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Whole farm decision making and tools for dairy farms profitability

Candidate: Andrea Bellingeri
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Coordinator: Ch.mo Prof. Marco Trevisan

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Tutor: Prof. Francesco Masoero

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Abstract

In trying to respond to the society demands for sustainable development, environmental, technical and economic challenges are faced by farming systems worldwide. Irregular crop yields, fluctuating commodities prices, and the impact of agricultural activities on the environment are growing concerns. Actual demographic trends and higher energy costs are likely to further complicate the scenario in the near future. Research is facing these challenges by working on more sustainable and environmental friendly cropping and livestock systems able to provide both high productivity levels and economical sustainability for farmers. To obtain an effect, innovations derived from the research, has to implemented at the farm level. However, due to the relationships between the various elements of the cropping-livestock in the dairy production system, the farms diversity even in a small area, make the fully implementation of such recommendations complex. We found that very few studies attempt to address the three main components of the dairy farm production systems (livestock, crop land, market and commodities) within a single research framework. We therefore developed a framework by connecting livestock characteristics and requirement, crop land characteristics and market opportunities to support cropping plan and nutritional management at the farm level in order to maximize profit and reducing milk costs of production.

We found that home-grown real cost of production of the main forages cultivated has a high variability among farms and that a dedicated crop plan decision making strategy is a suitable way to improve IOFC (Income Over Feed Cost) at the farm level.

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Chapter 1

Introduction

Background

The dairy farm system involves complex relationships between crop production and utilization by the herd. The many factors involved make it difficult to determine the costs and benefits of implementing various management techniques, input and strategic organization of the dairy farm. Thus, since dairy farms in Northern Italy combine produced and purchased feeds within a heavily integrated system, calculation of the cost of home-produced forages is often over-simplified by assigning a single universal cost to a particular feedstuff (O'Kiely et al. 1997). Mathematical programming is an optimization technique that has been widely used to analyze the integrated management of various components within systems (Cartwright et al., 2007). The used applications include the assessment of agricultural innovations, evaluation of alternative management practices, policy analysis, and research prioritization (Pannell, 1996), thus (Rotz et al. 1989) confirm that computer simulations are an approach that can be used for this type of evaluation.

This dissertation aims to study the effect of an optimization technique conducted at the whole dairy farm level as decision-making tools for dairy farm profitability. The primary objective was to estimate the real cost of production of home-grown forages among dairy farms developing a methodology to assess the costs. Thus, understanding the variability on costs of production via an extensive survey on 50 dairy farms in Northern Italy. As second objective, we develop a linear optimization procedure for allocating homegrown and purchased feeds across the herd to optimize the IOFC in a whole farm nutrient management plan considering crop land limitation and farm characteristics as constraints.

Thesis Outline

Chapter 2 is a comprehensive review of decision making models designed for dairy farms, to support management and decision making for both crop and livestock.

Chapter 3 is survey regarding crop enterprise management, forages cost of production, dairy cattle management including reproductive management, housing, heat abatement, body condition scoring, nutrition, grouping strategies, and income over feed cost performance conducted on 50 dairy farms in Northern Italy.

Chapter 4 is a follow-up study of the Chapter 3 where a linear optimization model has been developed and used for allocating homegrown feeds across the herd to optimize the use of nutrients, considering real cost of the home grown forages, intrinsic farm characteristics, herd performance and market condition, with as objective maximize the IOFC of the farm.

Chapter 2

Literature Review

Farming systems worldwide are facing challenges caused by irregular production levels, extremely volatile commodities prices and growing environmental concerns over the impact of agricultural activities. Increasing population and rising energy costs will enhance the difficult situation farmers already are facing. For these reasons, agricultural research is concentrating his effort in high yielding, profitable and sustainable cropping-livestock system in response to the growing population. Thus, the large number of possible adaptation options and the complexity of the farming systems, model-based tools are becoming more popular as supplement to traditional approaches (e.g. Vereijken 1997) for evaluating and designing innovative agricultural approaches. As stated by (O'Kiely., 1997), the published models developed to simulate the economics of feed production designated for dairy use is low. O'Kiely in 1997 and Finneran et al., 2010, are of the very few published studies to have examined the costs of producing and utilizing a range of feeds for ruminants while none have examined the impact of fluctuating variables on feed costs.

"forages cost of production"

The cost of production has deep implications in farmers' competitiveness and relative income. Production costs affects farm sustainability, dictate the development of farming systems, and determine overall food production potential. To test the competitiveness of different farming systems, cost of production analysis has become a powerful tool to understand and compare situations. Data availability is a key element for conducting comparative analysis for scientific output.

Cost of production is an economic indicator when is need to assess the economic performance of production. Cost is defined as the value of a factor of production (input) used in the production. A possible classification of cost of production that might be relevant from a methodological point of view is based on whether or not costs are traceable to a specific farm activity (i.e. direct versus indirect costs). A direct cost is a cost that can easily and conveniently be traced to a particular farm activity (e.g. a commodity). For example, in most cases the use of seeds is a direct cost of producing a particular crop. Conversely, an indirect cost is a cost that cannot be easily related to a particular farm activity. As example, if a farm produces several crops, a cost item such as machinery insurance is an indirect cost that benefits all crops for which the machinery that was utilized. Here, the reason is that machinery insurance costs are not used by a specific crop but are common to all the crops cultivated. Indirect costs are incurred to support multiple activities and cannot be traced to each individually. There are different methods for the allocation of indirect cost of production, for this and they depend on the management information available on the farm. If a farmer keeps detailed records of the use of various farm resources, those records will likely form a sufficient basis for allocation. However, it is difficult to record and track data at the farm level and, so, other allocation indicators must be used.

The methods developed to allocate indirect costs are derived from the methodology published on (AAEA CAR Estimation Handbook, 2000):

- allocation based on gross value of farm production
- allocation based on other allocated costs

The presented methodology, enterprises are impacted relative to their importance to overall farm profit. Decisions about enterprise selection and management are neutral to general farm indirect expenses. However, when an enterprise has a non-positive margin, this method creates a mathematical problem. In this case, it is recommended that the allocation should be done on a long-term estimated margin. In order to deal with this problem on mixed farms, there’s a method that takes the cost of fully specialized farms and uses the level of those costs to divide the costs of the mixed farms between the all products. Proni (1940), developed a scheme, where, the production cost of the prevalent output can be calculated in two steps:

- the whole farm costs are calculated, without distinction among the different productions, farm balance sheet can provide the total cost

- after that, the by-product cost is subtracted from the total cost and the difference is the cost of the main production. The cost of secondary production can be assimilated to the market price in the hypothesis of a perfect competition market.

Ghelfi (2000) proposes two scheme in order to allocate the costs of different farm enterprises or activities. In the case of predominance of specific costs, a direct costing procedure may be adopted, an example can be the monocultures and farms with one kind of livestock rearing. When the farms have more than one production (with a predominance of common costs) the allocation is made using an indirect costing methods. Another way to allocate indirect costs has been described in a research done in the UK by Drury and Tales (1995). To calculate indirect costs rates, direct labor hours and volume-based allocation procedures could be adopted: direct labor cost, labor hours, machine hours, material cost, units produced, production time, selling price, etc. It is important to highlight that the volume of production can be used but it cannot be the only allocation key. Is important to highlight, that the use of a volume-based method to allocate the indirect costs causes an overcharge of a product with higher volumes in favor of those with low volume or those with highly complex production (as example: corn silage vs alfalfa). The degree of accuracy that we can achieve using allocation keys is variable. The more detailed and accurate is the allocation key, more we can be accurate in cost estimation. Another study concerning analysis of the costs allocation system has been done by the Directorate General of Agriculture of the European Commission. As regards to arable crops, a program called ARACOST has been developed (EC DGAGRI, 1999). This program defines some indications for the allocation of indirect costs. Costs to different enterprises using a volume-based allocation model. All the indirect costs are allocated on the basis of the percentage of the specific crop output on the total output of arable crops. In particular, the methodology defines the allocation key for farming overheads, depreciation and other nonspecific inputs of specialized dairy. The aim is to estimate the cost of production for milk on farms with different levels of specialization in milk production. The allocation of the charges to milk production is based on three criteria depending on the kind of costs taken into account:

- specific costs (purchased feed for grazing livestock)
- other specific livestock costs (e.g. veterinary fees)
- all other costs (farming overheads, depreciation, external factors)

The percentage of dairy livestock units on the grazing livestock units is used to allocate grazing livestock feed costs, while for the other livestock specific costs the percentage of dairy livestock units on the total livestock units has been used. The specific costs of the crops (seed and seedlings, fertilizers and soil improvers, crop protection products) are shared according to the percentage of fodder crops, forage crops and temporary grass considering the total utilizable agricultural land. This method allows the estimation of the value of fodder plants. Another method used when it comes to milk production costs, De Roest et al. (2004) is based on analytical accounting and it takes the necessary data from a farm survey, following a scheme created by the European Dairy Farmers. The costs are divided into specific costs (exclusively concerning dairy production) and general costs (sustained for different activities on the farm). Using this method, the indirect costs allocation is made using these coefficients:

- Fodder Crop Surface / Utilized Agricultural Area
- Revenues from milk / Total Revenues
- Revenues from meat / Total Revenues

“calculation of own resources: labor, capital and land”

Forages cost of production estimation is an important step to do when it comes to long-term analysis. However, real and full cost of production, that consider also family labor, own land, own capital and include in the analysis specific farms characteristics, are difficult to be implemented and therefore, there’s a lack of data among the literature. Thus, the aforementioned cost items, should be estimated at their opportunity costs and be included in cost analysis. Opportunity cost is the value of best alternative use of the resources and is an important part of the decision-making process. Considering opportunity costs is one of the key differences between a full and partial cost configuration, economic cost and accounting cost. The AAEA Cost and Return Estimation Handbook give us some insight about estimation of the opportunity costs for own resources (labor, capital, land).

“Own labor”

Labor is one of the most important inputs in agricultural production. It can be divided in two categories: hired labor and unpaid labor. The first one includes wages, salaries, benefits and other associated costs, while family labor is included in the last mentioned. Following the indication in the AAEA Handbook (2000), the opportunity cost of farm labor is the maximum value per unit among an alternative use of that labor. The main factors affecting the opportunity cost value are the skills of the person involved, location and period. A second method that be used to estimate the family labor can be the use of:

- the average wage of professional farm managers to approximate the cost of the hours used by a farm operator in decision making

- the average wage rate of hired farm labor for all the other unpaid farm labor.

There are some problems when it comes to estimate these cost. (i) on farm it is very difficult to divide the farm operator’s labor from the “mental” work, since it’s a joint product of field work and decisions and this may lead to errors in calculating the work costs. (ii) The quality of decision making by farmers and professional farm managers may be different. (iii) A family worker is usually assumed to be more productive than a hired worker. At the light of these considerations, it is necessary to adjust calculations keeping in mind those elements.

The third approach uses the off-farm wage rates of farming people as information about wage opportunities of family work at it can be defined as the simplest estimation method to calculate the opportunity cost

“Own capital”

The cost of equity has to considered and evaluated including a fair market rate that can reflect the same investment level of risk. The risk of an investment in a farm is relatively low since much of the money invested is for land and buildings (and land usually does not depreciate). A simple approach can be associate a small premium with the use of an average rate of return on long-term government bonds.

“Own land”

Estimating land cost in farm production is complex. The categories related to land cost are, and the sum of these costs equals the cost of agricultural land use value:

- costs of owning land or opportunity cost (current value of the land multiplied by an appropriate interest rate)

- costs of maintaining land

- overhead costs: liability insurance, irrigation, etc. However, is difficult to estimate these costs separately. There’s many reason, but the first is that often markets are not active and do not provide a sufficient number of observations to make reliable estimates. The AAEA Handbook refers to different calculations among land costs.

1) When land is worked by the owners

    (a) Opportunity cost is obtained multiplying the land market value by an interest rate.

    (b) Annual maintenance cost and to the annual taxes

2) When part of the land cultivated is rented, the cash rent paid for land is the best

measure of the costs associated with the land’s agricultural use value.

“cropping plan design and decision-making”

Cropping plan optimization, can be one of the first element to investigate when it comes to better define the forage strategy of a dairy farm. Cropping plan can be defined as the land area cultivated by all the crops each year (Wijnands 1999) and the relative distribution of each crop within the farming land (Aubry et al., 1998b). Crop rotation is the practice of growing a sequence of crops on the same land (Bullock et al., 1992). Is important to define that cropping plan design is at the core of the farming system management and the relative cropping plan decision making concentrate all the complexity involved in cropping system management at the farm level because of the deep interactions between the different aspect related to the crop production process (Nevo et al.,1994). Cropping plan decisions are the stone angle in crop production processes and directly affect both short and long-term profitability. Among years, a large amount of models has been developed in order to help farmers, consultant, researchers to develop feasible cropping system according to different purposes. Cropping plan design models can have different target: local farm level (single farm) where more detailed and specific farm data are required, regional level or at a bigger, district level (such as a river basin). In order to allocate scarce resources in a more efficient way such as water, better define fertilization plan, maximize profit, workforce allocation, reduce environmental footprint, predict landscape changes and their effects, researchers developed cropping plan selection models to support farmers, policy maker and other stakeholders. For instance, in the following models, different objective has been chosen as goal of the model:

1. Maximize profit or net income (Dogliotti et al.,2005; Bartolini et al., 2007; Louhichi et al., 2010)
2. Minimize equipment costs and the relative initial investments: (Gupta et., 2000)

3. Minimize labor costs: (Dogliotti et al.,2005; Bartolini et al., 2007)
4. Maximize irrigated land area: (Tsakiris et al., 2006)
5. Minimize energy costs: (Gupta et al., 2000)
6. Minimize nutrient losses into the environment: (Annetts and Audsley 2002; Dogliotti et al., 2005)
7. Minimize pesticides usage and losses into the environment: (Foltz et al., 1995; Annetts and Audsley 2002; Dogliotti et al., 2005)

Optimization is the most common technique used to reach the objective of the model considering a defined spectrum of constraints. Among optimization techniques, linear programming (LP) is the procedure that has been used first time in 1954 by Heady et al. Using an LP based model give the advantage to be simple and offer the possibility to include different choices among the analysis. Biggest issues are related to model formulation and data interpretation as discussed by (Nevo et al., 1994). The next step among optimization techniques related to whole farm decision making is the usage of multi-objective linear programming. Multi-objective linear programming has the potential to help us maximizing profitability while keeping environmental sustainability, and more in general, took in consideration at the same time multiple model goals. For example, the following model can be described as multi-objective: (Piech and Rehman 1993; Annetts and Audsley 2002; Tsakiris and Spiliotis 2006; Bartolini et al. 2007). Among the cited models, different objectives are used in multi-objective optimization. The biggest challenge in the multi-objective approach is to give the right coefficient of importance to the different objective in order to obtain the desired output (Sumpsi et al. 1996). The LP optimization techniques can be used to solve annual solutions but also for solving the crop rotation issues. Dogliotti et al. (2005) used a mixed integer linear programming as an interactive multiple-goal linear program. Howitt (1995) and Louhichi et al. (2010), on the other hand, defined a non-linear optimization approach based on positive mathematical programming (PMP).

