring of four anatomical sections: general appearance, milking aptitude, body conformation and mammary system (Sánchez et al., 2005). Moreover, the parentage of each offspring to its putative mother and father was assessed *in situ* at birth and confirmed by a blood DNA test. Pedigree registration and calculation of the estimated breeding value (EBV) were performed using the Siamelk software (Diseño software Kerkus S.L, Malaga, Spain). In order to facilitate the identification of high and low valuable animals, a "management index" was calculated based on the sum of the genotype (EBV) and phenotype in terms of milk yield and the morphological results.

As described in Table 2, the main advantage of the Eskardillo tool was the automatic integration of the updated individual animal data to aid farmers during key decision-making processes such as: 1) create groups of females for AI (best goats) or natural breeding (worse goats) based on various criteria (i. e. milk yield, lactation length or genetic merit; 2) identify the best female kids for replacement based on a specific criteria, and 3) identify animals with health issues or productive and reproductive deficiencies for culling.

(Tables 1 and 2 here)

2.2. Commonalities among farms

This case study was carried out on the southern region of Spain (Andalusia) which has a census of 1.1 million goats. A total of 24 dairy goat farms belonging to the Murciano-Granadina breeding association (Caprigran, Spain) were chosen, half of them (n=12) implemented the Eskardillo in late 2014 (ESK), while the other half (n=12) did not implemented this innovation and were considered as control (CTL). The 12 ESK farms were chosen based on the premise that they were the first ones to implement the Eskardilllo within the breeding association. It was decided not to use the average productivity progression of all farms included in the breeding association as a control group (89 farms) because they broadly differ in their management production systems. Moreover over the course of this study a large proportion of these farms (over 80%) implemented the Eskardillo, an element that could bias the comparison. Thus, 12 CTL farms were selected to represent the progression of conventional intensive dairy goat farms in the Andalusian region based on three premises: 1) absence of implementation of the Eskardillo during the course of this study, 2) similar productivity than the average for the breeding association at the beginning of the observational period (2013), and 3) share as many similarities as possible with the ESK farms in terms of geographical location, production system, feeding and reproduction management.

The 24 selected farms in this study (Table 3) were located on the south-east of Spain, used the same Murciano-Granadina dairy goat breed and shared the same breeding program (Caprigran). All farms followed the same official milk recording data scheme and the same official referees morphologically evaluated all animals across farms. Moreover all farms had a similar intensive production system based on the use of moderately high concentrate diets (approximately 50/50 forage to concentrate ratio) and nearly absence of grazing (only applied in 20% of the farms). Although some farms allowed goats to graze during a limited number of hours over certain periods of the year, most of the nutrient supply relied on indoor feeding for all farms. This indoor feeding was similar across farms consisting on *ad libitum* access to preserved forage (mainly alfalfa hay and cereal straw) and commercial concentrate supplementation obtained from similar providers. In terms of reproduction, all farms used natural mating with selected males based on the breeding program and most farms also used artificial insemination with high merit males. All 24 farms kept a similar production system during the course of this study and did not suffer relevant health issues which could bias data interpretation. Despite all these considerations, ESK farms tended to have a higher herd size than CTL farms even prior the Eskardillo implementation.

(Table 3 here)

2.3. Data acquisition and interpretation

In order to evaluate the impact of Eskardillo tool on farm management, productivity data of the 24 farms was monitored from 2013 to 2016 using the official Caprigran records. Three databases compiling the most relevant information from individual animals were considered:

The lactations database contained information about all the lactations completed by each animal in terms of animal identity (ID and parentage), relevant dates (birth, dry off, death or culling), reproductive information (lactation number, type of partum and litter size) and lactation information (days in milk, number of milk controls, milk yield and milk composition in terms of butterfat, protein, lactose, dry extract and somatic cells counts). The day in which the lactation finished was used as the criteria to assign lactation into natural years. Lactations compiling two or less milk controls, equivalent to 60 days in milk (DIM), were not further considered. This lactation database was used to calculate the average first partum age (FPA), the dry period length (DPL), days in milk (DIM) and total milk yield from each farm. Normalized milk yield was also calculated for 150 and 210 DIM for primiparous and multiparous goats, respectively. Fat and protein corrected milk yield (FPCM) was calculated for 4% fat and 3.3% protein content based on the international standard (Gerber et al., 2011):

$$\text{FPCM (kg)} = \text{raw milk (kg)} * (0.337 + 0.116 \times \text{Fat content (\%)} + 0.06 \times \text{Protein content (\%)})$$

The Estimated Breeding Value (EBV) database compiled the updated genetic merit o each animal in terms of milk yield and milk components. This EBV and its accuracy were estimated based on the productivity of each animal and all its relatives using information from certified lactations. Only those lactations which fulfil set criteria (more than 150 and 210 DIM and no missing more than 1 or 2 milk controls, for primiparous and multiparous, respectively) were considered as certified lactations (RD 368/2005 Spanish Government). In order to determine the genetic progress, two complementary approaches were considered using the EBV data from the last genetic evaluation (2016): one consisting on the analysis of the genetic progress of the replacement animals and other considering the flock average progress over the years.

The milk control database collected the information of milk yield and milk composition for each animal through the year based on the monthly milk controls. This database was used to determine the effect of the Eskardillo tool on the production seasonality in terms of percentage of animals in milk and percentage of the total milk yield distributed throughout the year. The coefficients of variation were also calculated to summarize the seasonality progress during the years. This database was also used to describe the reproductive plan based on the distribution of the kidding periods in the year.

2.4. Statistical analysis

Productive data from ESK farms was recorded before and after the Eskardillo implementation, thus it was considered that the hypothetical acceleration in their productivity would represent the most reliable approach to assess the effectiveness of this innovation. On the contrary, CTL farms should only be considered as reference data to describe the natural progression of conventional intensive dairy goat farms in the Andalusian region. Based on those premises, the production data for CTL and ESK farms were analysed separately. Each farm was considered as an experimental unit and individual animal data were averaged per farm. Data were analysed by ANOVA using the SPSS software (IBM SPSS Statistics, Version 21.0 New York, USA) considering the year as a fix factor (2013, 2014, 2015 and 2016) and each farm as a block. To analyse the effect of Eskardillo on the inter-animal variation (heterogeneity across animals), the standard deviation between animals was calculated for each farm and year. Pooled standard deviations were analysed by ANOVA as described before considering the farm as experimental unit. Since the FPA and the DPL did not follow a normal distribution, data were grouped into intervals and further analysed by ANOVA. It has hypothesized that that Eskardillo implementation could promote an acceleration in productivity to a greater extent than observed before its implementation or than reported in control farms; thus, the yearly change of a selection of the main productive indicators were analysed as repeated-measures analysis of variance using the MIXED procedure of SPSS as follows:

$$Y_{ijk}=\mu+E_i+T_j+ET_{ij}+F_k+e_{ijk}$$

where Y_{ijk} is the dependent, continuous variable expressed as yearly change, μ is the overall mean, E_i is the fixed effect of the Eskardillo tool (i = CTL vs ESK), T_j is the fixed effect of the year (j = 2014 vs 2015 vs 2016), ET_{ij} is the interaction and F_k is the random effect of the farm (k = 1 to 24) and e_{ijk} is the residual error. When P-value was below 0.05, differences among means were compared by the LSD test, while P-values between 0.05 and 0.10 were considered as trends.

3. RESULTS

3.1 Farm size, animal longevity and culling management

The similarities among the 24 farms used in this study in terms of production system, feeding, reproduction and productive data are described in Table 3. At the beginning of the observational period (2013) CTL farms were rather similar to the average of the 89 farms included in the breeding association in terms of number of reproductive periods per year (3.0 vs 3.2), replacement rate (31% vs 28%), prolificacy (1.62 vs 1.70), DPL (113 vs 112 days) and FPCM yield in 210 DIM (432 vs 423 kg). ESK farms had a greater milk yield than CTL farms or the overall breeding association, while CTL farms had a smaller number of reproductive goats.

Regarding the progression during the observational period (Table 4), the percentage of productive goats with a full parentage increased over time in CTL and ESK farms, however the percentage of animals with no parentage was lower for ESK than for CTL farms (14.5% vs 3.8%, respectively). Reproductive goats had an age which averaged 3.9 years and remained constant for both experimental groups, as well as the partum number distribution. Results showed an increase in the percentage of reproductive goats that exit CTL but not ESK farms. The longevity of those exit goats was slightly higher in CTL than ESK farms when expressed in years (5.2 vs 4.8 years) but the functional longevity (in terms of lactations completed in the lifetime) tended to increase in ESK farms since the innovation was implemented. The longevity standard deviation across animals remained constant for CTL and ESK farms indicating a similar inter-animal variation. Two thirds of the exit goats were sold as meat and one third died at the farm independently of the treatments, moreover a small percentage of reproductive goats (up to 6%) from ESK farms were sold to other farmers.