Among models developed for dairy farm decision-making, which have the potential to improve farm profitability, a classification can be used to organize the different studies that can be found in literature according to the classification system developed by (Le Gal et al., 2011).

‘‘design modelling’’

This category includes models with the characteristics to have different goals: (a) understand and describe farmer’s decision making process, (b) evaluating the potential impacts of research/approach results or farmers’ decisions on simulated farms. This category of models is based on mathematical equations, that include a big amount of variables that enable to run the models. These kind of models will not be used by other users than their own designers, for this reason the aforementioned models haven’t a user-friendly interface. Example of this category of model can be found below:

1) Berentsen and Giesen (1995), model aim is to determine the effects of technical, institutional and price changes on the farm organization, economic results and nutrient losses to the environment

2) Brown et al. (2005), model has been developed to identify more sustainable systems of livestock production through the integration of mitigation strategies

3) Buysse et al. (2005), model helps the process of evaluation of management decisions on the dairy farms nutrients balance

4) Coleno et al. (2002), model has been developed to achieve a better use efficiency of spring grazing system manipulating the forage system management

5) Guerrin (2001), model has been developed to simulate the manure management and manure type effect on nutrient utilization by crops

6) Labbé et al. (2000), to investigate irrigation management strategies manipulating water scheduling usage at the farm level during water shortages scenarios

7) Romera et al. (2004) model is able to simulate and design, in a pastoral cow-calf beef breeding systems, the long term dynamics of this kind of rearing system

8) Rowe et al. (2006), model has been developed to explore the effects of different nutrient resource allocation strategies and the effects on the development of soil fertility

9) Sadras et al. (2003), has been developed to test the effect on whole-farm profitability of the adoption of a dynamic cropping strategy

10) Schiere et al. (1999), to design alternative feed allocation scheme in low input livestock systems

11) Shalloo et al. (2004), to allow investigation of the effects of varying biological, technical, and physical processes on farm profitability

12) Zingore et al. (2009), model has been developed to understand the interaction between crops, livestock and soils to develop the most efficiency and profitable strategies

‘‘support modelling’’

This models category includes models that allow through their usage to support farmer’s decision making process. Interactions between researchers and farmers/consultants are orientated towards an interactive process that enable a knowledge growth for all the stakeholders involved. The models described in these studies are very similar to the models described in the ‘‘design modelling’’ category; however, their target users and purposes are different. They are applied to real farm cases. The models output expectation is to improve the dialogue between farmers, advisors, researchers and policymakers while discussing innovation topics. The innovation developed by using these models, that include farmers, consultants, and researchers together, helps in the understanding of the reality and identify lack of knowledge at any level of the project involved in the analysis. There's three main objectives among the "support modeling" approach:

(a)Exchanging data and information regarding the biophysical, technical, economical and management processes among advisors, farmers and researchers (Louhichi et al., 2004; Milne and Sibbald, 1998; Vayssières et al., 2009b;). Simulate an ideal farm and the main farm components and apply those results under real farm cases (Tittonell et al., 2009; Waithaka et al., 2006; Calsamiglia et al.,2018).

(b)Compare simulated scenarios considering farmer's management strategies. Bernet et al., 2001, has developed a model to define specific production options and resource constraints under different socio-economic and biophysical settings. Cabrera et al., 2005 has developed a model to assess nitrogen leaching from dairy farm systems and evaluate the economic impacts resulting from a potential reduction, considering different climatic conditions. Giller et al., 2011 model has been developed to be used on African farming system to assess constraints and explore agronomics and cropping plan options. Lisson et al., 2010 developed and tested an approach for evaluating cattle and forage improvement due to the adoptions of technologies among these topics. Mérot and Bergez, 2010 developed a model to test new irrigation schedules, new designs for water channels and new distribution planning considering a certain amount of water availability for a for a given amount of land.

(c)Helping advisors and farmers improving their knowledge bottom-line by the use of model as front to front discussion tool (Cros et al., 2004; Duru et al., 2007; Rotz et al., 1999), thus, for supporting farmers' tactical strategies (Sharifi and van Keulen, 1994), thinking process (Dogliotti et al., 2005; Veysset et al., 2005). Among the "support modelling" papers published based on testing and understand the impact of technologies on farm performances. Bernet et al. (2001), model consider specific production option and resource constraints under different socio economic scenarios. Castelan-Ortega et al. (2003a,b) model aim is to support the farmer decision making process able to maximize farmer income while considering an optimal combination of resources and technologies. Dogliotti et al. (2004, 2005) developed two model, based on the simulation of a vegetable production systems in South Uruguay to explore potential alternatives production systems. Herrero et al. (1999) to represent pastoral dairy production systems and conduct trade-off analysis. Recio et al. (2003), model aims to help farmers dealing with the complexity of the farm planning problem. Sharifi and van Keulen (1994) model aims to better define the land use planning at the farm level developing a decision support system. Van de Ven and Van Keulen (2007) developed a model focused on minimizing the environmental impact through the usage of innovative and farming system.

Aarts et al. (2000), model is focused on nutrient management and developed to explore potential benefits due to a better nutrient management system. Alvarez et al. (2004), model works on water irrigation management through maximizing production levels. Cabrera et al. (2005), model, working under different climatic conditions assess nitrogen leaching from dairy farm systems and the relative economic impacts as an effect of its reduction. Lisson et al. (2010), model has been developed to test the effect on profitability of the introduction of cattle and forage improvement (genetics or management). Mérot and Bergez (2010), model is able to test irrigation schedules, simulate and design new water channels and pipes to bring water to the fields and relative optimization of the water source usage.

Rotz et al. (1999), model is able to test the effect of alternative dairy farming system on long-term performance. Schils et al. (2007), model aim is to provide simulation of the technical, environmental, and financial flows on a dairy farm. Val-Arreola et al. (2006), to help farmers defining the decision making process among feeding strategies in pasture based small-scale dairy farms.

Vayssières et al. (2009a,b), model is able to support farmers’ decision-making and the influence of management practices on the sustainability of dairy production systems working on a whole-farm system model.

“reproduction performances related models and studies”

The reproductive performance of high-producing dairy cows on commercial farms is influenced by a several factors and it greatly affect farm profitability (Giordano et al., 2012). Understand how fertility performance are associated with economic losses on dairy farms is a key factor (Ferguson and Galligan, 1999) has been largely investigated in the recent years by numerous authors. This has been possible through the development of models through scenario’s analysis. High producing dairy farms use a mixed management for reproduction: synchronization protocols and estrous detection (Galvao et al., 2013). Several reproduction performance indicators have been found in the literature as metrics and enable to be consistent and reliable (e.g., days open or calving interval) or the 21-day pregnancy rate (21-d PR; Ferguson and Galligan, 1999). However, difficulties have been found when it comes to assess his economic impacts. A series of simulation studies in recent years has been summarized by Cabrera (2014). Technologies as blood chemical pregnancy diagnosis tests or estrous detection devices have been adopted by modern high-yielding herd operations, and could improve the profitability and reproductive performance bottom-line. Once the dairy farm manager finds the best reproductive program for the herd, there are still opportunities to improve performances with the implementation of single-cow tool systems (Giordano et al., 2013). The concept of the economic value of a cow (Cabrera, 2012) or its equivalent retention pay-off (RPO; De Vries, 2006) allow to determine the value of a new pregnancy, the cost of a pregnancy loss, and the cost of a day open. The economic value of improving reproductive performance consistently improve the single cow and the herd economic net returns (Giordano et al., 2011; 2012; Kalantari and Cabrera, 2012; Cabrera, 2012; Galvao et al., 2013). To conclude, a curve of reproductive performance for pregnancy rate level evaluation, shows and confirm that a net economic return exists even at 40% 21-d PR levels.

Other simulations and model among the “repro” area has been developed by DeVries et al. 2006, using a bio economic model, on average dairy herd in the US, with the aim to study and evaluate the effects of the stage of gestation, stage of lactation, lactation number, milk yield, milk price, replacement heifer cost, probability of pregnancy, probability of involuntary culling, and breeding decisions. Giordano et al., 2012; developed a tool based on a mathematical model using a Markov chain approach to allow a partial budgeting simulation to obtain a net present value (NPV; $/cow per year) obtained through the simulations of different reproductive management programs. Since complexity among reproductive management strategies among dairies in the world are raising, the demands of a new decision support systems that accurately reflect the events that occur on the farm results to be needed to better understand impact of certain decisions and their monetary effects. The model input are productive, reproductive, and economic data needed to simulate farm conditions and in order to took into account all the factors related to reproductive management

“Advisory-oriented”

Few research aimed to support farmers in an advisory context has been found in the literature. Many works on this topic has not been published, and for that reason cannot be identified. For that reason, a paper from Moreau et al. (2009) explain the real exchanges that took place between scientists and workers in the field of forage crops since it is co-written by technicians and scientists.

In 1990, an experiment on French arable farms involving researchers and consultants that studied the work organization (Attonaty et al., 1993) with the objective to support farmers in selecting equipment/activities and understand the right amount of workforce needed has been organized. The advising process was individual and included the following steps (Chatelin et al., 1994): (1) formulation of the farmer’s actual work organization (2) transfer this knowledge into a simulation tool called OTELO (it has been developed to simulate the work organization), (3) considering various climate scenarios, simulation of the work organization,

(4) validation of the modelled work organization against the current one and evaluation of the obtained results among a 3-4 year life-span (5) simulation of alternative scenarios. In the process, both farmers and consultants can suggest modification to the actual organization plan. This approach has proven to be a powerful tool to support farmers and. However, it showed several limitations in terms of modelling power and it resulted to be too complex for a daily use and not user-friendly. This because a dedicated programming language require time in learning how to use the software. The use of complex software is time consuming and expensive for farmers and the advisors, especially if we consider that this is a software to use at the single farm. Lastly, the software has not been updated by the researchers and it became obsolete. For all of these reasons, the methodology here presented is not used anymore. Other papers have been found in the literature with the goal to advice directly farmers, however, the main characteristics of the aforementioned models can be summarized as:

(a) A majority of the studies focused their energy on animal feeding and grazing planning, in which the complexity of the production systems has been highlighted and become clear when farmers has to balance feed inputs (home-grown forages and feed purchase) with herd demand throughout the year.

(b) if we don’t consider the model “OTELO”, the other studies are based on user-friendly tools (Heard et al., 2004; Penot and Deheuvels, 2007; Moreau et al., 2009), database (Kerr et al., 1999; Lewis and Tzilivakis, 2000) or a combination of a database and a calculation process (Dobos et al., 2001, 2004).

(c) with the exception of GrazPlan, biophysical models are not deeply used

(d) from the GrazPlan and OTELO situation, we can conclude that complex model shows some difficulties when needed to be used for strategic decisions. Thus, as observed by our group of work and other authors, farmers request assistance more frequently for routine management issues (e.g. animal nutrition) than for long-term and strategic ones (e.g. grazing planning throughout the year or investments to be done) (Donnelly et al., 2002; Moreau et al., 2009).

A paper published by Rotz in 1999, shows the development and functioning of a dairy farm simulation model called DAFOSYM. The dairy submodel of the model is able to provide to the user what’s the best mix among the available feeds to fulfill the animal requirements in terms of energy, protein, fiber. A maximum of six nutritional groups can be considered by the model. The evolution of the aforementioned model, is the Integrated farm system model (IFSM), (Rotz et al., 2013). It has been released recently and has been widely used among the research community. This model is a whole farm process-based model developed for the U.S. dairy industry, developed from a previous and older version called DAFOSYM (Rotz et al., 1989). The model simulates crop growth and management, feed storage, machinery, dairy performance, manure management, nitrogen, carbon and phosphorus cycle, and profitability for a life-spam up to 25 years. Daily weather data are necessary to the model to simulate crop growth, establish the number of days where it can be possible to plant, tillage, harvest, and define crop yield, quality, and relative production cost. The model formulates a least-cost diet for each nutritional group to reach a specific milk yield or average daily gain (heifers) based on feed availability. The model formulates least cost diets for a maximum of 6 nutritional groups based on feed availability. Diet formulation models are usually using linear programming techniques, in which the objective is to minimize the feed cost or maximize profit. Hawkins et al. (2015) developed a farm-level diet formulating linear program model to maximize farm net return and maintaining the same milk productivity while reducing GHG emissions.

Cornell university, published a paper, Wang et al., 2000, where the authors developed a linear optimization procedure for allocating homegrown feeds across the herd to optimize nutrients usage with decreasing nutrient excretion in the environment. The first step has been developing optimal diets through a linear programming method related to the Cornell Net

Carbohydrate and Protein System (CNCPS). Farm data relative to feed analysis, nutritional requirement, environment has been prepared on a farm worksheet, here a second LP procedure import these data and considering allocation of homegrown crops, requirements and constraints of each animal group while optimizing return over feed costs and nutrient excretion. Model runs on sample farms shows how this model was used to reduce N, P, and K excretion by manipulating feeding strategies and keeping a positive income over feed costs.

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Chapter 3

A survey of dairy cattle management, crop planning, and forages cost of production in Northern Italy

Andrea Bellingeri [a,b], Victor Cabrera [a]*, Antonio Gallo [b], Di Liang [a] and Francesco Masoero [b]

[a]Department of Dairy Science, University of Wisconsin-Madison, Madison, Wisconsin, USA, 53705*; [b]Dipartimento di Scienze animali, della nutrizione e degli alimenti (DIANA), Facoltà di Scienze Agrarie, Alimentari e Ambientali, Università Cattolica del Sacro Cuore, 29100 Piacenza, Italy.*

*Corresponding author: Victor E. Cabrera. 279 Animal Sciences Building, 1675 Observatory Drive Madison, WI 53706-1284. Phone: (608) 265-8506, Fax: (608) 263-9412. E-mail: vcabrera@wisc.edu

A survey of dairy cattle management, crop planning, and forages cost of production in Northern Italy

A survey regarding crop enterprise management, forages cost of production, dairy cattle management including reproductive management, housing, heat abatement, body condition scoring, nutrition, grouping strategies, and income over feed cost performance, was carried out from December 2016 to January 2018 on 50 dairy farms by the Department of Animal Science, Food and Nutrition of Università Cattolica del Sacro Cuore (Piacenza, Italy). A total of 41 herds (82%) completed the survey. Average herd size was 327 ± 162 lactating cows with the average land size of 160 ± 94 ha per farm. Herds were located in the provinces of Cremona (17), Brescia (8), Mantova (7), Piacenza (5), Cuneo (4), Bergamo (3), Lodi (3), Torino (2), and Venezia (1). These farms sold 32.8 ± 2.01 kg of milk/d per cow, had an annual culling rate of 34.0 ± 4.00%, a calving interval of 14.16 ± 0.58 mo., and a 21-d pregnancy rate of 17.05 ± 2.58 %. Implementing effective management strategies to contrast the damage caused by *Ostrinia nubilalis*, *Diabrotica spp*. and *Myocastor coypus* were identified as the main crop enterprise challenges. Main forages cultivated were alfalfa and corn silage second seeding with a total cost of production of (€/ha) 1,968 ± 362 and 2,581 ± 221, with an average yield of 9.61 ± 1.24 and 17.22 ± 2.46 ton of DM per hectare respectively. Results of this study can provide useful benchmark or reference for dairy management practices, crops and dairy performances, forages production costs on very well managed North Italian dairy farms at the present time.

Keywords: dairy, management, reproduction, forages, costs

Highlights

- benchmarks for dairy farms
- management practices, economic and reproductive performance
- cost of production of forages in northern Italy

Introduction

The economic objective of a farm is generally to maximize net economic returns (de Ondarza and Tricarico 2017). The complexity of the dairy farm system, the multitude of variables that can affect the efficiency and profitability of a dairy farm, raise the importance of defining benchmarks and references as a useful way to help farmers pursuing efficiency. A descriptive paper can result in a practical way to synthetize benchmarks and useful references among the main aspects that affect the profitability of a dairy farm. For instance, reproductive efficiency is an important factor affecting the economic performance of dairy farms (Meadows et al. 2005). Several studies have reported a high variability in reproductive efficiency (Olynk and Wolf 2008). Lower reproductive efficiency is related to a lower milk yield per cow per day and lower economic efficiency (i.e. €/cow per yr.) (De Vries 2006). Furthermore, feed costs is another important factor affecting farm profitability, since it can range from 50 to 70% of the total operating costs to produce milk (Bozic et al. 2012). Consequently, farm efficiency should be evaluated by considering technical performance and economic outputs concurrently (Atzori et al. 2013). In Northern Italy, corn silage makes up to 90% of the total roughage in the lactating cow diet because of the soil fertility, favourable climate for corn silage, and its high DM yield potential per ha (Borreani et al. 2013). As a result, most dairy farms become self-sufficient for the energy requirements producing corn silage, but highly dependent for the protein sources from the market. This has led to a simplification of the cropping system and expose farmers to the market volatility of purchased feeds. This economic uncertainty represents one of the main economic challenges (Valvekar et al. 2010). Moreover, additional challenges with this cropping system have risen. Installation of many biogas plants has resulted on increased competition of available arable land and increased land costs (Demartini et al. 2016). Furthermore, climate change effects have influenced more persistent drought conditions in summer (Camnasio and Becciu 2011), aflatoxin issues (Battilani et al. 2016), and new and more aggressive corn pests (Boriani et al. 2006; Ciosi et al. 2008). All these new issues, have resulted in an increased uncertainty about the corn silage-based dairy farming system. As stated by Dury et al. (2013), defining cropping strategies represents a fundamental step in the decision-making process of a dairy farm, because it allows to improve the competitiveness as well as profitability of the dairies through reduction of feed costs. As a result, many dairy farms have introduced new cropping system strategies, adopted new environmental friendly soil tillage practices to reduce costs and improve soil fertility (Panagos et al. 2016), and improved the irrigation system practices. All these new elements prompt the need of understanding their impact on the cost of production of feeds and its role on farm sustainability (Wolf 2012). Different approaches have been used to compute feed costs such as fixed feed costs related to the energy content (Atzori et al. 2013) or adoption of variable feed costs associated to market prices for both purchased and homegrown feeds (Borreani et al. 2013; Buza et al. 2014). However, since dairy farms in Northern Italy combine produced and purchased feeds within a heavily integrated system, calculation of the cost of home-produced forages is often over-simplified by assigning a single universal cost to a particular feedstuff (O'Kiely et al. 1997). Although previous studies have provided a wealth of information, details regarding specific aspects of cropping strategies, actual cost of production of different forages, irrigation and tillage system adopted, yield obtained by different forages were not considered. The objective of the present study was to examine the current forages production cost, paying particular attention to factors that could influence the final costs of production per unit of product, via an extensive survey of dairy herds that participated in the Department of Animal Science, Food and Nutrition of Università Cattolica del Sacro Cuore (Piacenza, Italy) consulting services. Current crop and dairy management operations, nutritional and feeding strategies data has been recorded in order to give an update on the current management practices on very well managed Northern Italy dairy farms.

Materials and Methods

Farm survey

An interdisciplinary and comprehensive survey was developed with questions regarding the most important aspects of a dairy operation. It included general management issues, reproductive management, crop management practices, forages cost of production and economic performance. Between January and February 2018, the survey was mailed to 50 selected dairy farms located in the Po Valley (Italy). The selection of farms was purposefully based on previous knowledge of these farms recording the most and the best quality data. These farms are involved in the consulting service of the Department of Animal Science, Food and Nutrition of Università Cattolica del Sacro Cuore. These herds were located in the provinces of Cremona (17), Brescia (8), Mantova (7), Piacenza (5), Cuneo (4), Bergamo (3), Lodi (3), Torino (2), Venezia (1). All cows were Holstein-Friesian housed in free-stall barns without pasture access. Once the survey completed and was received back, trained people visited each farm to conduct an oral interview to complete and/or verify answers. Furthermore, specific data on direct input crop costs, crop management, and feed consumption data were collected during such visit. If a farm operation was done by a custom operator, the custom operation service cost was considered. If input costs were not available or not provided by the farmer, present market price were used (Heinrichs et al. 2013). Small grains silage was a category of crops that included wheat, barley, triticale, and oats. Field peas was a category that included winter protein grains such as dry peas or split peas *(Pisum sativum*).

Calculations

Forages cost of production were calculated considering direct and indirect costs of production. Direct costs of production considered all the operations from tillage and plating to harvest and other input sources, as seeds, herbicides, crop protection products (insecticides, fungicides, silage bacterial inoculants, and silage inhibitors), and fertilizers. In particular, tillage and planting considered all cost of fuel, lubricants and labour workforce for all the operation related to seed bed preparation and planting. Sprayers considered all cost of fuel, lubricants, and labour workforce for all the operation related to crop spraying. Complementary operation considered all cost of fuel, lubricants, and labour workforce for all the operation such as land rolling, rotary hoeing, between-row cultivation, irrigation canals cleaning, and fertilizers distribution. Irrigation considered all cost of fuel, lubricants, and labour workforce for all the operation related with the irrigation operations. The following irrigation systems were considered: flood irrigation, hose reel irrigation system, centre pivot irrigation, lateral pivot irrigation system, and drip irrigation. Manure considered all cost of fuel, lubricants, and labour workforce for all the operation related to handling, loading, transport, and spreading the manure from the farm pile to the fields. Harvest considered all cost of fuel, lubricants, and labour workforce for all the operation as mowing, conditioning, tedding, raking, baling, stacking, and storage when hay-based crops; chopping, transport, packing, and silo covering when silage-based crop; harvesting, transport, and drying when grain-based crops. Water for irrigation costs included surface water drainage as well as the water for irrigation. These costs are paid annually to the consortium whom manages the public canals that enables water to be used for irrigation in the summer as well as the drainage of excess rainfall in the fall and spring. Crop insurance cost was the annual insurance rate payed by the farmer by specific crop. Harvesting cost included the cost of items used for the storage of the crops, such as plastic, film, etc. Costs were calculated for each crop in € per unit of feed DM stored and these were converted in €/ha based on the productivity of the crops.

Indirect costs of production were calculated using different allocation indices for each cost item such as machineries and facilities insurances, repairs and maintenance costs, land cost, machineries, and facilities depreciation. Financial costs were not included due to lack of data. Machineries insurance costs reported by farmers were allocated to the different crops according to the hours used for each crop. Facilities insurance costs were allocated to the different crops according to the amount of DM stored for each crop. Repairs and maintenance cost that considered all the costs incurred in repairs and maintenance of the farm machineries involved in crop production were allocated to each crop according to the working hours spent by each machine in the different crop operations. Land cost involved land ownership and reported cost of land rental. Land ownership cost was calculated as the opportunity cost of owned land set to 500€/ha. For land that included double cropping in a yr., this cost was split between the 2 crops. Machineries and facilities depreciation cost amount was calculated as suggested by Rotz et al. (2011) and then allocated to each crop according to the working hours spent by each machinery in the different crop operations. Lactating cow DMI (kg/cow per d) year-round was obtained based on farmer-reported total amounts of feed consumed from January 1st, 2017 to December 31st, 2017. Income was calculated as the revenue generated from milk sales (Hardie et al. 2014). Feed cost were calculated for lactating cows, dry cows, and young replacement from weaning until 1st calving including expenses related to purchased feeds a farm grown feeds. Thus, income over feed cost (IOFC) was calculated every month as follows (€/lactating cow per d) = [(monthly income from milk sales) - (monthly expenses for both purchased and farm grown feeds)] / (average number of lactating cows per d by month). In the present paper, IOFC has been used as indicator of farm profitability, since it can represent a proven method to evaluate dairy farm profitability when complete balance sheet data are not available (Cabrera et al., 2010). Similar to Caraviello et al. (2006) survey, data of continuous variables collected on this selected group of dairy farm, being characterized by good knowledge and high quality data availability, were descriptively (means and their standard deviations) presented and discussed. Counts were tabulated for binary (e.g., yes or no) or categorical (e.g. specific management choices) variables. In order to provide benchmark values for specific parameters, the 75° and 95° percentiles were calculated for continuous variables related to crop costs of productions.

Equations to calculate cost of production

The calculation cost is a static, spreadsheet based, agro-economic simulation model for evaluation of the physical and financial performance of alternative feed crop production and utilization options in intensive, high input, dairy operations. It employs a single-year, deterministic approach to modelling feed crop costs. Agronomic operations and yield are provided by the farmer and reflect the real farm situation and conditions.

The annual cost of durable assets that depreciate with time is estimated for each machinery using a capital recovery formula in agreement to (Rotz et al., 2011)

$$CRF=[i*(1+i)^{n} / [(1+i)^{n} -1] \qquad [1]$$

Where CRF = capital recovery factor (€/year); i = fixed interest rate of 3.5%, n = accounting life (years)

An annual ownership cost is determined for each machinery where the annual cost is calculated as:

$$AOC = PP\ [\ (1-SV)\ CRF + SV\ (\ i\ )\ ]\ ] \qquad [2]$$

Where AOC = annual ownership cost of a durable, depreciable asset (€), PP = initial purchased price (€), SV = salvage value of the asset, % of initial cost (€). The initial cost is provided by the farmers; the accounting life is generally set at 10 years for machinery with a 30% salvage value of the initial cost (Rotz 2016).

Description of crop categories and calculation of crop production costs

The crop productions that usually were grown in selected dairy farms were grouped as follow: corn silage first seeding (CS) and second seeding (CSII), high moisture ear corn first seeding (HMEC-I), or second seeding (HMEC-II), alfalfa hay (AA-H), small grain silage (SG-S), ryegrass hay (RG-H), perennial grass hay (PG-H), raw soybean grain first seeding (SBI-G), or second seeding (SBII-G), sorghum silage first seeding (SFI-S) or second seeding (SFII-S), mixed-crops silage (BCS-S) mainly based on wheat, ryegrass, triticale, pea and vetch mixtures, winter legume grain (WP-G), based on peas grain.

The total cost of crop production was expressed as €/ha and were calculated for each specific crop category as described below:

$$Total\ cost\ of\ single\ crop = DC + IC \qquad [3]$$

Where, DC = direct cost, IC = indirect costs, LORC = land ownership and rental costs. Specific items entering into total cost of single crop calculation were presented on Table 1.1.

Direct costs

The direct costs (DC) were calculated as the sum of: SCbC (single crop based costs), cropping costs (CC), water irrigation costs (WIC), crop insurance cost (CIC), harvest items cost (HI).

$$DC = SCbC + CC + WIC + CIC + HI \qquad [4]$$

In particular, SCbC included all the operations considered for each crop typologies and were categorized as tillage and planting (tp), sprayers (sp), complementary operations (comp), irrigation (irr), manure handling (mh), harvest (hrv). Consequently, the $SCbC$ of each crop resulted by the sum of single crop operation costs ($SCOCs$) and were calculated in a summative approach in which as follow:

$$SCbC = SCOC_{tp} + SCOCsp + SCOCcomp + SCOCirr + SCOCmn + SCOChrv \qquad [5]$$

Generally, *SCOC* associated to each operation was calculated as described below:

$$SCOC = FC + LC \qquad [6]$$

SCOC = single crop operation costs, *FC* = costs of fuel used for each operation, *LC* = costs of labor workforce used in each operation. The *FC* was calculated as:

$$FC = \left(\frac{Fcons}{EFC}\right) * Fp$$

Where, *FC* = fuel cost, as total cost of fuel for the operation considered, expressed in, *Fcons* = fuel consumption, expressed as (L/h), specific for the operation considered, *EFC* = effective field capacity, is the productivity of the specific operation considered (ha/h), Fp = price of fuel on the market (€/L).

The *LC* were calculated as:

$$LC = \frac{CL}{EFC}$$

Where, *LC* = labor costs, *CL* = cost of labor, value obtained from the interview (€/h), *EFC* = effective field capacity, is the productivity of the specific operation considered (ha/h).

Cropping costs.

Cropping costs *(CC*) were calculated in agreement to formula proposed by Rotz et al. (2016):

$$CC = (S+H+CP+F) / L \qquad [7]$$

Where *CC* = cropping cost, *S* = total cost of seeds, *H* = total cost of herbicides, *CP* = total cost of other chemicals for crop protection, *F* = total cost fertilizers (€), *L* = the amount of land of the specific crop category (ha).

Water for irrigation and drainage costs.

Water for irrigation and drainage costs (*WIC*), are provided by farmers and they were different between crops. In particular, no irrigated crops were charged by cost of water drainage (a), whereas irrigated crops were charged by water drainage and water costs (b).

$$\text{(a)} \quad WIC = Wd / L \qquad [8]$$

$$\text{(b)} \quad WIC = (Wd + Wirr) / L \qquad [9]$$

Where *WIC* = water irrigation cost,*Wd* = water drainage cost for the specific crop (€), *L*= amount of land cultivated for the specific crop (ha), *Wirr* = water irrigation cost (ha) for the specific crop

Crop Insurances.

A crop insurances cost (*CIC*) is calculated in according to the following formula, adapted from (Rotz 2016).

$$CIC = ICcp / L \qquad [10]$$

Where *CIC* = Crop insurances cost , ICcp = Insurances cost from the specific crop production (€), L = amount of land cultivated for the specific crop (ha).

Harvest items.

An harvest cost (*HI*) is calculated per unit of feed DM stored and converted in based on the productivity of the crops and the land addressed, as detailed below:

$$HI = (HIp / DMs) * Pc \qquad [11]$$

Where *HI* = harvest item cost, *HIp* = cost of harvest item products used for the specific crop (€), *DMs* = total yield for the specific crop (Ton of DM), *Pc* = average yield in Ton of DM per hectare for the specific crop (TonDM / ha).

Indirect costs

$$IC = MI + FI + R\&M + Mdc + LORC + FD \qquad [12]$$

The indirect costs (*IC*) were calculated using different allocation keys (AAEA Task Force on Commodity Costs and Returns, 2000; Cesaro and Marongiu, 2013) for each costs item and the total indirect costs is the sum of: machinery insurance costs (machinery insurance cost), facilities insurance costs (*FI*), repairs and maintenance costs (*R&M*), machinery depreciation costs (*Mdc*), land ownership and rental costs (*LORC*), facilities depreciation cost (*FD*).

Machineries insurance costs.