(Table 4 here)

3.4. First partum age (FPA) and first lactation

Results showed a wider dispersion of the FPA in CTL vs ESK farm (Table 5 and Figure 2A). In CTL farms 46% of the animals had a FPA between 13 and 16 months of age, while a similar proportion (48%) did above 17 months of age with a tendency to decrease the values of these later intervals over time. As a result, CTL farms showed a decrease over time in the inter-animal variation across animals. On the contrary, in ESK farms most of the animals had a FPA between 13 and 16 months of age, and with increasing proportion over time (from 54% in 2013 to 73% in 2016). As a result, the FPA tended to decrease similarly over time for CTL and ESK farms, but ESK farms had a FPA 1 month earlier than CTL. For primiparous goats, there were not changes over time in the number of DIM between treatments. In CTL farms values of milk yield and FPCM yield during the first lactation remained constant over time but increased in terms of milk yield per day, milk yield per 150 DIM and FPCM yield per 150 DIM without modifying the inter-animal variation within each farm. In ESK farms there was a substantial increase over time in the milk yield per day, per lactation and per 150 DIM. This increase in milk yield of primiparous goats was more obvious from 2014 onwards, year in which the Eskardillo management was implemented. This was associated with an increment in the inter-animal variation in terms of mil yield per lactation and FPCM per lactation as Eskardillo allowed longer lactations for high yielding animals.

(Table 5 and Figure 2 here)

3.5. Reproductive indicators, milk yield and genetic progress

Similar figures were observed for CTL and ESK farms in terms of prolificacy, lactations per year, days open and DIM, being these values unaffected by the year considered (Table 6). However, wider dispersion of the DPL was observed in CTL than in ESK farms (Figure 2B). In CTL farms only 35% of the animals had an optimum DPL of 2 months, while the proportion of animals with a short (<2 months) or long DPL (>3 months interval) represented 10% and 55%, respectively. Eskardillo implementation tended (P=0.077) to increase the proportion of animals within the 2 months interval and to decrease the proportion of animals with a DPL longer than 3 months. As a result, no differences on the average DPL were noted for CTL farms (Table 5), while values tended to decrease over time in ESK farms. In both scenarios DPL showed a substantial decrease in the inter-animal over time indicating a greater homogeneity across animals.

Control farms showed unchanged average milk yield over the years when expressed as kg milk / lactation or kg of FPCM / lactation, but increased when expressed per day (P=0.008) or per 210 DIM normalized lactations (P<0.039). Milk yield increase was more evident in ESK farms independently of the expression form considered and particularly since the Eskardillo was implemented. This milk yield increase in ESK farms was associated to an increment in the inter-animal variation in terms of milk yield per lactation and FPCM per lactation since Eskardillo allowed customizing the lactation length according to the individual milk yield. In terms of milk composition; CTL farms decreased the percentage of milk solids, milk fat and milk protein as a result of the milk dilution effect resulting on similar yield of milk components per lactation over the 4 years considered. This dilution effect was less evident for ESK farms resulting on a tendency to increase the total production of solids, fat and lactose per lactation since the Eskardillo management was implemented.

(Table 6 here)

In order to investigate whether Eskardillo tool enables an acceleration of the overall farm productivity, the yearly change of a selection of the main productive parameters was analysed in CTL and ESK farms using repeated measures (Table 7). Results indicated that since ESK was implemented in 2014, primiparous goats in ESK farms tended to yearly increase the DIM (+7.3 days), milk yield per lactation (+27.4 kg/year) and FPCM yield per lactation (+27.1 kg/year), while CTL farms remained constant. Similarly, the overall flock productivity tended to increase year after year since Eskardillo was implemented in terms of milk yield per lactation (+26.1 kg/year) and FPCM per lactation (+27.1 kg/year) to a greater extent than before implementation (+7.25 and +0.29 kg/year, respectively) or than in CTL farms (+6.1 and +2.3 kg/year, respectively). ESK farms also showed a yearly increased in the number of reproductive goats (*P*=0.009) in comparison to CTL farms, while no differences were noted in terms longevity, DPL and DIM. Control farms showed a yearly increase in the exit goats rate (+7.7 %/year) while ESK maintained the same rate across years (*P*=0.045). No significant effects were noted for the effect of the time and the interaction Tool × Time for the parameters considered.

(Table 7 here)

3.6. Breeding Value

Unfortunately, information on the EBV was scarce for CTL farms and the genetic progress was only calculated for ESK farms (Table 8). The flock average EBV for milk yield and milk components linearly increased over the 4 years considered (+3.7 kg FPCM per year) and its accuracy remained high. A similar increment in EBV for milk yield and milk components was observed for youngstock animals born from 2013 to 2015 (+1.9 kg FPCM per year) but significantly higher for those born in 2016. Since all data came from the same genetic evaluation, the EBV accuracy for animals born in recent years was substantially lower.

(Table 8 here)

3.7. Production seasonality

Reproductive plan widely differed between farms (Supplemental Figure 1); on average CTL farms had 3.0 reproductive seasons per year, while figures increased up to 4.67 in ESK farms (Table 9). Both group of farms tended to decrease the number of days with any animal in milking and CTL farms also tended to increase the average number of milkings per day. Control farms had a greater variation between months in the percentage of animals in milk varying from 31% to 91% (Figure 3). These CTL farms showed a high proportion of animals in milk from March to August (average 70%) while a low percentage was noted from October to February (49%). As result, the production seasonality, expressed as the coefficient of variation between months (Table 7), remained high and constant in CTL farms in terms of animals in milking and milk yield. On the contrary, ESK farms showed a more stable production with a relatively constant percentage of animals in milking (74%). Coefficient of variation analysis showed that ESK farms had lower and decreasing production seasonality over the years in terms of animals in milking and milk yield. A trend to increase the percentage of animals in milking during the off-season period (January and February) was noted since the Eskardillo was implemented.

(Table 9 and figure 3 here)

4. DISCUSSION

4.1. First partum age (FPA)

Increasing productivity and decreasing unproductive periods, such as the FPA and DPL, are considered the two main strategies to improve farm profitability in intensive dairy farms (Riveiro et al., 2013). Dairy goats reach the puberty around 5-7 months of age and 50-70% of the adult weight, thus increasing FPA beyond 13-14 months of age had no positive effects on milk yield but may decreased functional longevity (Jainudeen et al., 2000). The average FPA for the entire breeding association in 2013 (based on 89 farms) was 16.7 months which represents 3.7 months more than the economical optimum leading to an extra feeding cost equivalent to 100 maintenance rations. Our results showed that FPA tended to decrease in CTL and ESK farms, however the Eskardillo tool allowed better monitoring of the animal's age, which together with a higher number of kidding seasons per year, increased the proportion of animals with an optimum FPA since this innovation was included (up to 73%). Moreover, primiparous goats from ESK farms, despite having FPA 1 month earlier than CTL farms, yielded more milk during their first lactation (+146 kg). Indeed, primiparous goats experienced an acceleration in FPCM yield since the Eskardillo management was implemented (+27 kg/lactation per year) in comparison to the average increase in previous years (+16 kg) or in CTL farms during the same period (+4 kg), possibly as a result of greater genetic progress (see below). A study using Saanen goats (Torres-Vazquez et al., 2009) showed that FPA has a reasonable heritability (0.31±0.09) and was negatively correlated with milk yield, as noted in our study. Thus, the higher precocity observed in goats from ESK farms may partially explain their greater genetic progress and milk yield, although, special care must be taken to prevent an accelerated growth during pre-puberty which could compromise the mammary gland development (Macdonald et al., 2005).

4.2. Lactation and dry period length (DPL)

Current intensive dairy goats production systems result in significant overlap of lactation and pregnancy, however a dry period between lactations seems to provide several advantages to the animal such as replenishment of the body reserves, regeneration of mammary tissues, optimization of the endocrine events (Annen et al., 2004) and prevention of milk yield drop (-12%) in the subsequent lactation (Knight and Wilde, 1988). As a result, many farmers opt for having a lengthy DPL looking for further improvements. Several factors such as the parity number, inter-partum interval or level of production have been described to affect the optimal

DPL (Grummer and Rastani, 2004), however a general recommendation of approximately 2 months is frequently applied in dairy goats (Capuco and Akers, 1999, Caja et al., 2006) because no further improvements (and some detriments) on the subsequent lactation length and milk yield have been noted with longer DPL (Knight and Wilde, 1988). The average DPL for the entire breeding association in 2013 was 112 days which implies an extra feeding costs equivalent to 52 dairy goat rations. Our study showed that ESK farms tended to decrease the DPL leading to 21 days short DPL than CTL farms without detrimental effects on milk yield. This DPL shortage was accompanied by a decrease in the inter-animal variation over time suggesting a correct monitoring of the animal´s age in ESK farms. Several studies suggest that DPL in dairy goats can be decreased to 40 days without negative affecting milk yield and udder health (Fowler et al., 1991, Capuco and Akers, 1999, Salama et al., 2005). Since the Eskardillo tool facilitated tracking the health and physiological stage of each animal, it could open the possibility to further shortages of unproductive periods.

More controversy appears regarding the optimum duration of the lactation in goats (Salama et al., 2005). Farms are often managed in groups of animals which share a similar physiological stage and are dried off at a fixed date after parturition. This approach simplifies flock management but can lead to keeping animals in lactation with low productions, or otherwise drying animals with high milk yields, having both situations a negative impact on farm profitability (Salama et al., 2003). An analysis of 69,330 lactations in Murciano-Granadina goats from 130 farms (León et al., 2012) revealed that the lactation curve in terms of milk yield, predicted day of peak and persistency were highly affected by the lactation number, type of partum, kidding season and the geographical region, suggesting that this variation should be considered for optimizing flock management (Fernández et al., 2002). Moreover, pregnancy in goats has been shown to cause a significant decline in milk yield during the last third of the gestation (up to 57%) as a result of hormonal changes and foetus requirements (Knight and

Wilde, 1988). To better control these changing scenarios, a drying strategy driven by production and gestation stage can be applied (Grummer and Rastani, 2004). The Eskardillo tool allowed farmers to set a productivity threshold which represents the amount of milk yield required to cover their theoretical production costs. The lactation curve for each animal was modelled based on the aforementioned variation factors in order to determine the optimum conception time which ensured milk yield to be always kept above the productivity threshold throughout the entire lactation. Eskardillo also took into account the conception date and pregnancy tests results to optimize the dry off date for each animal in order to maintain a short and constant DPL (2 months). In other words, Eskardillo allowed decreasing DIM for low producing animals and increasing DIM for high yielding goats but keeping the same DPL. Our data showed that the implementation of this management strategy did not modify the average number of lactations per year, inter-partum interval, number of days open nor the DIM but tended to decrease the DPL in ESK farms (-10.5 days). These observations suggest that the decreasing in the DIM of low yielding animals was compensated by the increased in DIM of high yielding animals resulting on similar average DIM but increased productivity.

4.3. Milk yield and genetic progress

Our findings showed that milk yield in CTL farms had a minor increase over the years in terms of kg / lactation (+6.1 kg/year) or kg FPCM / lactation (+2.3 kg/year). Similar figures were noted in ESK farms before the innovation was applied (+7.3 and +0.3 kg/year, respectively), but a substantial acceleration was noted after Eskardillo implementation (+26.1 and +27.1 kg, respectively) revealing a step forward in productivity. This increment in milk yield tended to generate a slight dilution effect of the milk components for both CTL and ESK farms. Somatic cell counts in milk tended to increase in both groups of farms, being more evident for ESK farms. Similar high SCC in milk from cows with a shortened or omitted dry period but without clinical mastitis have been reported (Rémond et al., 1997) as a response to the typical SSC pattern throughout the lactation: high values at freshening, a nadir at mid-lactation and a gradual increase in late lactation (Annen et al., 2004).

A number of reasons, such as the genetic progress and reproductive intensification, could explain the observed increase in milk yield since the Eskardillo management was implemented. Eskardillo allowed customizing the lactation length according to the productivity of each individual goat as described before. Our analysis noted that this customization resulted on an increase in the inter-animal variation in terms of milk yield per lactation and in the overall flock productivity. Moreover Eskardillo helped to create breeding groups according to the EBV, despite all farms considered in this study shared the same breeding program. Thus goats with low EBV had natural mating while high EBV goats were artificially inseminated with semen from high merit males to generate replacement animals. Eskardillo also allowed optimizing the effectiveness of the AI by rejecting females with special circumstances which could limit the effectiveness of the insemination (e.g. reproductive problems, old females, peak of lactation, etc.) and facilitated the identification and allocation of newly born kids to their mothers. As a result, ESK farms increased the percentage of animals with full parentage (reaching 96% in 2016). The Eskardillo tool also aided farmers to identify the best animals for replacement based on customized selection criteria (e.g. milk yield, milk quality, morphology or a combination of them) according to the business priorities. These interventions accelerated the youngstock EBV which passed moderate +1.9 kg FPCM / lactation per year before Eskardillo was implemented to +15.3 during the last year of study. Although this acceleration should be carefully interpreted due to the low number of replacement animals and the low accuracy of the EBV, it seems to indicate that this smart-farming innovation can represent a step forward to maximize the genetic progress. Moreover, the Eskardillo tool provided real-time recommendations for each newborn kid based on its genetic merit (e.g. sale as meat / farm replacement / breeding buck). Thus, considering that high genetic merit kids with full parentage assigned have 2 to 3 times higher market price than similar kids sold for meat, this new income source is gaining interest in ESK farms. Beyond the Eskardillo tool, other factors such as the milk price, which picked in 2014, could also have affected milk yield across farms since farmers often increase the concentrate supply during those periods in order to maximize income from milk selling. As a result, these productivity data should be carefully interpreted despite no changes in the feeding management was reported by the farms used in this study.

Longevity is a highly desirable trait that affects overall farm profitability because the replacement cost is decreased and the proportion of mature animals, which produce more milk than young animals, is increased (Sewalem et al., 2008). Eskardillo eased the identification of poor performing animals in terms of low lifetime or current milk yield, low genetic merit, reproductive problems or morphological insufficiencies, resulting in a theoretical optimization of the culling off strategy. Although there is a general lack of scientific information about the strategies for culling dairy goats, an extensive French study using Alpine and Saanen goats under intensive production systems (Malher et al., 2001) revealed an average replacement rate of 34.4%, the main reasons for exiting goats being: mortality (36.6%), age (22.3%), infertility (20.2%), culling for voluntary reason (14.5%) and health issues (6.4%). Our study using the Murciano-Granadina breed showed lower exiting rates (22% per year) but the percentage of deaths in the farm was similar (34% of exiting animals) suggesting that a large proportion of animals kept high production levels until their death. However, the Eskardillo increased the proportion of culling decisions based on production, as a result up to 6% of the exiting goats from ESK farms were sold as reproductive animals to other less demanding farmers. Despite this exit rate, Eskardillo implementation did not affect the longevity (4.8 years) which remained similar to the average figures observed in the breeding association (5.0 years). Instead, functional longevity, in terms of lactations completed in the lifetime, tended to increase (+11%) since the Eskardillo was implemented. This approach based on removing animals with low productions or genetic merit could partially explain the increments in milk yield but also the increase in flock average EBV observed in ESK farms (+3.7 kg FPCM/year). Prolificacy rate was not affected by the Eskardillo implementation because this trait was not included in the selection program, but a higher prolificacy rate was noted in ESK vs CTL farms (+6.1%). Higher prolificacy "*per se*" should have a minor impact on the farm profitability since sales of suckling kids as meat only represent about 10% of the total income per goat (Sánchez, 2008). On the contrary, higher prolificacy may indirectly explain part of the milk yield increase observed in ESK farms as a result of the positive correlation between both traits in dairy goats (Crepaldi et al., 1999).

4.4. Production seasonality

The Murciano-Granadina breed is well adapted to Mediterranean environmental conditions and both sexes experience a reduction in their reproductive activity from February to May (Falagan et al., 1989, Arrebola et al., 2010). Our study noted such effects and CTL farms had a high proportion of animals in milk from March to August (70%) and a low proportion from October to February (49%) causing an unequal FPCM yield over those periods (64% vs 36%, respectively). Using computational models, it has been demonstrated that increasing the number of breeding seasons per year allows a decrease in feed, labour and other expenses to maintain the same number lactating does (Guimarães et al., 2009) but also to decrease the production seasonality as noted in our study. Control farms averaged 3 kidding seasons per year but varied from 1 to 5 resulting in a noticeable seasonality. Contrarily ESK farms showed a more stable production across the year with a relative constant percentage of animals in milking (74%) and monthly milk yield. This seasonality tended to decrease since the Eskardillo management was implemented resulting in similar percentages of animals in milking (79 vs 69 %) and FPCM yield (53 vs 46%) during the periods from March to August and from September to February, respectively. As a result, ESK farms increased the percentage of animals (+20%) and FPCM yield (+17%) during the off-season period (January and February). Eskardillo also facilitated establishing more but smaller groups of animals leading to a reproductive intensification consisting of 5 kidding seasons per year as the predominant strategy in the farms studied (83%). This strategy based on one breeding period every 72 days, provides sufficient time to perform a diagnostic test (ultrasound scan at 42 days post-conception) and offers non-pregnant does a second chance for conception in the following reproductive period. This decrease in seasonality in ESK farms together with the production of milk during the off-season-period should allow farmers to achieve a higher milk price and / or to prevent milk price volatility (Zarazaga et al., 2012). However, further research is needed to determine the impact of Eskardillo tool on economic indicators, carbon footprint and overall farm sustainability.

As a result of the advantages described in this case-study, many farmers have recently implemented the Eskardillo tool and over 80% of the farms in Caprigran are currently using this technology. However, some farmers are reductant to implement the Eskardillo. Among the reasons provided to adopt this technology are: i) the cost of the tool may not be profitable in small farms with a very low income; ii) the additional time required for the reproductive intensification and data collection, iii) the need for versatile facilities to house increased number of groups of animals with different physiological requirements, iv) the difficulty to adopt this innovation by farmers which are not familiar with new technologies and v) the farmers´ feeling of interference or intrusion of the Eskardillo in their decision making process. Thus, more technical training suitable to these farmers is needed to maximize the full potential of this innovation in the years to come.