A machineries insurance cost (*MI*) were considered for whole farm equipment used for crop production. A specific *MI* were calculated as:

$$MI = [(MIcy / hT) * hC] / L \qquad [13]$$

Where, *MI* is the cost per hectare of the machineries insurance cost for the specific crop, *MIcy* is the total amount of insurance costs for the machinery used in crop production per year of the farm, *hT* is the total amount of hours of work of all the machineries used in crop production per year, *hC* is the total amount of hours of work of the machinery used in crop production for the specific crop considered per year, *L* (ha) is the amount of land addressed to the specific considered crop.

Facilities insurance costs.

A facilities insurance cost (*FI*) is considered for whole farm facilities used for crop production. A specific *FI* is calculated as:

$$FI = [(FIcy / dmT) * dmC] / L \qquad [14]$$

Where, *FI* is the cost per hectare of the facilities insurance cost for the specific crop, *FIcy* is the total amount of insurance costs for the machinery used in crop production per year of the farm, dm*T* is the total amount of DM produced on farm from crop production per year, dm*C* is the total amount of DM produced by the specific crop considered per year, *L* (ha) is the amount of land addressed to the specific considered crop.

Repairs & Maintenance costs.

These costs consider all the costs incurred in repairs and maintenance (*R&M*) of the farm machineries involved in crop production. A specific *R&M* costs (€/ ha) is calculated as:

$$R\&M\ costs = [(R\&Mtc / Th) * hwc] / Tlc \qquad [15]$$

Where, R&M costs is the total cost per hectare of the single crop, *R&Mtc* is the total cost of *R&M* per year (€), Th is the total hours of machinery works per year (h), *hwc* is the total hours of work for the single crop considered (h), *Tlc* is the amount of land of the single crop considered (ha).

Land ownership and rental costs.

Land ownership and rental cost (*LORC*) include annual costs for rented land and the opportunity cost of owned land, the formula proposed were:

$$LORC= (Tcrl + Tcol) / (Tl) \qquad [16]$$

Where *LORC* = Land costs, *Tcrl* = Total cost rented land, provided by farmers as annual cost (€), *Tcol* = Land owned * average cash rental price of the region (€), *Tl* = total amount of land owned and rented of the farm (ha). If on a certain amount of land, annual double crops are established, the *LORC* were split between the two crops involved in the rotation.

Machineries depreciation.

Mdc is defined as:

$$Mdc = \sum [(Tmdc / hmw) * Th] / L \qquad [17]$$

Where, *Mdc* = machinery depreciation cost, *Tmdc* = total machinery depreciation costs per year for the single machinery involved in a specific operation (€), *hmv* = total hours of work per year of the single machinery involved in a specific operation (h), *Th* = total hours of work per year of the single machinery in the specific crop considered (h), *L* = land cultivated with the specific crop considered (ha).

Facilities depreciation.

Since building have a useful life of many years, it is necessary to convert their initial cost into an annual cost. The annual cost of durable assets that depreciate with time is estimated using a capital recovery formula:

$$CRF=[i*(1+i)\ n] / [(1+i)\ n -1]$$

Where *CRF* = capital recovery factor (n), *i* = interest rate (%), *n* = accounting life, years (n).

An interest rate of 3.5% is used, but interest rate is the result of a general inflation rate subtracted from the nominal interest rate, where the nominal interest rate is the typical rate paid for a bank loan approximates a real interest rate. All permanent facilities are assumed to be long-term investments.

An annual ownership cost is determined for each building where the annual cost is calculated as:

$$AOC = PP\ [\ (1\text{-}SV)\ CRF + SV\ (\ i\ )\ ] \qquad [18]$$

Where *AOC* = annual ownership cost of a durable, depreciable asset, *PP* = initial purchased price, €

SV = salvage value of the asset, % of initial cost. The initial cost is provided by the farmers, the accounting life is generally set at 20 years for structures, with no salvage value. That equations are modified in according to (Rotz 2016).

The facilities depreciation cost is calculated in according to the following formula, adapted and expanded from (Rotz 2016).

$$FD = (\ \sum AOC + OrC\ )\ /\ Land \qquad [19]$$

Where *FD* = facilities depreciation, *AOC* = Annual ownership cost from facilities asset (€), *Orc* = Ordinary cost for repairs and maintenance (€), *L* = total amount of cultivated land.

Results and Discussion

Forty-one of the fifty selected herds responded to the survey, resulting in an 82% response rate. Due to criterion (i.e., previous knowledge of these farms recording the most and the best quality data) used to select these high performance dairy herd, all the data presented and discussed in current survey, either for continuous, binary or categorical collected information, were descriptively reported in agreement to Caraviello et al. (2006). The response rate was relatively high because most of these herds had a good relationship with the University. Herd size of respondents was 327 ± 162 lactating cows (Table 1).

Table 1 provides a summary of information regarding labour, herd size, milk production and components, calving interval, and culling strategies. About 63% of labour was provided by nonfamily employees with most of the employees working full-time. Calculation done on a basis of a 50-hr work week showed an average of 79 cows and 821.6 tons of milk per year per full-time equivalent employee, an intermediate value when compared with the US reports of (Bewley et al. 2001; Caraviello et al. 2006) but lower than reported in Evink and Endres (2017). Cow/heifer ratio was 1.08 ± 0.13 (ranging from 0.77 to 1.36). Average daily milk yield, as kg milk sold per cow/d, was 32.83 ± 2.01. Annual culling rate was 34.00 ± 4.00 % and calving interval was 14.16 ± 0.58 mo.

Table 2 provides a summary of responses regarding detection of oestrous, hormonal synchronization, voluntary waiting period, and reproductive performances. Among technologies introduced in dairies to aid the oestrous detection, pedometers were the most common technologies. Most of the herds used a voluntary waiting period of 55.2 ± 8.7 d for primiparous and 53.2 ± 7.6 for multiparous, thus, extending the time until first insemination might enhance the first-service conception rate (Stangaferro et al. 2017). Ovsynch was the most common synchronization protocol used for first AI service. Only a few herds have introduced the Double-Ovsynch due to a higher labour requirement of this protocol. Almost 75% of the herds used ultrasound for pregnancy check. An early and accurate detection of nonpregnant cows has been reported as very important in order to re-breed these cows as soon as possible (Wijma et al. 2017).

Table 3 summarizes housing and bedding management. The surveyed farms had an average of 0.98 ± 0.1 stalls/lactating cow (ranging from 0.74 to 1.33), which indicated that some farms were subjected to a severe overcrowding. Fewer than a quarter of dairies have a specific maternity pen, and less than a half of them cleaned the maternity pens after every calving, whereas many allowed ≥ 4 calvings between fully cleanings.

Table 4, summarizes responses among opinion provided by farm managers. Ovarian cysts and conception rate has been identified as the major sources of concern among reproductive management. Among the health problems listed on a 10-point scale, paratuberculosis (8.57 ± 1.05) and mastitis (7.15 ± 1.12) were of greatest concern, followed by ketosis (6.91 ± 1.22) and milk fever (6.69 ± 1.36). Among employee management, the greatest concern is related to training employees and supervising them. Additionally, farmers spontaneously reported that major issues faced at the crop production level are related to the implementation of strategies to control the population of pests and other noxious animals like, *Ostrinia nubilalis* and *Diabrotica spp*. and *Myocastor coypus.*

Table 5 summarizes nutrition, body condition scoring, and grouping strategies. The mean frequency of feed delivery was 1.27 ± 0.47 times/d, and feed was pushed up an average of 6.8 ± 1.2 times/d. These results are very similar to the results in the US reported by Caraviello et al. (2006). Increased feeding frequency and greater bunk space may improve DMI and promote more balanced nutrient intake and greater milk production (Sova et al. 2013). Diets were reformulated every 48 ± 7 d, and feeds were tested every 52 ± 2 d. Among transition cows nutritional management strategies, only 3 farms had introduced anionic diets, despite literature showing that managing the prepartum dietary cation-anion difference [DCAD = (Na + K) - (Cl + S)] to maintain an average urine pH between 5.5 and 6.0 would result in additional benefits in Ca status, postpartum DMI, and milk yield (Leno et al. 2017). Only a small proportion of herds evaluated cows' BCS as a routine on a consistent way, despite benefits for reproduction and health of BCS monitoring are well documented in the literature (Domecq et al. 1997).

Improved nutritional grouping strategy can be a potential way to improve IOFC and feed efficiency in these herds, since substantial improvement are obtained by switching from 1 to 2 or 3 nutritional groups (Cabrera and Kalantari 2016; Kalantari et al. 2016). Despite undeniable advantages as higher milk productivity, better herd health, and higher IOFC due to better tailored diets and lower environmental impact because of nutritional grouping strategies (Bach 2014), many farmers concerned about the management complexity, the higher labour costs, and loss in milk production due to more frequent intra-group movement (Contreras-Govea et al. 2015), and TMR formulations errors (Hutjens 2013). The feed cost, was calculated considering the whole feed consumption of the herd, excluding the feeds used for calves under 3 months of age, and expresses as € per lactating cow per day, using cost of production for farm grown feeds and market prices for purchased feeds. The feed cost, range from 5.68 to 10.09 € per lactating cow per day with an average and SD of 7.33 ± 0.77. Milk income of the herd has been calculated as the sum of milk income including premiums for components and somatic cell count; the average milk income as € per lactating cow per day was 12.38 ± 1.11. IOFC, calculated as the difference of the two precedent mentioned index, and average of the whole year of 2017, was 5.05 ± 0.87 €/d per lactating cow with a minimum of 3.85 €/d and a maximum of 6.88 €/d.

Table 6 summarizes response regarding insemination strategies, heifers and calves rearing on farms. All farms used sexed semen, in different proportions, with an average level of utilisation on heifers of 67.83%. Beef cattle semen usage on heifers was not popular (1.45% of the total heifers inseminations), however, usage of beef semen on cows has been recorded to be more popular (14.59 % of total cows inseminations).

Table 7 provides a summary of information regarding labour, land size, soil type and crop management strategies. Average land size of respondents was 160 ± 94 ha. Double cropping strategies, expressed as the amount of land used for growing 2 crops in the same year, was 33 ± 13%. The most common type of soil was the ‘loam’ soil, and the most common tillage practice encountered was the chisel ploughing. In addition, not so many farms (10 out of 41) were able to provide recent soil analysis to better asses their fertilization plans in order to reduce environmental pollution and costs. Some farms (n=13) have introduced the umbilical injection as a common practice for slurry management. This practice is more cost effective than hauling or spreading raw manure (Plastina et al. 2015).

Table 8 summarizes farm crop plan, yields, the crop DM at harvest, total direct costs, total indirect costs, total costs of production, and the relative cost of production per t of DM produced. Alfalfa hay resulted the most common crop with a percentage of the total crop plan of 17.3 ± 7.66 % with a total cost of production of 1,968 ± 362 €/ha with an average of 6 cuts per year, for a total duration of 3.5 ± 0.3 yr. In the best 10 and 25% of farms considered (10th and 25th percentiles respectively), cost of production resulted lower than average with cost of production in € per ton of DM of 166.6 and 179.4 respectively.

Mixed crop silage, which includes a mixture of small grains, vetch and pea that was sown during the fall and harvested as silage in May, has become a very popular crop cultivated in 17 surveyed farms with a yield of 10.15 ± 0.75 t DM/ha. This yield was very similar as small grains silage crop (9.85 ± 0.58 t DM/ha), however, with a slightly higher CP content. Corn silage first seeding (CSI) have higher total costs of production compared to corn silage second seeding (CSII), this was due to higher land costs, since the total land cost per hectare in case of corn silage second seeding was shared with the previous crop. Anyway, is important to notice the lower direct cost for CSI compared to CSII since it has lower irrigation cost and higher yield. In the best 10% of farms, CSI cost of production was lower than average being 118.7 € per ton of DM and 112.9 € per ton of DM for the CSII.

High moisture ear corn first seeding (HMEC) and second seeding (HMEC-II) was used as the main starch source, in 36 and 5 farms respectively with a crop plan % as 20 ± 8.9 and 6.6 ± 3.1% respectively. Cost of production trend for HMEC and HMECII follow the same pattern describe for CSI and CSII. Perennial grass hay (PG) take place in crop plan for 13.9 ± 13.6% with many difference among farms, since in certain farms their presence is confined in marginal areas, whereas in other farms their presence is much more extensive. Ryegrass hay (RG) (Lolium multiflorum) was used in many farms (35), with a mean proportion of 19.5 ± 10.1 % of the crop plan, due to high forage quality and low cost of production (1057 ±164.30 €/ha). Ryegrass is usually harvested as hay or silage from mid-April to mid of May as function of the weather and allow to grow a second crop after it as corn/sorghum/soybeans. Soybeans first seeding (SBI) and second seeding (SBII) was cultivated in (11) and (8) farms respectively with a proportion of 9.8 ± 6.6 and 6.5 ± 3.9 % of the crop plan. SBI present a higher total cost pf production if compared to SBII and higher yield. In particular, SBI has lower direct cost compared to SBII and higher indirect cost due to higher land cost, since SBII share land cost with the previous cultivated crop. Sorghum popularity is raising in northern Italy in recent years, the main causes to this success is related to the lowest mycotoxin risks if compared to corn and lower irrigation requirements, sorghum in first seeding (SFI) enter in crop plan of (8) farms with an average 6.5 ± 3.9 % of the crop plan, whereas sorghum silage second seeding (SFII) was used by (20) farms with an average 12.3 ± 7.5% of the crop plan. About SFI, since all the farms have access to irrigation in almost all the fields, SFI lost much of its convenience in favor to CS, a crop that provide higher yields and more energy per hectare at lower cost in €/ton DM produced. Among SFII, these results show how SFII was much more appreciate than SFI, this because SFII shows a small difference in yield production if compared to SFI, SFII result competitive also with CSII especially in light soil farms with high irrigation cost and become more interesting if compared to CSII in case of late planting (i.e. second seeding after a late small grain silage harvest). As small grains silage, we assume a category that include, in the farm surveyed, wheat, barley, triticale and oats. This crop category was cultivated in (24) farms with an average proportion of 17.4 ± 8.8% of the crop plan. Winter protein grains (WPG), is a category referred to field peas (Pisum sativum).

Among cost of production of forages, at the best of our knowledge, very limited sources of data have been published in order to compare cost of production of forages for the area considered (Northern Italy). To obtain some kind of comparable data, (Borton et al., 1997) showed great difference in cost of production of forages among different farm dimensions considering a 100 and 500 lactating cows farms as sample. (Cesaro and Marongiu, 2013) provided a very detailed cost of production analysis for crop commodities as maize, wheat, durum wheat. Only a small part of these data can be compared with our database. Anyway, the comparable data as seeds, fertilizers, crop protection, depreciation costs, shows high similarity among corn and small grains cost of production. Table 9 provides a detailed summary of direct cost of production of forages. Large difference among irrigation costs among farms is noticed. Farms that rely on flooding and pivots had lower irrigation costs than farms that used hose reel equipment or drip irrigation. It is important to notice that not all farms were suitable for flooding irrigation system or pivots due to fields and soil intrinsic characteristics. Farms with minimum tillage or chisel ploughing had significant lower tillage and planting costs. Costs of spraying operations were relatively high because almost all farms have recently introduced an insecticide treatment for the control of European corn borer (*Ostrinia nubilalis*) and Western corn rootworm (*Diabrotica spp.),* in addition to pre-emergence and sometimes post-emergence herbicides treatments. The use of transgenic corn hybrids is currently restricted in Italy and the use of chemical insecticides is still the main method for European corn borer control in field conditions (Labatte et al. 1996), since the associated grain yield losses vary between 5% to 45% (Lynch et al. 1979). The treatment also reduces aflatoxin contamination problem (Masoero et al. 2010). In addition, potential opportunities can be derived by the introduction of fungicides application on corn, in order to improve corn silage yield (Paul et al. 2011) and overall quality (Venancio et al. 2009). These effects are beneficial also at the cows' level in order to improve feed efficiency, as reported by (Haerr et al. 2015). Among fall seeding crops the most expensive items were the harvest operations and tillage and planting operations.