5. CONCLUSIONS

This case study showed that the implementation of the Eskardillo tool can help to succeed with the intensification process in dairy goat systems allowing to: i) minimize the unproductive periods such as the first partum age and dry period length, ii) increase milk yield and accelerate the genetic progress and iii) minimize the production seasonality. However, more studies are needed to reveal the implications of this innovation on farm economics and sustainability over a longer time period as well as to minimize the effects of potential co-occurring factors inherent to the farm intensification process.

6. ACKNOWLEDGEMENTS

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Table 1. Summary of the information related to each animal available to the farmer via Eskardillo tool.

INPUT[1]	OUTPUT / FEEDBACK TO FARMER
ANIMAL DATA	**ANIMAL MANAGEMENT**
Date of birth and sex (f)	Updated age / Optimization first conception age
Type of partum (single / tween / caesarean) (f)	Animal records
ID / Ear-tag / Tattoo / Blood sample (f)	Records for parentage test
Mother ID and father ID (f)	EBV and appropriateness as replacement
Animal location / Collar colour (f)	Sorting animals for treatments / measurements
Sanitary treatments (f)	Grouping of animals for sanitary treatments and records
Movement of animals from farms / slaughter (f)	Animal traceability / Fulfilment of drug withdraw
Date and reason of culling / Death (f)	Update records of productive animals
REPRODUCTIVE DATA	**REPRODUCTIVE MANAGEMNT**
Days in milk and milk yield at conception (b)	Optimization of the conception timing
AI/Breeding dates and male used (f)	Estimated partum date and parentage
Pregnancy diagnostics results and date (b)	Relocation of non-pregnant / culling off
Miscarriages (f) / unsuccessful mating periods (b)	Detection of reproductive problems
Partum number and date (b)	Identification old animals / Prediction lactation curve
Number of kids born and sexes (b)	Prolificacy records / Prediction lactation curve
Offspring selected for replacement (b)	Optimizing animal selection
PRODUCTIVE DATA	**PRODUCTIVE MANAGEMNT**
Lifetime milk production (b)	Selection of high or low producing animals
Dry period length (b)	Detection of excessive dry period length
Lactation length (b)	Optimization of lactation length
Milk yield and quality every 4 weeks (b)	Identify top and bottom animals
Milk Somatic Cells Counts (b)	Identify mastitis
Lactation curve prediction (b)	Optimization of the conception timing / feeding
Current milk yield (b)	Optimization of feeding strategy
Number of milking periods per day (b)	Optimization of labour resources
Current physiological stage (b)	Updated physiological situation of all animals
GENETIC DATA	**GENETIC MANAGEMENT**
EBV for milk yield / milk fat / milk protein (b)	Customized selection
Morphological assessment (4 components) (b)	Morphological information for selection
Management index (b)	Overall indicator for replacement selection

[1] In brackets is described whether the inputs are manually assigned by the farmer (f) or remotely acquired from the breeding association (b). Inputs and outputs within the same raw are related.

Table 2. Description of the different options to generate groups of female goats for breeding, replacement or culling using the Eskardillo tool.

NATURAL BREEDING PROPOSAL
1) Generate a breeding group based on individual milk yield (profitability threshold):
a) Select primiparous below a milk yield threshold (e.g. 1.7 kg) or a percentile (e.g. bottom 20%)
b) Select multiparous below a milk yield threshold (e.g. 2.2 kg) or a percentile (e.g. bottom 20%)
2) Generate a breeding group based on lactation length:
a) No select females with less than a lactation length threshold (e.g. 90 DIM)
b) Select all females with more than a lactation length threshold (e.g. 210 DIM)
3) Select all dry and non-pregnant females*
4) Select all females in the same group*
5) Select a fixed number of females per group (e.g. 100 does)
ARTIFICIAL INSEMINATION PROPOSAL
1) Generate a breeding group based on the Estimated Breeding Value (EBV):
a) Select females with positive EBV for milk yield*
b) Select females with positive EBV for milk yield, milk fat and milk protein*
2) Generate a breeding group based on individual milk yield (profitability threshold):
a) No select primiparous below a milk yield threshold (e.g. 1.9 kg) or a percentile (e.g. bottom 50%)
b) No select multiparous below a given milk yield (e.g. 2.5 kg) or a percentile (e.g. bottom 50%)
3) Select all available best females (mothers of future breeding bucks)*
4) No select females currently located with bucks*
5) No select females with less than a lactation length threshold (e.g. 120 DIM)
6) No select females with more than a lactation length threshold (e.g. 290 DIM)
7) No select old females (e.g. more than 7 parturitions)
8) No select females without enough milk potential to generate breeding bucks*
9) No select more than a given number of females for AI (e.g. 60 does)
PROPOSAL FOR FEMALE REPLACEMENT
1) Define annual number of females to be selected as replacement (e. g. 120)
2) Define the number of females to be selected from the last or next breeding season (e.g. 30)
2) Select all daughters from breeding bucks with a management index above a given number (e.g. 80)
3) Select females based on a specific criteria:
a) Management index*
b) Productive value*
c) Morphology value*
d) Estimated breeding value for milk yield*
e) Estimated breeding value for milk protein*
f) Estimated breeding value for milk fat*
f) Estimated breeding value for milk yield and composition*
CULLING PROPOSAL
1) Define annual number of females to be culled off (e. g. 80)
2) Select low productive females based on:
a) Low lifetime milk potential (e.g. 1.2 kg)
b) Low milk yield during the last lactation (e.g. 1.3 kg)
c) Low milk quality
3) Select females with reproductive or health problems:
a) Select females with high number of mating periods without gestation (e.g. 4)
b) Select females with high number of consecutive miscarriages (e.g. 2)
b) Select dry and non-pregnant females*
c) Select nulliparous goats above a certain age (e.g. 18 months)
d) Select females with consistently high milk SCC or mastitis*

*This option is a binary question (yes / no)

Table 3. Description of the feeding and breeding management and productivity of the farms selected for this study and the average for the breeding association (all data based in 2013).

Farm	Location	System	Feeding[1]	Forages[2]	Concentrate[3]	Breeding[4]	RP/yr[5]	Goats	Repl.[6]	Prolificacy	FPA[7]	DPL[8]	DIM[9]	MY[10]	FPCM[11]
Caprigran[12]							3.2±1.5	299±167	28±14	1.70±1.12	16.7±5.40	112±64	244±107	1.70±0.70	423±151
CTL 1	Almeria	Intensive	In.	AH, ST	Alimer	NM	2	145	45	1.60±0.61	17.8±3.32	88±49	224±31	2.1±0.59	549±273
CTL 2	Almeria	Intensive	In.	AH, ST	Alimer	NM	3	190	24	1.78±0.59	14.3±2.83	109±74	265±95	1.7±0.60	429±216
CTL 3	Granada	Intensive	In.	AH, ST	Nanta	NM+AI	2	108	42	1.13±0.56	19.2±3.12	113±48	217±50	1.3±0.46	351±180
CTL 4	Cordoba	Intensive	In.	AH, ST	Covap	NM	5	138	29	1.69±0.65	17.0±4.67	99±31	314±157	1.9±0.60	486±252
CTL 5	Granada	Intensive	In.+Gz.	AH, ST	Nanta	NM+AI	2	220	16	1.67±0.61	24.3±7.76	90±29	235±88	1.3±0.34	303±153
CTL 6	Granada	Intensive	In.	AH, ST	Nanta	NM+AI	1	192	27	1.95±0.61	14.2±0.46	89±61	255±43	1.6±0.42	443±178
CTL 7	Almeria	Intensive	In.+Gz.	AH, ST	Alimer	NM	1	228	20	1.71±0.59	14.5±5.74	91±12	263±40	1.5±0.46	368±129
CTL 8	Cordoba	Intensive	In.+Gz.	AH	Cereals mix	NM	3	213	35	1.36±0.59	29.7±9.30	181±92	201±61	1.2±0.37	320±167
CTL 9	Granada	Intensive	In.	AH, ST	Nanta	NM+AI	5	184	28	1.80±0.63	19.3±4.67	131±103	220±90	1.4±0.50	455±243
CTL 10	Almeria	Intensive	In.+Gz.	AH, ST	Alimer	NM	1	160	51	1.53±0.63	17.8±5.37	116±59	268±49	1.9±0.48	462±216
CTL 11	Cordoba	Intensive	In.	AH, ST	Covap	NM+AI	4	229	21	1.57±0.53	14.7±2.95	133±62	304±112	1.9±0.58	522±237
CTL 12	Cordoba	Intensive	In.	AH, ST	Covap	NM+AI	5	338	21	1.63±0.57	18.4±3.59	94±63	248±96	1.7±0.64	507±272
ESK 1	Granada	Intensive	In.	AH, ST	Nanta	NM+AI	6	543	35	1.74±0.81	15.6±2.0	70±15	267±74	2.2±0.60	585±251
ESK 2	Jaen	Intensive	In.	AH	Filabres	NM+AI	3	158	14	1.82±0.67	17.0±2.18	77±21	287±86	1.4±0.46	404±183
ESK 3	Cordoba	Intensive	In.	ST	Covap	NM+AI	6	233	24	1.68±0.68	16.2±2.84	65±24	281±74	2.7±0.78	674±267
ESK 4	Granada	Intensive	In.	AH, ST	Nanta	NM+AI	2	114	11	1.87±0.64	15.7±3.66	99±23	260±35	1.3±0.31	338±125
ESK 5	Almeria	Intensive	In.	ST, BP	Nanta	NM+AI	3	187	40	1.80±0.65	15.7±3.61	95±53	226±70	1.6±0.40	396±205
ESK 6	Almeria	Intensive	In.	AH	Nanta	NM+AI	4	320	52	1.57±0.64	17.4±3.57	85±25	266±49	2.2±0.56	550±209
ESK 7	Granada	Intensive	In.	AH, ST	Nanta	NM+AI	6	518	41	1.56±0.68	16.2±2.48	77±23	239±67	1.9±0.55	508±250
ESK 8	Granada	Intensive	In.	AH, ST	Nanta	NM+AI	4	344	24	2.07±0.71	18.4±3.32	74±45	295±100	2.3±0.68	627±263
ESK 9	Almeria	Intensive	In.	AH, ST	Alimer	NM+AI	4	127	38	1.76±0.62	13.4±1.64	72±23	256±68	2.5±0.72	655±292
ESK 10	Granada	Intensive	In.	AH, ST	Nanta	NM+AI	3	131	25	1.73±0.64	24.0±9.43	58±14	217±52	2.1±0.66	536±252
ESK 11	Granada	Intensive	In.+Gz.	AH, ST	Moreno	NM+AI	4	494	40	1.68±0.65	14.0±2.55	74±32	253±109	1.8±0.50	472±238
ESK 12	Toledo	Intensive	In.	ST	Uniproca	NM+AI	1	282	28	1.94±0.34	16.8±1.64	127±77	287±105	1.7±0.54	481±227

Abbreviations: 1) In, Indoor feeding; Gz, Grazing outdoor. 2) AH, alfalfa hay; ST, cereal straw; BP, horticultural by-products. 3) Concentrate feed supplier. 4) NM, natural mating with selected males; AI, Artificial insemination with high merit males. 5) Number of reproductive periods per year. 6) Replacement rate percentage. 7) Fist partum age in monthss. 8) Dry period length in days. 9) Days in milk. 10) Milk yield per day (kg/d). 11) Fat and protein corrected milk yield in 210 days in milk (kg/lactation). 12) Average values for the Breeding Association based in 89 farms.

Table 4. Progression of number of animals and lactations, parentage and culling rate of dairy goats from a group of Control farms and in farms that implemented the Eskardillo management in 2014.

	CONTROL						ESKARDILLO					
	2013	**2014**	**2015**	**2016**	**SED[1]**	***P*-value**	**2013**	**2014**	**2015**	**2016**	**SED[1]**	***P*-value**
Productive goats	196	193	208	196	10.88	0.507	288^{b}	295^{b}	346^{ab}	393^{a}	21.9	0.006
Age, years	4.06	4.08	3.99	3.82	0.139	0.282	3.73	3.85	3.85	3.84	0.137	0.799
SD	*2.00*	*1.99*	*2.07*	*2.05*	*0.071*	*0.543*	*1.70*	*1.81*	*1.82*	*1.88*	*0.104*	*0.396*
Known parentage, %												
Full	74.1^{c}	77.3^{bc}	81.6^{ab}	84.5^{a}	2.93	0.001	88.9^{c}	90.9^{bc}	93.9^{ab}	95.7^{a}	2.12	0.015
Half	2.23^{a}	1.19^{b}	1.07^{b}	0.97^{b}	0.476	0.041	2.34^{a}	1.61^{ab}	0.80^{b}	0.50^{b}	0.608	0.020
None	23.7^{a}	21.5^{ab}	17.3^{bc}	14.5^{c}	2.712	0.002	8.74	7.52	5.31	3.85	1.916	0.068
Lactations completed	220	213	233	212	9.67	0.131	318^{b}	336^{b}	380^{b}	446^{a}	30.8	0.001
1st partum, %	26.7	25.1	27.5	31.7	3.96	0.397	27.0	28.4	28.1	27.2	3.64	0.977
2nd partum, %	24.4	22.0	21.3	21.2	3.07	0.694	26.6	21.1	24.3	22.0	3.57	0.414
3rd partum, %	17.1	17.4	16.4	15.6	2.13	0.847	16.6	18.2	15.8	18.8	2.83	0.702
4rd partum, %	12.8	13.9	12.2	11.2	1.94	0.532	13.1	11.4	12.5	11.3	2.49	0.872
5th partum, %	8.59	10.3	10.1	7.42	1.71	0.328	5.78	9.77	7.5	8.45	1.8	0.176
6th or more, %	9.47	11.2	12.5	12.9	1.66	0.170	10.9	10.5	11.7	12.2	1.56	0.673
Number of exit goats	31.7^{b}	40.5^{ab}	58.1^{a}	65.5^{a}	13.0	0.027	57.5^{c}	70.0^{bc}	81.8^{ab}	93.3^{a}	10.1	0.011
Exit goats, %	14.7^{c}	21.8^{bc}	28.9^{ab}	35.7^{a}	6.09	0.004	17.5	22.3	23.6	23.6	3.50	0.277
Longevity, years	5.12	5.32	5.08	5.21	0.301	0.861	4.65	4.64	4.86	4.91	0.187	0.331
SD	*2.24*	*2.13*	*2.17*	*2.27*	*0.144*	*0.772*	*1.828*	*1.889*	*2.032*	*2.075*	*0.147*	*0.302*
Lactations completed	3.70	3.87	3.64	3.67	0.244	0.782	3.75	3.56	3.72	3.97	0.161	0.100
SD	*2.10*	*1.90*	*1.98*	*2.07*	*0.160*	*0.651*	*1.84*	*1.84*	*1.94*	*2.07*	*0.141*	*0.285*
Reasons for exit												
Dead in the farm, %	31.4	37.5	33.9	25.7	12.3	0.796	35.9	36.8	34	34.2	8.95	0.986
Culled as meat, %	68.6	62.5	66.1	74.3	12.3	0.796	63.9	62.5	60.1	63	9.32	0.979
Sold to farmers, %	ND	ND	ND	ND			0.11	0.68	5.98	2.78	3.78	0.411

[1] Standard error of the difference among means. Within a raw and group, means without a common superscript differ ($P < 0.05$). Standard deviation (SD) indicates the inter-animal variation within each farm and year.

Table 5. Progression of the first partum and age and milk yield of primiparous dairy goats from a group of Control farms and in farms that implemented the Eskardillo management in 2014.

	CONTROL						ESKARDILLO					
	2013	**2014**	**2015**	**2016**	**SED[1]**	***P*-value**	**2013**	**2014**	**2015**	**2016**	**SED[1]**	***P*-value**
First partum age, months	18.6	17.0	17.1	16.2	0.530	0.057	16.5	15.3	15.2	15.2	0.560	0.076
SD	*4.85*^{a}	*3.33*^{b}	*3.48*^{b}	*3.73*^{ab}	*0.497*	*0.042*	*3.24*	*2.20*	*2.57*	*2.49*	*0.500*	*0.216*
Days in milk, d	244	237	233	222	8.80	0.465	251	250	258	265	12.2	0.594
SD	*89.1*	*76.9*	*79.7*	*78.6*	*8.56*	*0.798*	*65.5*	*71.4*	*81.4*	*82.2*	*9.07*	*0.211*
Milk yield												
kg / d	1.38^{bc}	1.34^{c}	1.48^{ab}	1.51^{a}	0.057	0.013	1.64^{c}	1.69^{bc}	1.78^{ab}	1.85^{a}	0.059	0.006
SD	*0.45*	*0.40*	*0.43*	*0.46*	*0.026*	*0.130*	*0.45*^{ab}	*0.40*^{b}	*0.43*^{ab}	*0.48*^{a}	*0.027*	*0.064*
kg / lactation	344	325	353	343	17.5	0.716	413^{c}	434^{bc}	466^{ab}	489^{a}	24.6	0.020
SD	*170*	*162*	*180*	*172*	*17.8*	*0.700*	*165*^{b}	*170*^{b}	*202*^{a}	*205*^{a}	*15.4*	*0.019*
kg / 150 DIM	212^{bc}	204^{c}	229^{ab}	237^{a}	7.42	0.012	252^{c}	264^{bc}	276^{ab}	293^{a}	9.36	0.001
SD	*90.4*	*82.1*	*91.4*	*92.4*	*6.19*	*0.350*	*85.8*	*86.4*	*84.5*	*85.9*	*7.07*	*0.994*
kg FPCM / lactation	404	387	402	394	29.2	0.961	486	502	533	556	28.3	0.080
SD	*199*	*192*	*208*	*196*	*21.4*	*0.850*	*190*^{b}	*199*^{ab}	*232*^{a}	*232*^{a}	*19.3*	*0.073*
kg FPCM /150 DIM	242	239	255	268	11.5	0.054	300	303	313	325	9.61	0.054
SD	*102*	*94.0*	*100*	*102*	*6.80*	*0.629*	*100*	*96.9*	*93.6*	*93.5*	*8.80*	*0.861*

[1] Standard error of the difference among means. Within a raw and group, means without a common superscript differ ($P < 0.05$). Standard deviation (SD) indicates the inter-animal variation within each farm and year.