Table 10 provides a detailed summary of indirect cost of production of forages. Land cost results lower in crops involved in double cropping strategies, since the land cost (€/ha) were splitted between the two crops involved. Machineries depreciation (Md) costs were higher in crops that required expensive equipment and longer working hours such as the case of corn silage and alfalfa hay with costs of 154.67 ± 97.12 and 164 ± 155.33 €/ha, respectively. Facilities depreciation (Fd) costs were higher for high producing crops and for crops that require expensive storage facilities (e.g. horizontal silo is more expensive than a hay shed). For those reasons, corn silage and sorghum silage first seeding had the higher facilities depreciations costs of 59.66 ± 58.68 and 59.09 ± 29.56 €/ha respectively. Machineries insurance cost (Mi) and facilities insurance costs (Fi) follow the same pattern as Md and Fd respectively. Among repairs and maintenance costs (R), results showed higher costs for AA and CS, since these are the crops with the higher requirement in machinery work hours per hectare, with a cost of (150.11 ± 41.76) and (134.88 ± 39.95) €/ha respectively, followed by CSII, HMC and PG. The cost of production of forages showed a great variability among farms, even if the sample of farms considered include farms with similar characteristics, similar land management, dimensions and machineries used. This means that cost of production of forages is farm specific and general market value to estimate costs for farm grown forages can be described as an oversimplification.

Conclusions

The present study provides a comprehensive summary about dairy herd management and farm performances with emphasis on cost of production of the main forage crops on medium to large very well managed commercial dairy farms located throughout Northern Italy. As such, it can serve as a useful reference regarding crop general management issues, employee management, crop management practices, and forages cost of production. Several key challenges and opportunities were identified. Crop managers identified training good employees and finding good employees as their greatest labour management challenge. Contrast pests as *Ostrinia nubilalis*, *Diabrotica spp*. and noxious animals as *Myocastor coipus* has been identified as another important challenges farmer faced from an agronomical standpoint. With regard to the high variability among cost of production of forages showed in this paper, additional opportunities may exist. First, cost of production references can be useful to find points of weakness in the crop management practices and highlight inefficiencies. Second, forage cost of production analysis carried out at the farm level, can be the first step, for a new kind of decision making process, in order to provide to dairy farmer's better suggestions among cropping plan design based on their herd nutritional requirements. An integration of this aspect through least cost ration formulation using mathematical optimizations can be an interesting argument to focus future research. Forages cost of production analysis require a high input effort in order to collect all the data necessary for a correct cost calculation and a bigger analysis that include more farms can be beneficial in order to obtain more variability, new insight and different farm situations. In summary, this study can provide useful references with regard to commonly used crop management practices and relative costs on well managed commercial dairy farm located in Northern Italy at present time.

Geolocation Information: Italy

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Table 1. Summary response by herd managers (n=41) to questions related to the dairy enterprise among labour, herd size, milk production, calving interval, culling. Means ± SD or counts (binary or categorical variables)

Question	Mean ± SD or (counts)	Min	Max
How many people are working in your operation?			
Full-time family (n; hr/wk)	1.39 ± 1.07; 65.7 ± 14.5		
Part-time family (n; hr/wk)	0.78 ± 0.76; 21.4 ± 12.4		
Full-time nonfamily (n; h/wk)	3.46 ± 2.30; 52.8 ± 11.2		
Part-time nonfamily (n; h/wk)	0.29 ± 0.46; 18.7 ± 5.28		
What is the lactating cow herd size? (n)	327 ± 162	96	750
Dry cows	51 ± 25	14	117
Heifers and calves	360 ± 196	86	851
How many calves were born in your herd last year?	380.9 ± 205.1	86	939
(calves)	32.83 ± 2.01	28.74	36.73
How much milk do you deliver per cow per day? (kg/d)	32.54 ± 2.00 (34)	28.74	36.37
Milking 2X	34.23 ±1.52 (7)	32.42	36.73
Milking 3X	3,939 ± 2,055	1,159	9513
How much milk you delivered last year? (t/yr)	3.86 ± 0.12	3.65	4.10
Average fat content (%)	3.39 ± 0.06	3.25	3.51
Average protein content (%)	232 ± 46	135	315
Average SCC content (1000 cells/mL)	23.78 ± 0.95	21.9	26
Age at 1st calving (mo)	14.16 ± 0.58	13.3	16.3
What is the average calving interval in your herd? (mo)	34.0 ± 4.00	27	45
What percentage of your cows left the herd last year? (%)			

Table 2. Summary response by herd managers, question related to detection of oestrus, hormonal synchronization, voluntary waiting period and reproduction performance. Means ± SD or counts (binary or categorical variables)

Question	**Mean ± SD or (counts)**	**Min**	**Max**
Who is responsible for estrus detection on your farm?	Hired employee (28)		
	Family member (10)		
What estrus-detection technologies/practices are used?	Tail chalk (10)		
	Pedometers (36)		
	Collars (5)		
Do you use a voluntary waiting period?	Yes (30)		
Primiparous (d)	55.24 ± 8.73	45.7	73.2
Multiparous (d)	53.23 ± 7.62	43.8	71.1
Do you use estrous detection or synchronization timed AI?	Yes (37)		
Which protocol you use to synchronize your cows for the first breeding?	(5)		
Double-Ovsynch	(16)		
Ovsynch	(4)		
Presynch	(2)		
Other	9.9 ± 3.49 d		
How frequently are pregnancies diagnosed?			
What method is used for diagnosis?	(11)		
Palpation	(30)		
Ultrasound			
Are pregnant cows reexamined?	(15)		
Yes	(16)		
No	56.14 ± 7.75	39.09	70.61
What's the HDR of your herd in the last year? (%)	30.52 ± 3.32	21.01	39.07
What's the CR of your herd in the last year? (%)	17.05 ± 2.58	11.48	25.00
What's the PR of your herd in the last year? (%)			

Table 3. Summary response by herd managers (n=41) to question related to housing, heat stress, manure removal and bedding. Means ± SD or counts (binary or categorical variables)

Question	Mean ± SD or (counts)	Min	Max
How many stalls per lactating cow have your herd? (stalls/lactating cow)	0.98 ± 0.1	0.74	1.33
How much water access space per cow have lactating cows? (cm/lactating cow)	12 ± 4.3	6.5	19
What is the predominant bedding type in your lactating cows barn?	Straw (20) Sawdust (1) Mattress (12)		
At what frequency is fresh bedding applied? (d)	4.1 ± 2.1	2	7
If individual maternity pen is used, how often do you clean and disinfect them?	Every calving (0) >4 calving (6) 2 to 3 calving (1)		
Do you use electronic sorting gates?	Yes (12) No (29)		

Table 4. Summary response among opinion by farm managers (n=41). Means ± SD or counts (binary or categorical variables)

Question	Mean ± SD or (counts)	Min	Max
Indicate the importance of these reproductive issues in lactating cows in your herd (1 = easy to handle to 10 = major problem)			
AI service rate	7.3 ± 1.2	6	8.5
Conception rate	8.1 ± 0.9	6.5	9.5
Twinning	4.1 ± 0.3	3	5
Retained placenta and metritis	7.1 ± 1.5	5.5	9
Estrous detection	7.5 ± 1.4	6	9
Early embryonic loss	6.5 ± 1.2	5	8
Ovarian cysts	8.7 ± 0.3	7.5	9
Reproductive record keeping	6.5 ± 0.9	5.5	9
At which level these diseases are problems in your herd? (1=no problem to 10 = major problem)			
Mastitis	7.15 ± 1.12	5	9
Dermatitis	5.01 ± 1.32	5	7.5
Lameness	5.11 ± 1.24	5	7.5
Abortions	4.61 ± 0.72	3	6.5
Death losses	4.34 ± 0.74	3	6
Paratubercolosis	8.57 ± 1.05	7	9.5
Ketosis	6.91 ± 1.22	5	8.5
Milkfever	6.69 ± 1.39	4.5	8
Bovine viral diarrhea	4.01 ± 0.51	3	5
Infectious bovine rhinotracheitis (IBR)	4.21 ± 0.47	3	5
Describe the following aspects of employee management on your operation (1 = easy to handle to 10 = major problem)	7.15 ± 1.51	5	9
Finding good employees	8.51 ± 1.21	7	9
Training employees	8.14 ± 0.71	7	9
Supervising employees	6.15 ± 0.51	5	7
Keeping good employees			

Table 5. Summary response by herd managers (n=41) to question related to nutrition, body condition scoring and grouping strategies. Means ± SD or counts (binary or categorical variables)

Question	**Mean ± SD or (counts)**	**Min**	**Max**
At what frequency is fresh feed delivered? (times/d)	1.27 ± 0.47	1	2
How many times is feed pushed each day? (times/d)	6.8 ± 1.82	4	9
How much bunk space per cow have lactating cows? (cm/lactating cow)	55.9 ± 3.91	43	73
What is the targeted feed refusal rate? (% feed delivered)	4.2 ± 0.4	2.5	5
How often are your feed tested? (d)	52 ± 2	15	85
How often are the diets reformulated? (d)	48 ± 7	30	90
Who is the main persona responsible for formulating diets?			
Feed company nutritionist	(34)		
Private consultant	(5)		
Other	(2)		
Do you use anionic diets in dry cows diets?			
Yes	(3)		
No	(38)		
How often do you BCS your cows?			
Never	(17)		
Evaluate at pen level every	45 ±6 d (13)	7	60
Evaluate cows individually every	65 ± 24 d (13)	7	60
Who does the BCS?			
Veterinary	(10)		
Nutritionist	(1)		
Farm employee	(2)		
Do you use anionic diets in dry cows diets?			
Yes	(3)		
No	(38)		
Does nutritionist use these scores when balancing rations?			
Yes	(1)		
No	(13)		
What's your different nutritional groups among lactating cows?	One group (8) Post fresh, primiparous + multiparous (25) Post fresh, primiparous, multiparous (5) Post fresh, primiparous, multiparous high, multiparous low (3)		
IOFC[1] (€ / lactating cow / day)	5.05 ± 0.87	3.85	6.88
Milk Income[2] (€ per lactating cow per day)	12.38 ± 1.11	14.61	10.43
Feed cost[3] (€ per lactating cow per day)	7.33 ± 0.77	5.68	10.09

[1] Milk income over feed cost from January to December 2017

[2] Milk Income for lactating cows from January to December 2017

[3] Feed cost whole herd, except calves under 3 months of age, from January to December 2017

Table 6. Summary response by herd managers (n=41) to question related to animal health, insemination strategies, heifers rearing. Means ± SD or counts (binary or categorical variables)

Question	**Mean ± SD or (counts)**	**Min**	**Max**
In which proportions you use sexed semen on heifers? (% of total heifers inseminations)	67.83 ± 18.79	20	90
In which proportions you use sexed semen on cows? (% of total cows inseminations)	1.45 ± 2	0	7
In which proportions you use beef cattle semen on heifers? (% of total heifers inseminations)	1.52 ± 2.05	0	10
In which proportions you use beef cattle semen on cows? (% of total cows inseminations)	14.59 ± 11.41	0	45
Did you have a waste-milk feeding program for your calves?			
Yes	(25)		
No	(16)		

Table 7. Summary response by crop managers (n=41) to questions related to the crop enterprise among labour, farmland size, soil type, tillage practices, irrigation. Means ± SD or counts (binary or categorical variables)

Question	**Mean ± SD or (counts)**	**Min**	**Max**
How many people work in your operation? (n)			
Full-time family	0.54 ± 0.5	0	1
Part-time family	0.07 ± 0.26	0	1
Full-time nonfamily	1.29 ± 0.96	0	3
Part-time nonfamily	1.12 ± 0.51	0	3
How many ha of tillable land your farm manages? (ha)	160 ± 94 ha	50	420
How much double cropping? (%)	33 ± 13%	0	66
Describe the most common soil type of your farm	Sandy (4) Sandy loam (13) Loam (16) Silty loam (5) Clay (3)		
Describe the most common tillage practice adopted in you farm	Conventional tillage Ploughing (17) Conservation tillage Chisel plowing (18) Minimum tillage (6)		
What's the most common irrigation system adopted?	Flooding irrigation direct from canals without pumps (8) Flooding irrigation with pumps (17) Hose reel (10) Central pivot (2) Rainger linear (3) Drip irrigation (1) Solid spreader (2)		
What kind of equipment you use the most to manage slurry?	Slurry tank spreader (21) Umbilical spreader (5) Umbilical injector (13)		
	Yes (6)		
Do you use cover crop in order to reduce leaching and erosion?	No (35) Yes (21)		
Do you systematically implement strategies to control *Ostrinia nubilalis* and *Diabrotica spp* in corn?	No (20)		

Table 8. Crop yield, direct, indirect and total cost of production of forages in farms, means ± SD, 10th and 25th percentiles (€/ha)