Table 6. Progression of reproductive indicators and milk yield of dairy goats from a group of Control farms and in farms which implemented the Eskardillo management in 2014.

	CONTROL						ESKARDILLO					
	2013	**2014**	**2015**	**2016**	**SED**[1]	***P*-value**	**2013**	**2014**	**2015**	**2016**	**SED**[1]	***P*-value**
Physiology												
Prolificacy, kids / partum	1.62	1.70	1.63	1.64	0.046	0.214	1.77	1.73	1.73	1.74	0.052	0.823
SD	*0.60*	*0.60*	*0.59*	*0.59*	*0.012*	*0.741*	*1.12*	*1.05*	*0.68*	*0.69*	*0.343*	*0.448*
Lactations per year	1.05	1.06	1.09	1.11	0.025	0.392	1.07	1.13	1.09	1.11	0.035	0.439
SD	*0.50*^{a}	*0.49*^{a}	*0.50*^{a}	*0.21*^{b}	*0.034*	*<0.001*	*0.19*	*0.24*	*0.21*	*0.19*	*0.029*	*0.233*
Days in milk, d	251	253	243	244	4.670	0.118	261	255	263	264	6.35	0.774
SD	*79.0*	*77.9*	*74.8*	*81.6*	*5.010*	*0.576*	*74.1*	*79.6*	*85.5*	*86.0*	*6.30*	*0.213*
Days open, d	219	210	204	208	10.17	0.601	204	191	201	191	9.98	0.432
SD	*113*^{a}	*105*^{a}	*98.3*^{a}	*39.8*^{b}	*8.52*	*<0.001*	*101*^{a}	*100*^{a}	*108*^{a}	*80.9*^{b}	*7.38*	*0.006*
Dry period length, d	113	105	105	91.2	4.99	0.219	81.2	78.3	76.6	70.7	2.91	0.094
SD	*56.6*^{a}	*39.6*^{a}	*38.5*^{a}	*17.8*^{b}	*7.39*	*<0.001*	*31.3*^{a}	*30.4*^{a}	*26.6*^{a}	*17.8*^{b}	*3.84*	*0.005*
Milk yield												
kg / d	1.63^{c}	1.69^{bc}	1.77^{ab}	1.85^{a}	0.050	0.008	1.96^{c}	2.02^{bc}	2.08^{b}	2.17^{a}	0.037	<0.001
SD	*0.51*	*0.55*	*0.54*	*0.57*	*0.021*	*0.029*	*0.56*	*0.58*	*0.58*	*0.61*	*0.022*	*0.263*
kg / lactation	415	431	435	432	13.0	0.614	513^{c}	520^{bc}	554^{ab}	572^{a}	12.4	0.005
SD	*199*	*213*	*209*	*228*	*13.4*	*0.132*	*221*^{b}	*227*^{b}	*254*^{a}	*256*^{a}	*10.7*	*0.003*
kg / 210DIM	368^{b}	388^{ab}	401^{a}	409^{a}	7.76	0.003	446^{c}	461^{bc}	478^{ab}	493^{a}	7.20	<0.001
SD	*183*^{b}	*194*^{ab}	*197*^{a}	*204*^{a}	*6.42*	*0.013*	*201*^{b}	*217*^{ab}	*222*^{a}	*221*^{a}	*9.52*	*0.124*
kg FPCM / lactation	493	510	501	500	21.2	0.837	604^{b}	604^{b}	637^{ab}	658^{a}	21.8	0.045
SD	*236*	*250*	*240*	*262*	*16.6*	*0.286*	*254*^{b}	*260*^{b}	*289*^{a}	*290*^{a}	*13.8*	*0.020*
kg FPCM / 210DIM	432^{b}	452^{ab}	458^{a}	465^{a}	11.7	0.039	519^{c}	530^{b}	546^{ab}	560^{a}	12.1	0.011
SD	*213*	*221*	*222*	*229*	*6.64*	*0.090*	*230*	*245*	*251*	*246*	*11.53*	*0.329*
Milk components, %												
Total solids	14.9^{a}	14.7^{ab}	14.4^{b}	14.5^{b}	0.16	0.016	14.8	14.6	14.4	14.4	0.17	0.054
Fat	5.37^{a}	5.37^{a}	5.17^{b}	5.21^{b}	0.078	0.014	5.35	5.23	5.15	5.17	0.113	0.683
Protein	3.80^{a}	3.75^{a}	3.64^{b}	3.61^{b}	0.048	<0.001	3.75^{a}	3.73^{ab}	3.65^{bc}	3.59^{c}	0.044	0.003
Lactose	4.83	4.78	4.81	4.83	0.058	0.786	4.85	4.8	4.76	4.8	0.053	0.450
SCC, log/ml	3.03	2.96	3.00	3.06	0.028	0.079	5.95^{ab}	5.89^{b}	5.92^{b}	6.00^{a}	3.023	0.016
Components, kg / lactation												
Total solids	61.8	63.4	62.6	62.4	1.86	0.910	75.6	75.3	79.3	82.1	2.78	0.061
Fat	22.3	23.2	22.4	22.5	0.70	0.813	27.3	27	28.4	29.5	0.71	0.054
Protein	15.7	16.1	15.7	15.5	0.47	0.811	19.1	19.3	20.1	20.5	0.74	0.214
Lactose	20.2	20.6	20.9	20.8	0.626	0.781	24.9^{b}	24.9^{b}	26.4^{ab}	27.5^{a}	0.915	0.022
SCC, log / d	9.24	9.18	9.24	9.30	0.039	0.121	9.23^{b}	9.19^{b}	9.23^{b}	9.33^{a}	0.031	<0.001

[1] Standard error of the difference among means. Within a raw and group, means without a common superscript differ ($P < 0.05$). Standard deviation (SD) indicates the inter-animal variation within each farm and year.

Table 7. Summary of the yearly variation of productive parameters in of dairy goats from a group of Control farms and in farms which implemented the Eskardillo management in 2014.

	CONTROL			ESKARDILLO				*P*-value		
	2014	**2015**	**2016**	**2014**	**2015**	**2016**	**SED[1]**	**Tool**	**Time**	**Tool×Time**
Primiparous										
First partum age, d	-39.0	3.7	-27.8	-36.2	-1.85	-1.49	36.50	0.562	0.117	0.663
Days in milk, d	-5.45	-3.78	-11.2	-0.41	7.46	7.19	23.53	0.115	0.920	0.846
Milk yield / lactation, kg	-17.6	28.3	-10.1	21.2	32.2	22.6	52.21	0.085	0.540	0.792
FPCM yield / lactation, kg	-16.2	15.6	-7.9	16.0	30.9	23.3	58.96	0.117	0.762	0.957
All flock										
Reproductive goats	-2.11	14.5	-11.8	7.56	50.6	47.3	50.13	0.009	0.509	0.632
Age, d	26.3	-32.4	-63.6	42.2	-1.17	-1.21	69.57	0.273	0.143	0.787
Exit goats, %	9.27	7.12	6.81	5.09	2.25	0.00	11.59	0.045	0.870	0.973
Longevity, d	0.12	-0.24	0.14	0.00	0.22	0.06	0.549	0.499	0.924	0.487
Longevity, lactations	-0.04	-0.22	0.02	-0.18	0.16	0.25	0.448	0.186	0.599	0.414
Dry period length, d	-6.40	-0.18	-1.90	-2.84	-1.71	-5.96	11.08	0.986	0.725	0.839
Days in milk, d	2.20	-10.2	-6.06	-5.94	7.42	1.57	16.75	0.245	0.999	0.292
Milk yield / lactation, kg	16.9	4.48	-3.25	7.25	33.5	18.6	40.30	0.143	0.853	0.581
FPCM yield / lactation, kg	17.5	-9.19	-1.32	0.29	32.4	21.7	46.30	0.180	0.997	0.420

[1] Standard error of the difference among means for the interaction Tool × Time.

Table 8. Evolution of the Estimated Breeding Value for milk yield and milk components in terms of flock average and replacement animals in a group of dairy goat farms which implemented the Eskardillo management in 2014.

	ESKARDILLO					
	2013	**2014**	**2015**	**2016**	**SED[1]**	***P*-value**
Flock average						
EBV accuracy, %	67.6^{a}	68.0^{ab}	67.0^{a}	65.4^{b}	0.908	0.032
FPCM yield, kg / lactation	+4.93^{c}	+9.33^{bc}	+12.8^{ab}	+16.0^{a}	2.639	0.001
Milk yield, kg / lactation	+4.69^{c}	+8.93^{bc}	+12.3^{ab}	+15.4^{a}	2.548	0.001
Milk fat, %	+0.27^{c}	+0.44^{bc}	+0.59^{ab}	+0.72^{a}	0.102	<0.001
Milk protein, %	+0.22^{c}	+0.36^{bc}	+0.46^{ab}	+0.56^{a}	0.087	0.002
Milk solids, %	+0.74^{c}	+1.27^{bc}	+1.68^{ab}	+2.07^{a}	0.312	0.001
Replacement average						
EBV accuracy, %	68.7^{a}	61.0^{b}	50.6^{c}	36.2^{d}	2.105	<0.001
FPCM yield, kg	+11.1^{b}	+13.4^{b}	+14.9^{b}	+30.2^{a}	4.400	<0.001
Milk yield, kg	+10.6^{b}	+12.9^{b}	+14.3^{b}	+29.1^{a}	4.250	<0.001
Milk fat, %	+0.54^{b}	+0.60^{b}	+0.71^{b}	+1.23^{a}	0.179	0.002
Milk protein, %	+0.42^{b}	+0.43^{b}	+0.52^{b}	+0.99^{a}	0.140	<0.001
Milk solids, %	+1.56^{b}	+1.68^{b}	+2.04^{b}	+3.72^{a}	0.529	<0.001

[1] Standard error of the difference among means. Within a raw means without a common superscript differ ($P < 0.05$)

Table 9. Progression of different production seasonality of dairy goats from a group of Control farms and in farms which implemented the Eskardillo management in 2014.

	CONTROL						ESKARDILLO					
	2013	**2014**	**2015**	**2016**	**SED[1]**	***P*-value**	**2013**	**2014**	**2015**	**2016**	**SED[1]**	***P*-value**
Reproductive periods/year	3.00	2.92	3.17	3.00	0.159	0.287	3.83^{b}	4.00^{b}	4.58^{a}	4.67^{a}	0.198	0.010
Days without milking	63.6	60.7	65.3	53.7	4.67	0.062	32.7	23.3	18.7	0	12.32	0.078
Number of milkings per day	1.44^{b}	1.48^{b}	1.66^{a}	1.69^{a}	0.086	0.024	1.72	1.73	1.83	1.83	0.068	0.207
Production seasonality[2]												
Animals in milk, %	58.0	58.0	58.7	57.0	3.281	0.930	36.7^{a}	31.6^{a}	24.2^{ab}	17.6^{b}	6.670	0.038
Annual milk yield, %	63.9	64.4	63.9	62.7	3.635	0.943	40.2^{a}	34.5^{ab}	26.9^{b}	22.5^{b}	6.410	0.044
Annual FPCM yield, %	61.7	62.1	61.4	60.5	3.536	0.939	39.9^{a}	34.9^{a}	27.1^{ab}	21.1^{b}	6.570	0.036

[1] Standard error of the difference among means. Within a raw and group, means without a common superscript differ ($P < 0.05$)

[2] Data based on the coefficient of variation across the different months within the same year

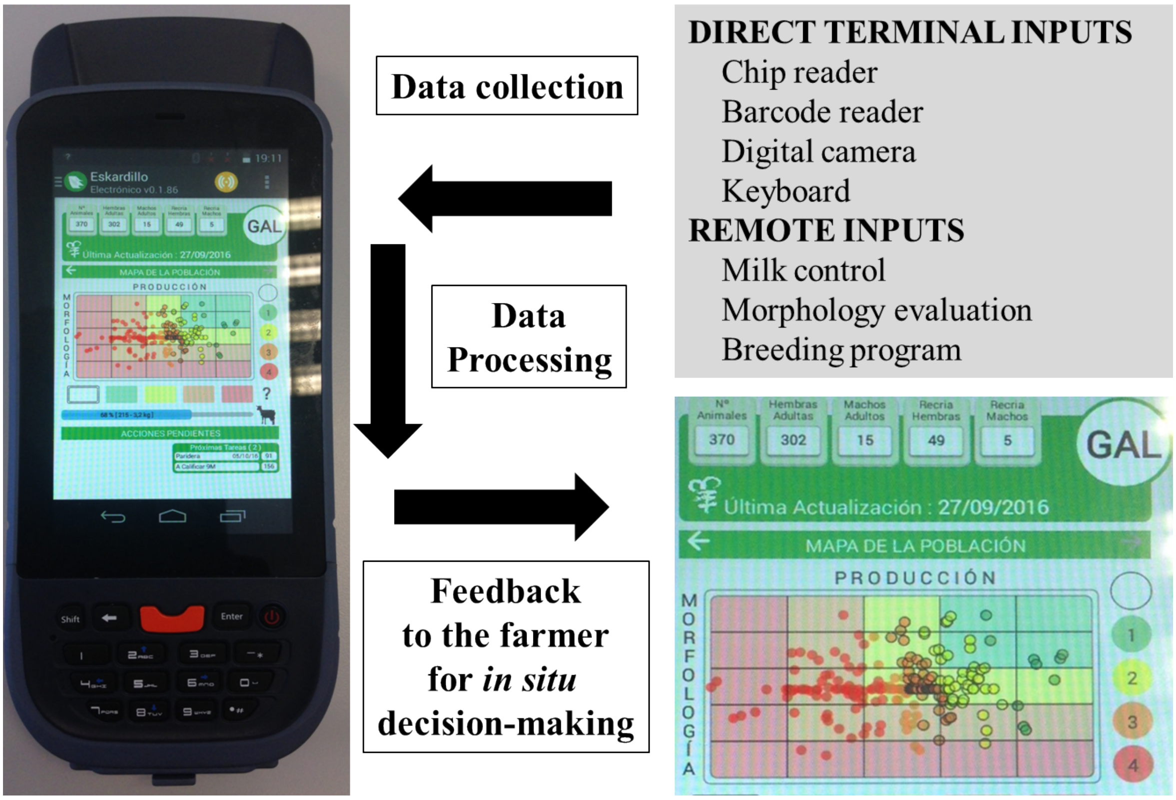


Figure 1. Image of the Eskardillo terminal, data flows and a screenshot in which the population map of the goats in the farm according to their physiological stage, morphology and productivity are represented.

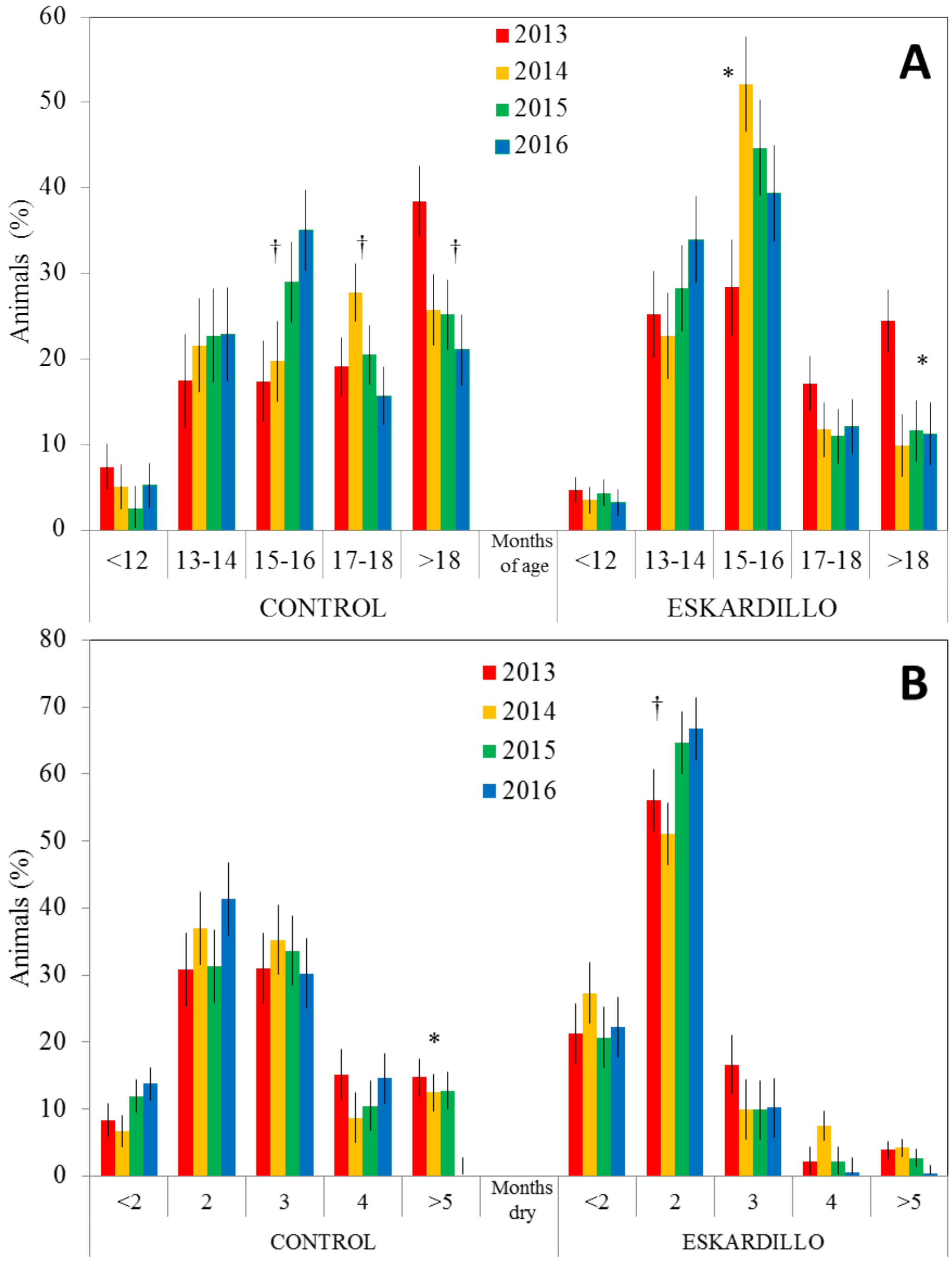


Figure 2. Progression of the first partum age (A) and dry period length distribution (B) in a group of Control farms and in farms which implemented the Eskardillo management in 2014. †, P<0.10; *, P<0.05.