Crops	Farms		Land [1]	yield	DM	tDC[2]	tIC[3]	tC[4]	tC per Unit
	n		%	Ton DM / ha	%	€ / ha	€ / ha	€ /ha	€ / ton DM
Alfalfa hay	40	Means ± SD	17.3 ± 7.66	9.61 ± 1.24	88.2 ± 1.9	895 ± 90	983 ± 204	1,968± 362	207.1 ± 41.9
		25th				830.6	806.3	1719.8	179.4
		10th				806.2	784.9	1647.9	166.2
Corn silage second seeding	38	Means ± SD	24.7 ± 10.4	17.22 ± 2.46	32.4 ± 2.0	1,693 ± 153	662 ± 132	2,356 ± 185	139.4 ± 21.8
		25th				1543.3	563.4	2263	122
		10th				1494.4	531.6	2185.8	112.9
Corn silage first seeding	37	Means ± SD	25 ± 10.2	20.38 ± 1.78	33.4 ± 1.4	1,600 ± 160	981 ± 183	2,581 ± 221	127.4 ± 14.1
		25th				1471	814.8	2397.7	121.1
		10th				1441.1	799.5	2377.9	118.7
High moisture ear corn first seeding	36	Means ± SD	20 ± 8.1	11.98 ± 0.98	59.0 ± 3.3	1,534 ± 116	903 ± 149	2,437 ± 168	204.8 ± 22.7
		25th				1442.5	768.2	2299.1	189.5
		10th				1421.8	755.4	2276.8	183.8
Ryegrass hay	35	Means ± SD	19.5 ± 10.1	5.85 ± 0.35	88.8 ± 2.0	522 ± 78	536 ± 125	1,058 ± 164	181.4 ± 30.3
		25th				460.5	428.8	917.7	163.6
		10th				447	413.2	897.9	154.3
Small grains silage	24	Means ± SD	17.4 ± 8.8	9.85 ± 0.58	29.3 ± 2.4	777 ± 85	452 ± 55	1,230 ± 110	125.2 ± 12.6
		25th				719.7	403.6	1167.3	119.9
		10th				696.6	399.2	1135.5	114
Sorghum silage second seeding	20	Means ± SD	12.3 ± 7.5	12.14 ± 0.53	29.5 ± 1.6	932 ± 99	510 ± 108	1,442 ± 167	119.0 ± 15.8
		25th				851.1	450.5	1303.4	109.9
		10th				835.4	405.8	1285.9	106.1
Mixed crops silage	17	Means ± SD	16.9 ± 8.9	10.15 ± 0.75	31.5 ± 1.9	721 ± 78	461 ± 84	1,182 ± 185	116.5 ± 11.5
		25th				689.8	409	1051.1	109.9
		10th				654	382.9	1010.5	107.6
Perennial grass hay	17	Means ± SD	13.9 ± 13.6	8.80 ± 1.62	89.1 ± 1.9	709 ± 155	914 ± 129	1,622 ± 253	187.1 ± 30.2
		25th				571.9	759.9	1410.1	168.8
		10th				559.1	787.9	1380.3	160.3
Soybeans grain first seeding	14	Means ± SD	5.2 ± 2.8	3.71 ± 0.40	87.8 ± 1.3	966 ± 74	768 ± 87	1,734 ± 136	474.3 ± 71.4
		25th				901.2	701.4	1612.1	421.2
		10th				896.2	682.5	1599.2	409.5
Soybeans grain second seeding	11	Means ± SD	9.8 ± 6.6	2.92 ± 0.34	87.0 ± 3.6	1,016 ± 79	472 ± 53	1,489 ± 118	517.6 ± 79.2
		25th				970.8	441.9	1392.2	454.2
		10th				939.2	423.7	1377.9	441.1
Sorghum silage first seeding	8	Means ± SD	6.5 ± 3.9	13.36 ± 0.84	29.4 ± 1.8	982 ± 101	795 ± 105	1,777 ± 126	133.7 ± 14.2
		25th				895.5	710.8	1687.7	127.4
		10th				890.4	697.3	1654.6	121.1
Winter protein grains[5]	6	Means ± SD	4.2 ± 1.6	2.40 ± 0.36	88.9 ± 1.1	579 ± 49	711 ± 41	1,290 ± 62	549.5 ± 97.7
		25th				543.4	678.3	1256.4	469.3
		10th				531.3	671.2	1231.4	455.2
High moisture ear corn second seeding	5	Means ± SD	6.6 ± 3.1	9.34 ± 0.38	56.0 ± 1.5	1,658 ± 113	546 ± 64	2,204 ± 112	236.2 ± 12.1
		25th				1561.2	496.5	2109.2	229.2
		10th				1549.9	485.1	2098.2	226.6

[1] some fields allow for a second crop (corn silage second seeding, sorghum silage second seeding, soybeans grain second seeding): area of these fields was considered in the numerator and denominator. [2] total direct costs. [3] total indirect costs. [4] total costs. [5] (*Pisum sativum spp*)

Table 9. Direct cost of production of forages in farms (n=41) means ± SD, (€/ha)

Crops	Tillage[1]	Sprayers[2]	Comp[3]	Irrigation[4]	Manure[5]	Harvest[6]	Seed[7]	Herbicides[8]	Crop[9]	Fertilizers[10]	Water[11]	items[12]	Harvesting[13]
Alfalfa hay	64.6	28.3	17.5	64.8	44.8	418.5	71.5	88.4	29.0	10.8	28.4	0.0	27.8
	22.2	3.0	1.5	24.5	16.8	61.1	3.8	28.5	15.5	18.8	16.0	0.0	3.1
Corn silage second seeding	206.8	56.8	76.1	296.0	128.0	331.3	197.8	64.3	59.3	77.7	122.1	50.5	26.6
	55.7	34.5	18.0	139.1	32.4	58.2	7.4	1.9	21.1	25.8	60.7	8.6	1.24
Corn silage first seeding	198.9	56.6	60.1	215.6	123.9	355.2	206.4	77.9	59.2	82.9	81.4	49.6	31.4
	55.8	35.0	21.5	111.1	31.9	61.9	9.3	12.0	21.4	42.7	40.2	24.4	1.9
High moisture ear corn first seeding	197.9	62.0	43.4	202.4	121.0	321.9	202.8	64.9	65.7	99.4	94.1	48.3	10.6
	57.7	27.7	20.7	100.3	30.1	63.9	12.2	4.4	13.9	48.8	40.0	26.2	0.8
Ryegrass hay	150.1	0.0	17.9	0.0	97.6	140.4	84.9	0.0	0.0	1.3	11.2	0.0	18.3
	67.3	0.0	2.2	0.0	26.4	39.3	6.6	0.0	0.0	8.1	9.2	0.0	1.7
Small grains silage	107.9	0.0	24.5	0.0	107.8	268.0	137.4	32.0	0.0	42.2	14.6	28.3	14.2
	46.5	0.0	2.2	0.0	21.5	68.4	6.2	11.1	0.0	23.2	18.7	18.9	2.4
Sorghum silage second seeding	100.5	22.8	23.8	113.3	67.2	286.8	181.4	61.2	0.0	22.9	28.2	0.0	23.3
	46.2	6.2	1.7	37.1	17.6	73.6	6.9	2.2	0.0	30.4	12.6	0.0	0.8
Mixed crops silage	91.2	0.0	16.2	0.0	120.3	288.7	176.1	0.0	0.0	0.0	13.8	0.0	14.0
	58.7	0.0	2.1	0.0	18.1	61.97	5.4	0.0	0.0	0.0	8.4	0.0	0.4
Perennial grass hay	0.0	0.0	15.3	67.6	104.3	376.0	0.0	0.0	0.0	26.8	94.4	0.0	24.1
	0.0	0.0	1.3	65.6	25.5	66.2	0.0	0.0	0.0	64.1	58.2	0.0	2.2
Soybeans grain first seeding	169.2	25.0	40.4	89.8	32.6	292.0	165.5	65.6	0.0	0.0	34.0	51.4	0.0
	41.0	5.6	5.8	19.5	46.7	7.7	4.5	18.4	0.0	0.0	20.5	15.1	0.0
Soybeans grain second seeding	168.5	26.0	25.3	112.8	40.4	292.8	158.1	72.6	37.1	0.0	41.0	41.5	0.0
	35.4	3.3	2.4	45.3	48.7	15.8	6.5	14.2	12.3	0.0	20.4	13.9	0.0
Sorghum silage first seeding	147.9	22.2	15.7	67.0	71.0	354.1	179.6	58.2	0.0	18.1	23.3	0.0	24.3
	66.9	6.1	0.6	10.3	17.7	66.2	7.6	8.1	0.0	33.6	13.4	0.0	0.6
Winter protein grains[14]	106.5	1.5	38.2	0.0	60.7	191.3	165.5	0.0	0.0	0.0	15.4	0.0	0.0
	46.6	3.8	1.8	0.0	35.8	3.6	13.6	0.0	0.0	0.0	6.0	0.0	0.0
High moisture ear corn second seeding	166.9	63.7	65.9	311.4	109.6	331.2	195.9	62.0	63.9	118.4	111.0	50.0	8.1
	62.3	20.4	10.0	147.6	20.5	90.8	4.8	0.0	0.0	36.7	56.5	0.0	0.3

[1]tillage and planting operations costs. [2]sprayers operations costs. [3]complementary operation costs. [4]irrigation costs. [5]manure handling and spreading costs. [6]harvest operations costs. [7]seeds costs [8]herbicides costs. [9]crop protection costs (fungicides. Insecticides) [10]fertilizers costs. [11]Drainage and water for irrigation costs. 12crop items costs. [13]harvest items costs (film, plastics). [14](*Pisum sativum spp*).

Table 10. Indirect cost of production of forages in farms (n=41), means ± SD, (€/ha)

Crops	Land[1]	Machineries depreciation	Facilities depreciation	Machineries insurance	Facilities insurance	Repairs and maintenance
Alfalfa hay	617.3	164.4	17.7	10.5	22.9	150.1
	112.6	155.3	47.5	6.7	19.8	41.7
Corn silage second seeding	304.5	149.8	53.3	9.06	11.4	133.9
	57.1	89.3	51.0	5.65	5.9	40.7
Corn silage first seeding	609.0	154.6	59.6	9.40	13.5	134.8
	114.1	97.1	58.7	5.81	6.5	39.9
High moisture ear corn first seeding	604.8	121.5	38.4	7.65	8.53	121.7
	103.8	71.7	37.8	5.31	4.74	39.8
Ryegrass hay	308.7	107.3	16.5	5.97	13.7	83.4
	58.8	80.3	43.0	4.07	10.2	23.2
Small grains silage	307.5	49.8	29.4	3.17	5.53	56.7
	40.0	40.1	26.0	2.79	2.82	20.1
Sorghum silage second seeding	318.3	71.1	48.8	4.62	8.01	58.9
	65.0	46.5	28.1	3.60	3.73	25.2
Mixed crops silage	296.6	70.3	30.2	4.16	5.42	54.2
	51.0	48.8	23.5	2.45	2.05	16.1
Perennial grass hay	613.0	103.1	44.9	7.81	15.0	129.6
	80.2	51.2	75.3	4.36	4.3	41.5
Soybeans grain first seeding	593.1	75.5	0.0	2.98	33.9	62.8
	72.5	22.5	0.0	1.54	27.1	20.3
Soybeans grain second seeding	294.6	93.1	0.0	3.29	18.7	62.4
	43.7	33.0	0.0	1.00	9.9	16.2
Sorghum silage first seeding	613.4	53.7	59.1	2.75	8.38	57.8
	73.7	31.3	29.5	1.65	4.05	15.4
Winter protein grains[2]	590.9	45.7	0.0	2.65	29.3	42.4
	41.0	33.6	0.0	1.75	21.6	8.0
High moisture ear corn second seeding	594.2	104.1	32.4	6.57	4.29	101.7
	43.8	79.6	25.0	3.76	1.32	18.0

[1] land ownership and rental costs

[2] (*Pisum sativum spp*)

Chapter 4

Development of a decision support tool for the optimal allocation of nutritional resources in a dairy herd

A. Bellingeri, *† V. E. Cabrera,*[1] D. Liang,* F. Masoero, † A. Gallo †

* Department of Dairy Science, University of Wisconsin-Madison, Madison, Wisconsin, USA, 53705

† Department of Animal Science, Food and Nutrition (DIANA), Facoltà di Scienze Agrarie, Alimentari e Ambientali, Università Cattolica del Sacro Cuore, 29100 Piacenza, Italy.

[1]Corresponding author: Victor E. Cabrera. 279 Animal Sciences Building, 1675 Observatory Dr. Madison, WI 53706-1284. Phone: (608) 265-8506, Fax: (608) 263-9412. E-mail: vcabrera@wisc.edu

Development of a decision support tool for the optimal allocation of nutritional resources in a dairy farm. *By Bellingeri et al.* We examined the effect of the optimal allocation of nutritional resources using a whole dairy farm optimization approach and data from 29 farms. Results showed that the manipulation of the cropping plan and allocation of feeds and forages in diets through optimization under baseline farm specific constraints improved farm feed efficiency and overall income over feed cost. A simplified optimization decision support tool was developed to help farmers and consultants better defining cropping plans, evaluate forage plans and feed investments at the specific farm level.

ABSTRACT

A linear programming model that selects the optimal cropping plan and feeds' allocation for diets to maximize the whole dairy farm income over feed cost (IOFC) was developed. The model was virtually applied on 29 high yielding Holstein-Friesian herds, confined, total mixed ration dairy farms. The average herd size was 313.2 ± 144.2 lactating cows and the average land size was 152.2 ± 94.6 ha. Farm characteristics such as herd structure, nutritional grouping strategies, feed consumption, cropping plan, intrinsic farm limitations (e.g., silage and hay storage availability, water for irrigation, manure storage) and on farm produced forage costs of production were collected from each farm for year 2017. Actual feeding strategies, land availability, herd structure, crops production costs and yields, milk and feeds' market prices for year 2017 were used as model inputs. Through optimization, nutritional requirements were kept equal to the actual farm practice. These included DMI, RDP, RUP, NE_L, NDF, ADF, f-NDF, which were group calculated according to NRC (2001) equations. Production levels and herd composition were considered to remain constant as the nutritional requirement would remain unchanged. The objective function was set to maximize the whole farm IOFC including milk and cash crops sales as income, and crops production costs and purchased feed costs as expenses. The optimized scenario resulted in different diets and cropping plans with different feed allocation for all the dairy farm considered. Optimization improved IOFC by (+7.8 ± 6.4%), from baseline to optimized scenario, the improved IOFC was explained by lower feed costs per kg of milk produced due to a higher feed self-sufficiency and higher income from cash crop. In particular, the model suggested to maximize, starting from baseline to optimized scenario, the NE_L (+8.5 ± 6.4%) and CP (+3.6 ± 3.2%) produced on-farm, whereas total feed cost (€/100 kg of milk) was greater in the baseline (20.4 ± 2.3) than the optimized scenario (19.0 ± 1.9), resulting in a 6.7 % feed cost reduction with a range between 0.49 % and 21.6 %. This meant €109 ± 96.9 greater net return per cow per yr. The implementation of the proposed linear programming decision support tool for the optimal allocation of the nutritional resources and crops in a dairy herd has the potential to reduce feed cost of diets and improve the farm feed self-sufficiency.

Key words:

Net income maximization, nutritional accuracy, feed efficiency, optimization

INTRODUCTION

The economic objective of a dairy farm is generally to maximize net economic returns (de Ondarza and Tricarico, 2017) and feed cost is an important factor affecting farm profitability, representing more than 40% of dairy farms variable cost (Ishler et al., 2009). Further, volatility in milk and feed prices has increased since the mid-1980s and it represents one of the main economic challenges dairy farmers face (Valvekar et al., 2010). Borreani et. (2013) sustains that there is an increase in market exposure of the protein supplementation due to a strong increase in soybeans price volatility (Lehuger et al., 2009) and consequently high uncertainty of concentrate costs. Further, several issues related to climate change such as persistent drought conditions in summer (Camnasio and Becciu 2011), aflatoxin contamination of crop during growing season (Battilani et al. 2016), or new and more aggressive corn pests (Boriani et al. 2006; Ciosi et al. 2008) are additional challenges farmers ponder on their decisions for crop plans. Several authors have pointed out the critical need of designing specific optimization tools for making appropriate decisions on crop plans in dairy farms (O’Kiely et al., 1997; Shalloo et al., 2004). The decision in selecting certain crops inevitably interacts with many other farm productive factors (i.e., farm size, soil type, water for irrigation, equipment availability, crop rotations, environmental impact, worker organization) as discussed by

Dury (2012). Cropping plan selection models are used to support farmers, policy makers, and other stakeholders in defining strategies to allocate resources more efficiently or design policy options to anticipate their effects (Dury et al., 2010; Dury, 2011). Among these, linear programming optimization (LPO) models have often been used for strategic decisions on cropping plans at a farm level (Sharifi and van Keulen 1994, Vayssières et al., 2009, Dogliotti et al., 2010). These models find the best combination between land availability and crops by solving static and deterministic problems under specific farms' constraints (Dury et al., 2012). However, to the best of our knowledge, these models have not been developed to concomitantly optimize the cropping plan and feedstuff allocation in different diets. Consequently, our objective was to develop and test an LPO-based model to maximize farm IOFC, through crop plans and feeding plan optimizations in high yielding, confined, total mixed ration dairy farm systems considering actual homegrown feed production cost, specific farm constraints, and cash crops usage.