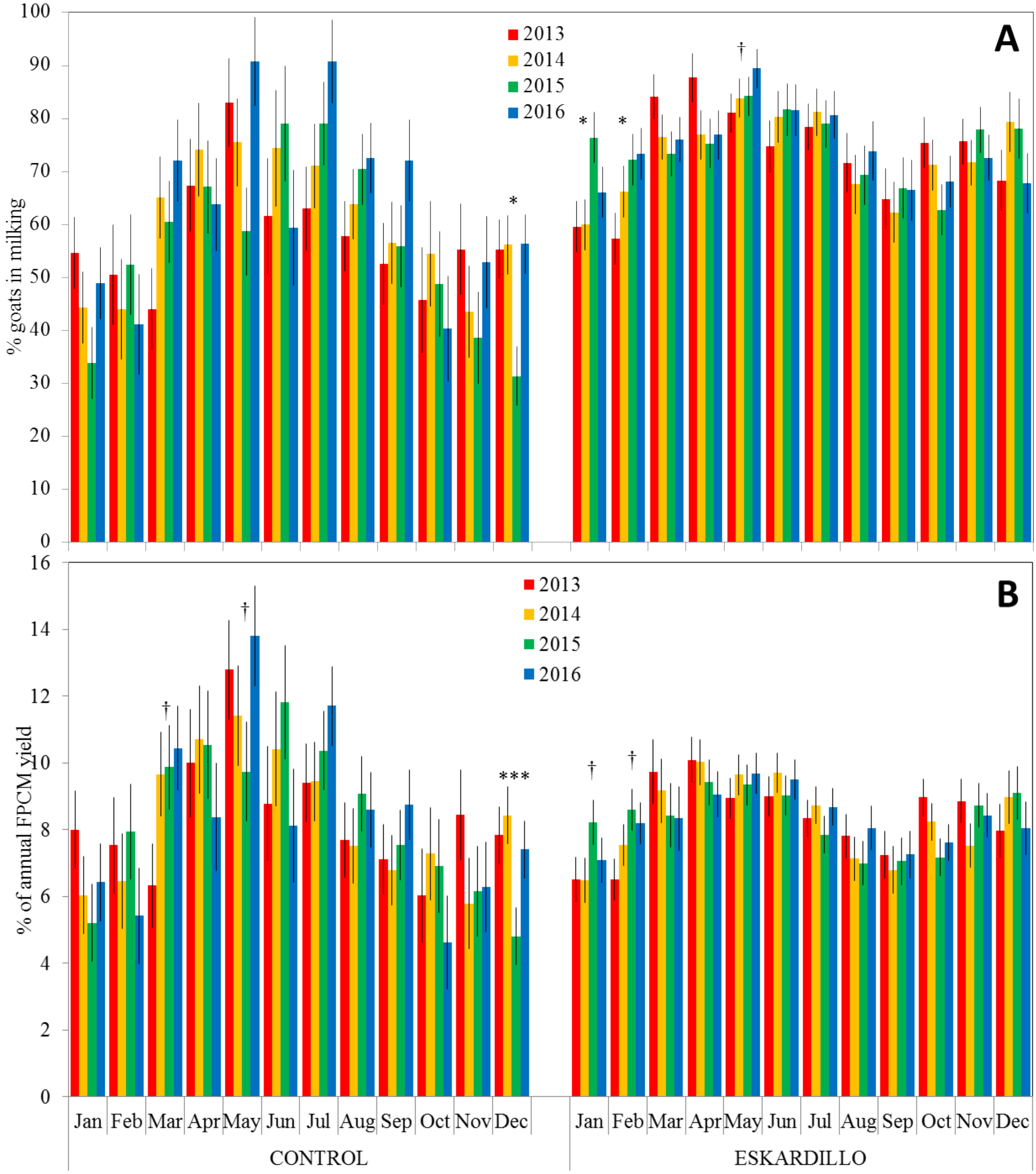
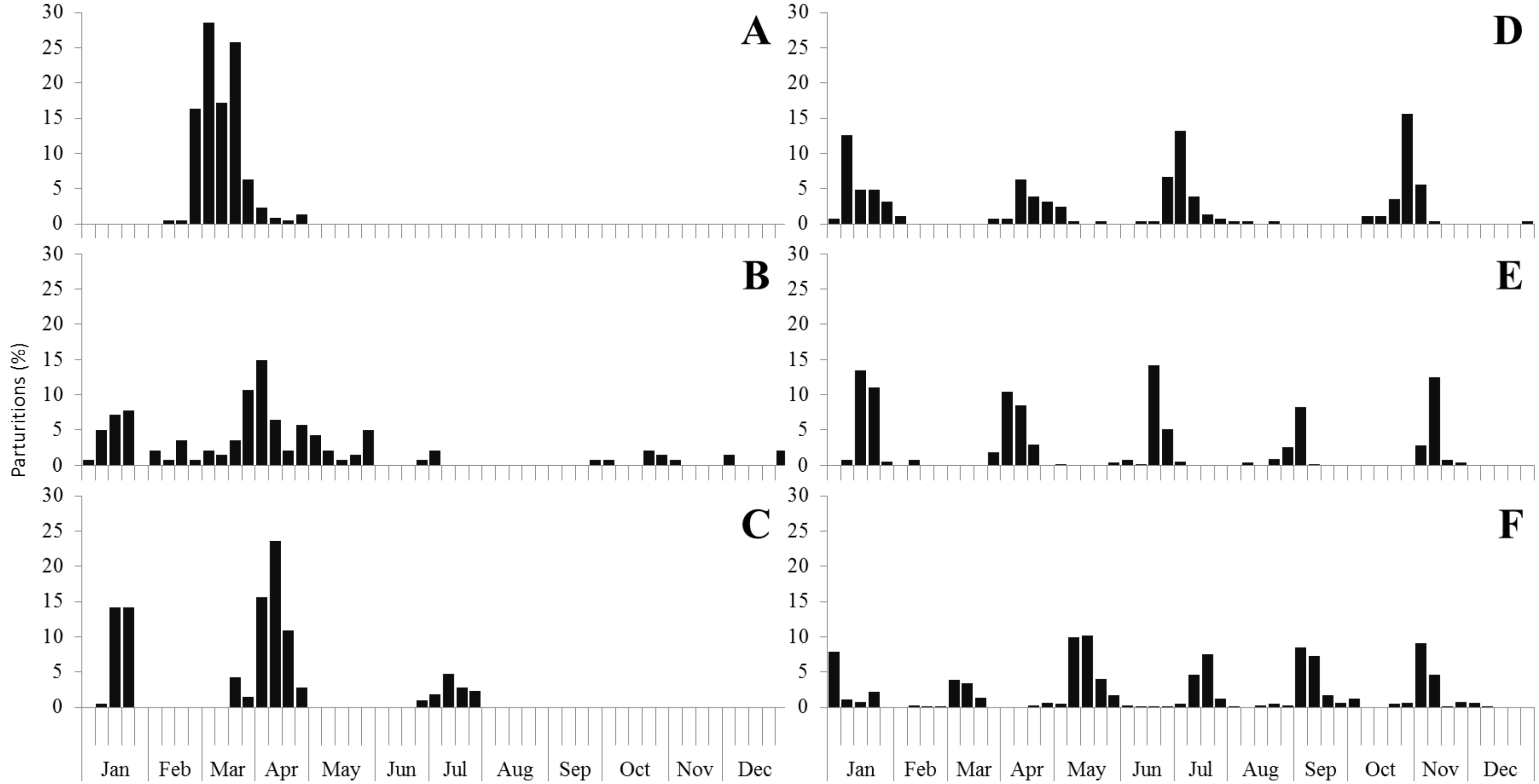


Figure 3. Progression of the production seasonality from 2013 to 2016 in terms of monthly proportion of animals in milking (A) and percentage of FPCM annual yield (B) in a group of Control farms and in farms that implemented the Eskardillo management in 2014. † P<0.1, * P<0.05; *** P<0.001



Supplemental Figure 1. Examples of the parturitions distribution throughout the year in Control dairy goat farm (A, B, C) and farms which implemented the Eskardillo management (D, E, F).