MATERIALS AND METHODS

The assessment is organized according to the framework presented in Figure 1. After selecting and describing a dairy farm, homegrown forages' cost of production are calculated according to Bellingeri et al. (2019). After description and evaluation of farm's baseline situation, the optimized scenario is developed with an LPO having as objective function the maximum IOFC and as final outcome the optimal cropping and feeding plans. Income over feed cost (IOFC) that included milk sold and cash crops sales as income and crops production costs and purchased feed costs as expenses, was used as indicator of farm profitability.

Annual data of herd composition, nutritional grouping strategies, feed consumption, cropping plan choices, intrinsic farm limitations (i.e., irrigation water, land, workforce, machinery, silage storage availability) and forages cost of production were collected on 2017 in 29 selected dairy farms located in the Po Valley (Italy). In each farm, the feed self-sufficiency as the percentage of animal diet (% of DM per yr) produced on the farm was calculated.

Farm selection

The farms were purposefully selected based on previous knowledge that these farms record high quality data (Bellingeri et al., 2019). All herds were composed of Holstein-Friesian cows, housed in free-stall barns, fed TMRs, had no access to pasture, and were high-yielding. In general, farms had a unique diet for lactating cows, single diet for dry cows and 2 diets for heifers from weaning to first calving. A total of 14 crops were available for the farms to grow and they were corn grain (CG), corn silage first seeding (CS), corn silage second seeding (CSII), high moisture ear corn (HMEC), high moisture ear corn second seeding (HMECII), alfalfa hay (AA), ryegrass hay (RG), perennial grass hay (PG), small grain silage (SG), mixed crop silage (MCS), sorghum silage (SFI), sorghum silage second seeding (SFII), soybean grain first seeding (SBI), soybean grain second seeding (SBII). Farms were not growing all the crops listed above at the study time. Hence, cost of production of crops not grown in 2017 in a farm were estimated based on current farm agronomical practices and data from the overall sample of farms.

Linear programming optimization (LPO) model overview

The whole farm optimization model can be stated as:

$$\text{Maximize: } Z = C'X \quad [1]$$

Subject to: AX >, = , or < B

$X > 0$

Where:

Z = maximum whole farm income over feed cost (IOFC) including milk and cash crops sales as income and crops production costs and purchased feed costs as expenses (€/d)

C' = n x 1 vector of objective function coefficient (e.g., price of milk and feeds)

A = m x n matrix of technical coefficients [e.g., DMI, NE_L, NDF, ADF, RUP, RDP, f-NDF (forage NDF), crop yield].

B = m x 1 vector of constraints (e.g., DMI, RDP, RUP, NDF, f-NDF, ADF, NE_L, Starch, total crop hectares, first seeding crop hectares, second seeding crop hectares, specific crop hectares limitation, silages storage capacity, hays storage capacity, feeds inclusion level in the diets), and

X = n x 1 vector of variables (e.g., feed consumption, crop hectares)

The LPO model was developed using the General Algebraic Modeling System (GAMS) with the GAMS/CPLEX solver (GAMS Development Corporation, 2013). The optimization model has the following components: cropland with yields and cost of production, cropland characteristics, economic parameters, farm storages and facilities capacity, herd consistency and performances, animal feed and nutrient, market feeds availability and prices. Each component has constraints (Table 1) and equations as explained below. In each farm, given a determined production level and relative nutritional supplies to match each nutritional group, the model formulate optimized diets, the relative cropping plan and the amount of feeds to purchase on the market with the goal to maximize the whole farm IOFC considering specific farm constraints. For the crop plan, the model has the ability to select between producing forages for farm usage or cultivate cash crops to sell in the market. In this study, the only crop allowed as cash crop was corn grain in first seeding. The model was able to formulate diets for each animal group. Nutrient content in the diet had to meet the actual farm nutritional management strategies. The nutrient allocation strategy followed a standard least cost optimization linear programming approach (Wang et al., 2000, Fox et al.,2004)

Animal feed and nutrient

In the optimized scenario, dry matter intake and dietary nutritional supplies were kept equal to the actual farm nutritional level used. The model required an input of milk production, which was used to calculate milk income and the IOFC. Production levels were considered to remain constant as the nutritional supplies remained unchanged, however diets and feed allocation could change between the baseline situation and the optimized scenario.

$$F_{ij}MIN \leq F_{ij} \leq F_{ij}MAX \qquad [2]$$

Where F_{ij} is the ith feed supply from the jth diet, and $F_{ij}MIN$ and $F_{ij}MAX$ the lower and upper constraints expressed as kg DM / animal per d, respectively.

$$DMI_jMIN \times r \leq DMI_j \leq DMI_jMAX \times R \qquad [3]$$

DMI from jth diet, lower and upper constraints expressed as kg DM / animal per d

$$\text{NUTRIENT}_j\text{MIN x r} \leq \text{NUTRIENT}_j \leq \text{NUTRIENT}_j\text{MAX x R} \quad [4]$$

Where NUTRIENT is a general term to refer to the following nutrients categories (NDF, f-NDF, ADF, NE_L, RDP, RUP) from the jth diet, lower and upper constraints expressed as kg of NUTRIENT / animal per d

Cropland

The focus of the agronomic-cropland component of the model was to find the best allocation between cash crops and crops to feed the herd given the constraint of available land and the productivity expected on that land. Below are the equations and constraints used in the cropland component of the model.

$$\mathrm{TL} = \sum_{\mathrm{z}=1}^{Z} \mathrm{L1st}_{z} + \sum_{\mathrm{f}=1}^{F} \mathrm{L1stA2nd}_{f} \quad [5]$$

Where TL are the total farm land in ha, $\mathrm{L1st_z}$ the hectares of crops in first seeding grown for the crop z_{th}, $\mathrm{L1stA2nd_f}$ the hectares of land in first seeding allowing a second crop f_{th} in the same year.

$$\sum_{\mathrm{f}=1}^{F} \mathrm{L1stA2nd_f} = \sum_{\mathrm{g}=1}^{G} \mathrm{L2nd_g} \quad [6]$$

Where $\mathrm{L2nd_g}$ *a*re the sum of the hectares of second seeding crop

$$\mathrm{TL_iY_i} = \sum_{\mathrm{i}=1}^{I} \mathrm{L_i} \text{ x } \mathrm{Y_i} \quad [7]$$

Where $\mathrm{TL_iY_i}$ are the total t of DM produced on land *i* growing crop *i*

$$\mathrm{TF_i} = 365 \text{ x} \sum_{\mathrm{i}=1}^{n} (\mathrm{F_{ij}} \text{ x } G_{\mathrm{j}}) \quad [8]$$

Where $\mathrm{TF_i}$ are the total annual feed supply, $\mathrm{F_{ij}}$ is the *ith* feed supply from the *jth* diet and $\mathrm{G_j}$ is the animal number in the jth group

$$\mathrm{TF_iBUYMIN} \leq \mathrm{TF_iBUY} \leq \mathrm{TF_iBUYMAX} \quad [9]$$

Where $\mathrm{TF_iBUY}$ is the purchased portion of the ith feed, expressed as percent of the annual whole herd requirement, $\mathrm{TF_iBUYMIN}$ is the lower and $\mathrm{TF_iBUYMAX}$ the upper requirement

$$\mathrm{YHa}_i = \mathrm{Y_i} / \mathrm{L_i} \quad [10]$$

Where YHa_i is the annual crop yield for the crop i, expressed as t of DM/ha, obtained by the total yield for the crop i (Y_i) expressed as t of DM and the relative cultivated area for the crop i (L_i) expressed in hectares.

$$CPDM_i = CP_i / YHa_i / L_i \qquad [11]$$

Where CPDMi is the cost of production as € per t of DM for crop i obtained by the the total cost of production for the crop i (CPi) expressed as €, the relative annual crop yield for the crop i, expressed as t of DM per hectare and and the relative cultivated area for the crop i (L_i) expressed in hectares.

Economic parameters

$$TF€ = \sum_{i=1} TF_i \text{ x } F_i \text{ €} \qquad [12]$$

Where TF€ is the total feed cost for all the i feeds, considering total annual feed supply TF for the feed *i* and the relative feed price F, for the feed *i*

$$CC = \sum_{i=1}(\quad Y_i \text{ x } P_i) - (L_i \text{ x } CP_i) \qquad [13]$$

Where CC is the cash crops net income, obtained by the yield as ts of DM of the crop i and the relative market price P for the crop i, minus all the cost of production of the crop i, obtained as the amount of land cultivated (L) for the crop i, and the relative cost of production expressed as € per hectare (CP) for the crop i.

$$IOFC = MILK - TF€ \qquad [14]$$

Where IOFC is the Income Over Feed Cost, expressed as € per year and was obtained by the difference between total annual milk income (MILK) expressed as € per year and the total feed cost to feed the herd (TF€) expressed as € per year.

$$WIOFC = IOFC + CC \qquad [15]$$

Where WIOFC is the Whole Farm Income Over Feed Cost, expressed as € per year and was obtained by the sum of IOFC and CC, and expressed as € per year.

Storage

$$\mathrm{TSSC_i} = \sum_{\mathrm{i}=1}^{\mathrm{m}} (\mathrm{L_i} \times \mathrm{Y_i}) \quad [16]$$

Where TSSC is the total silages storage capacity, considering land *i* grown for ensiled crop *i*, *m* are all the crops grown on farm that require silage storages to be stored

$$\mathrm{THSC_i} = \sum_{\mathrm{i}=1}^{n} (\mathrm{L_i} \times \mathrm{Y_i})^2 \quad [17]$$

Where THSC is the total hay storage capacity, considering land *i* grown for hay crop *i, n* are all the crops grown on farm that require hay storages to be stored

Feed and Milk Prices, Income over Feed Cost

The farm could purchase feed ingredients from the market following prices obtained by (CLAL S.r.l., 2018; Advisory in Dairy and Food Product; https://www.clal.it) plus transportation costs. These prices were the same for all farms considered. At the end, market purchase prices (€/t DM) were: 100 for straw, 232 for corn grain 142 for corn silage, 222 for legume hay, 155 for grass hay, 404 for soybean meal, 250 for sunflower meal, 355 for whole cottonseed, 233 for molasses, and 1,000 for rumen protected fat. Feed sale prices were the same as the market purchase prices. Minerals and vitamins supplementation were considered to remain constant between the baseline situation and optimized scenario. Composition of feed ingredients were assumed to resemble NRC (2001) feed tables and were used consistently in all scenarios.

Assumptions

For simplicity, the model considered the herd size and herd structure, and group-DMI to remain unchanged during the simulation. Also, the meat sold off the farm was not considered in the economic analysis because farm-level data on it were not available. Finally, the analysis was made for a calendar year and therefore the model assumed that if feed inventory (purchased or homegrown) remained at the end of the year, it was sold (Tedeschi et al., 2010).

Statistical analysis

A hierarchical cluster analysis considering the following variables: land usage (first and second seeding), relative cropping plan, herd composition and performance (milk yield and components), energy and protein self-sufficiency, and economic parameters such as milk price, feed costs and IOFC. The analysis used the unweighted pair group mean with the arithmetic averages (UPGMA) method by the CLUSTER procedure of SAS (SAS, 2000). Then, the obtained clusters grouping different dairy farms, were descriptively presented (arithmetic mean ± standard deviation) for farm characteristic or yield and cost of home-grown forages. Differences in cropping plans between baseline and optimized scenario among clusters were analyzed in agreement to a completely randomized design in which the main tested effect was the cluster. Significance was declared at a $P < 0.05$.

RESULTS

Cluster 1 could be described as dairy farms characterized by having a high stocking rate (4.09 cows/ha, when the average of all the farms was 3.65 cows/ha). Cluster 2 included dairy farms with low incidence of double cropping strategies (i.e., only 21.2% of the land). Cluster 3 can be described as dairy farms having a low stocking rate (3.2 cows/ha) but with high usage of double cropping (i.e., 33% of the land). Cluster 4 included a small group of perennial grass based dairy farms with a high stocking rate (3.91 cows/ha) and high usage on double cropping strategies (33% of the land) considering the high proportions of perennial grasses in the crop plan (37.5% of the crop plan). Among the cropping plan strategies, cluster 1 has the greatest usage of corn grain as cash crop, whereas cluster 3 and have the highest land area dedicated to corn grain. Corn silage in first seeding has been used in cluster 1 and 2 with a higher degree than cluster 3, whereas it has not been used on cluster 4. Inversely, corn silage in second seeding has been used at a higher inclusion rate in the rop plan in cluster 3. High moisture ear corn in first seeding has been used at the highest inclusion rate in cluster 1 and 2. On the other hand, high moisture ear corn second seeding has not been used in most the farms considered. Alfalfa has the highest proportions among the crop plan in cluster 3, while the minimum usage of alfalfa has been found to be typical among cluster 1 and 3. Small grains silages has been used at a high proportion in cluster 1, at an intermediate level in cluster 2 and 3, while has not been cultivated in cluster 4. Ryegrass usage has the highest proportions in the crop plan among cluster 4, whereas it has been used at an intermediate level in cluster 1 and 3, while has not been used in cluster 2. Farms' average size was 152.2 ± 94.6 ha with 313.2 ± 144.2 lactating cows, producing 32.7 ± 2.2 kg milk/cow per d, among herd composition differences in the clusters considered, cluster 2 has the biggest farms involved in the study, cluster 1 and 3 has dairy farm characterized by a slightly less number of lactating cows, while cluster 4 included a group of small farms. Milk yield and components performance has been found to be similar among the clusters considered, same pattern has been found for milk price, with a slightly higher milk price for farms included in cluster 4. Different pattern has been found for IOFC, where cluster 4 has the highest IOFC (8.35±1.04 € per lactating cow), cluster 2 has an average IOFC among the farms included of (7.85±1.27 € per lactating cow), cluster 3 has an average IOFC of (7.73±1.24 € per lactating cow), while cluster 1 has the lowest IOFC (7.56±1.55 € per lactating cow). Feed cost has been found to be the lowest in cluster 2 (19 ± 1 euro per 100 kg of milk), whereas the highest feed cost has been found in cluster 4 (22 ± 4 euro per 100 kg of milk), with intermediate value for cluster 1 and 3. Feed self-sufficiency, calculated for both energy and protein, has been expressed as % of the total nutritional requirement of the whole herd. These parameters has been found to be the highest in cluster 3 with a feed self-sufficiency of 60.2 ± 10.3% for the energy and 43.3 ± 6.9% for the protein, cluster 4 has the lowest feed self-sufficiency, with values of 36.4 ± 8.73% for the energy and 29.1 ± 1% for the protein, cluster 1 and 2 shows intermediate values.

Table 3 presents the average yields of different crops as well as the associated costs of production and market prices of purchased feeds. As expected, the greatest yields were reported for corn and sorghum silages of either first and second seedings. The lowest yield was reported for soybean grains, particularly as second seeding (i.e., 3.21 and 2.76 t DM/ha, respectively). There was not great difference in yield performance among farms (coefficients of variation≦ 10%). The average costs of production among the considered farms, was highest for soybeans in second and first seeding (i.e., 473.25 and 423.6 € / t DM) whereas was the lowest for small grains silage and corn silage first seeding (i.e. 108.5 and 110.6 € / t DM). Among dairy farms, there were moderate difference in production costs, being coefficient of variation associated to cost of production higher than 25% for perennial grass hay and soybean grain first seeding and lower than 15% for corn grain, corn silage and high moisture corn both first and second seeding. Market prices for the purchased feeds used in the diets are presented as average for the whole 2017 year. On average, as expected, the highest prices were for soybean meal and whole cottonseed and the lowest price was for ryegrass.

The differences within dairy farms in crop plan, feed cost per 100 kg of milk, NE_L and CP self sufficiency, IOFC between baseline situation and optimized scenario can be found in Table 4. After the cluster analysis, 4 clusters has been identified. Corn grain land area dedicated shows a reduction in cluster 2 and 3 with an overall reduction equal to (-4.13 ± 6.5%) ($P<0.05$). Cluster 2, 3 and 4 shows an increase in the cultivated area with an overall increase equal to (12.05 ± 13.4%) ($P<0.05$). Corn silage first seeding shows an overall increase by (12.05 ± 13.4%) with a strong increase in cluster 4 by 39.41 ± 0.55%. Small grain silage cultivated land area among the clusters showed an average overall decrease by (-4.53 ± 8.7%) ($P<0.05$), while a strong reduction in cluster 1 and an increase in cluster 4 has been found. Corn silage second seeding shows a slight reduction on average of all the clusters considered (-0.9 ± 9.45%) ($P<0.05$), same pattern has been found for small grain silage, ryegrass hay amnd perennial ryegrass ($P<0.05$). Mixed crop silage shows an increase in all the clusters (+15.1 ± 10.9%) ($P<0.05$), with a peak in cluster 1 (24.30 ± 11.03%). After optimization total feed cost shows a reduction in all the clusters with an average of (-1.39 ± 1.09 Euro per 100 kg of milk) ($P<0.05$). Feed self-sufficiency from an energy standpoint (expressed as % of the total herd requirement) shows an improvement in all the clusters considered with an average of 8.47 ± 6.32% ($P<0.05$). Thus, the protein feed self-sufficiency shows an improvement in all the clusters considered with an average of 3.57 ± 3.11% ($P<0.05$). The model was able to increase whole farm IOFC in all clusters ($P=0.057$) by 0.38 Euro per cow per day, due to feed cost reduction ($P<0.05$) from 20.4€/100 kg milk (52.5% of milk income) to 19€/100 kg milk (48.9% of milk income).

Difference in forages allocation by diets and cluster of baseline situation and optimized scenario can be found in Table 5 and Figure 3. Lactating cow diets were suggested to decrease alfalfa by 4.22%, 12.2%, and 1.6% in clusters 2, 3, and 4, respectively, and to increase it by 1.6% in cluster 1. Ryegrass hay inclusion in the lactating cows diets showed a reduction in all the clusters. Similar trend was found for perennial grass hay, which was substituted with mixed crop silage. Soybean grain in second seeding showed an increase for cluster 3 (1.5%) and a reduction in clusters 2 and 4 (-1.25 and -2.3%, respectively).

Among dry cows diets, corn silage in first seeding inclusion in the diets showed a reduction in cluster 1 (-0.7%), whereas it showed an increase for clusters 2, 3, and 4 (3.77, 1.18, 5.78%, respectively). Similar trend was found for corn silage in second seeding being suggested to increase its utilization among diets. Perennial grass hay utilization among dry cows diet showed a reduction in cluster 1 and 4 (-6.7 and 8.5%, respectively) and a slight increase for cluster 2 and 3. Mixed crop silages increased in all the clusters, whereas the total amount of feeds purchased on the market was reduced in all the clusters, except in cluster 2.

Among heifers diets, corn silage first seeding inclusion in the diets increased among clusters 2, 3, and 4 (9.89, 5.61, and 15.6%, respectively), but it was reduced in cluster 1. Thus, corn silage second seeding increased in all the clusters considered. Even in heifers diets, the total amount of feeds purchased on the market were reduced in all the clusters considered (-1.4, -17.5, -8.6, and -36.8% in clusters 1, 2, 3, and 4, respectively).

DISCUSSION

Linear programming is a widely used tool to solve cropping plan decisions (Dury et al., 2012). Although farmers have multiple objectives, assuming a gross margin maximization while testing cropping plan and diets can be a feasible way to operate as it has been done in similar models testing different normative approaches (Manos et al., 2013; Cortigliani and Dono 2015). However, gross margin, could not be used in our model due to a lack of complete data at the farm level (i.e., farms' complete balance sheets were not available). For this reason, a least-cost diet formulation approach was chosen, resulting in an Income Over Feed Cost (IOFC) maximization maintining milk yield as fixed factor (milk income fixed for Baseline and Optimized scenarios). The IOFC has been found to be a good indicator of farm profitability (Wolf, 2010), when a complete balace sheet data are not available (Ely et al., 2003; Bailey et al., 2005; Cabrera, 2010).

The model framework and its associated decision support system provides opportunities to improve dairy farm feeding strategies reorganizing crop plan as well as feed allocation. Importantly, suggested results could be combined with the intuitive rationale of the farmer, nutritionist or consultant to take more appropriate decisions. Usually, farmers and consultants use diets planning combined to amounts of silage and hay storage availability to define the cropping plan (Schils et al., 2007). The presented model was able to concomitantly optimize feeding strategies, diets and crop plans based on specific nutrient requirement among the nutritional groups of the herd, considering other farm related factors such as land and market opportunities, intrinsic farm constraints and real forages cost of production. Feedsuffs market prices (adjusted for transport and storage) could be considerd appropriate for purchased feedstuffs, but it would represent an over-simplified measurement for the cost of home-produced feedstuffs (O'Kiely et al., 1997). High variability in home-produced feedstuffs production costs exist among farms (Bellingeri et al., 2019). Due to this variability, we decided to use home-produced feedstuffs cost as input data calculated in according to Bellingeri et al. (2019).

Concerning intrinsic farm constraints, silages and hay storage availability were considered because bunkers overfilling or failures in silo management due to extra production could cause severe losses (Ruppel et al., 1995, Wilkinson et al., 2015, Borreani et al., 2018). The model considered storage availability as a farm constraint, representing a limitation on the farm decision making process. Another intrinsic farm constraint considered in the model was the amount of available land (Val-Arreola et al., 2006).

The model presented here used as input data the same nutritional groups and nutritional level used on the real farm situation, with a specified level of milk production (for lactating cows) and average daily gain (for heifers), which reflected the average farm performances. The reason to this choice was due to the fact that complex interactions among multiple biological and management factors affecting dairy herd dynamics, efficiency and productivity, is difficult to predict the milk yield level outcome just based on a nutritional standpoint (Morton et al., 2016).

An optimal feed allocation through a linear programming has been chosen in order to leave to the mathematical computation the decision making process, using diet nutritional requirements and feed quality as key drivers. In contrast to it, Rotz et al. (1999) proposed a dairy herd model for whole-farm simulation, in which the feed allocation to all animals of farm-grown and purchased forages/concentrates followed a scheme that represent the producer’s approach (decision rules to prioritize feed use). Results obtained by running the model on baseline farms data was evident that the feed allocation through LPO give reasonable and similar results to the farmers’ approach as an evidence that the model represented well farms’ conditions.

Market prices, on average, were relatively higher with respect to production costs. It is important to notice that this is not always the case. Several farms produced forages at higher costs than market prices in 2017. That shows an evident crop enterprise inefficiency and different strategies could be suggested. As an example, an extreme scenario could be rent out all the land cultivated and become more dependent from the market for the feed supplies. A simulation of such an hypotetical situation was carried out and it showed an economical advantage, however, several complications from a management point of view can result from a such strategical choice. For example, higher exposure to market uncertainties is a risk many farmers would not be willing to take. In summary, such effect is difficult to estimate in an ex-ante analysis and could result in an economical evaluation mistake.

The Optimized model suggestions confirmed the high value of corn silage as the main forage in the lactating cow’s diets. This suggestions led to a simplification of the cropping plan to a higher level of specialization of the farms sustained by a higher IOFC, DM and NE_L self-sufficiency. Substantial economical differences are highlighted between clusters (i.e., greater IOFC (€/lactating cow per d) of 0.24 for cluster 2 and 0.96 for cluster 4). Considering average number of lactating cows of our pool of farms, this would translate in an improvement of 27,400 €/yr for cluster 2 and 109,600 €/yr for cluster 4. Very similar results have been obtained by Gaudino et al. (2014) where, gross-income maximization suggested a specialization, decreased cash crop area and increased farm feeds self-sufficiency. However, such specialization induced a strong reduction of alfalfa, perennial grass and other hay crops, resulting in a reduction of permanent vegetation within undisturbed fields (i.e., alfalfa and perennial grass), which led to a reduced landscape biodiversity (Bretagnolle et al., 2011) with a worsening situation among soil health and structure, lower water infiltration, altered soil nutrient cycling, downgraded carbon sequestration by the soil, and exacerbated problems in weeds, insect and disease control (Franzluebbers et al., 2011). In order to deal with those results, the model can be constrained, introducing limitations (upper or lower) on the crop land dedicated to a specific crop, in order to maintain, for example, biodiversity, while maximizing the IOFC.

The higher proportion of crop plan dedicated to corn silage was possible with the reduction of corn grain, perennial grasses, ryegrass, and alfalfa. The model suggested to decrease the amount of land addressed to alfalfa (on average from 14.9% to 5.3%) due to its high cost of production (161.3 € / t DM on average) and relatively low production of DM per ha compared to corn silage (9.68 vs. 20.12 t / DM per ha). These results do not consider the agronomical benefit of this crop, and in general, the value of a more diversificated cropping system and rotations as proven by Davis et al. (2012). The model suggested to decrease the acreage addressed to small grain silages in all farms considered (from 5.8% to 1.3%) and ryegrass (from 10.2 to 0%) in favor to mixed crop silage (blend of small grains species with legumes species to enhance the protein content). A possible reason to explain this behavior of the model is the higher CP content, and the relatively similar yield level of mixed crop silage versus small grain silage. Ryegrass reduction in the Optimized Scenario was mainly due to his lower yield and the low quality of the harvested product, due to a late harvest forced by unstable weather conditions that occur frequently during the “ideal” rygrass harvest period. For these reason, mixed crop has been favored by the model in contrast to small grain and ryegrass. Mixed crop silage has a higher CP content than ryegrass and small grains, allowing a positive effect on the farm CP self sufficiency (+3.6%) despite the lower alfalfa acreage. This result aligns with the findings of Borreani et al. (2013). Among perennial grass hay, a strong reduction was noticed in cluster 4 (-21%), which evidences the lack of convenience of perennial grass, especially in a situation where a lack of available land to grow crops take place, like in farms of cluster 4. Model results confirm a higher cost of production of corn silage second seeding compared to corn silage first seeding. This results, once again, comfirm the importance of maximizing yield and quality in all farming situations and the potential effect on the cropping plan decision making to apply at the farm level. As example, farms with a low stocking rate, usually do not rely on a heavy usage of double cropping strategies (i.e., ryegrass hay and corn silage second seeding in the same year) since they do not need extra forage to feed their cows. On the other hand, farms with high stocking rate, have 2 choices: (i) rely heavily on double cropping strategies to maximize energy and protein self-sufficiency or (ii) avoid to increase the double cropped area and purchase on the market the amount of feeds they need to counteract their lack of self-produced forages. The right decision making strategy to apply in this situation is strongly related to the farm management (i.e., does the farm workforce handle an heavy double cropping strategy?), cost of production and performance (ts of DM per hectare and quality) obtained. For this reason, a farm level decision making is crucial to achieve the right decision when it comes to cropping plan design. This higher cost of production is mainly due to the higher irrigation costs and a lower DM yield per ha compared to corn in first seeding (17.1 vs 20.12 t DM / ha). The presented model can be used in “what if” scenarios’ analyses to evaluate, for example: (1) investments in new crop equipments, silage storage, hay sheds; (2) herds expansion plan and it’s effect on cropping plan, forages and storages requirements; and (3) to compare different crops and forages plan considering simultaneously both crop and dairy farm caratheristics.

CONCLUSIONS

The present study demonstrated that a formulation of the crop and feeding plans using a linear programming approach is valid and can improve overall farm Income Over Feed Cost. The model developed in this study contributes to the research literature by providing an integrated approach to the feeding strategy, crop plan and least cost diet formulation integrating crops and herd data. The general outcome from these farms simulations suggests that the optimization process increased, on average, the IOFC by 7.8%. The model was suitable for building a decision support system. This decision support model could be more likely to be adopted and applied for decision making at the farm level on commercial dairy enterprises under the oversight of experienced dairy farmers or consultants.

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Table 1. Abbreviations and constraints used in the whole farm nutrient optimization model

Lower constraint	Name	Upper constraint	Unit	Description
NUTRIENT$_j$MIN	NUTRIENT	NUTRIENT$_j$MAX	kg DM / d	NUTRIENT from the jth diet, lower and upper constraints
DMI$_j$MIN	DMI$_j$	DMI$_j$MAX	kg DM / d	DMI from jth diet, lower and upper constraints
NDF$_j$MIN	NDF$_j$	NDF$_j$MAX	kg NDF / d	Neutral detergent fiber DMI from jth diet, lower and upper constraints
ADF$_j$MIN	ADF$_j$	ADF$_j$MAX	kg ADF / d	Acid detergent fiber from jth diet, lower and upper constraints
f-NDF$_j$MIN	f-NDF$_j$	f-NDF$_j$MAX	kg f-NDF / d	Neutral detergent fiber from forages from jth diet, lower and upper constraints
NE$_{lj}$MIN	NE$_{lj}$	NE$_{lj}$MAX	Mcal / d	Net energy lactation DMI from jth diet, lower and upper constraints
RDP$_j$MIN	RDP$_j$	RDP$_j$MAX	kg RDP / d	Rumen degradable protein from jth diet, lower and upper constraints
RUP$_j$MIN	RUP$_j$	RUP$_j$MAX	kg RUP / d	Rumen undegradable protein from jth diet, lower and upper constraints
	F$_i$€		€ / t	Price of the ith feed
	G$_j$		#	Animal number in the jth group
F$_{ij}$MIN	F$_{ij}$	F$_{ij}$MAX	kg / d	The ith feed supply from the jth diet, lower and upper constraint
	TF€		€ / year	Whole herd feed expense
	TF$_i$		t / year	The ith annual herd feed requirement
HF$_i$BUYMIN x r	HF$_i$BUY	HF$_i$BUYMAX x R	t / yr	Purchased portion of the ith annual herd feed requirement
	TL		ha	Total farm land hectares
	TL$_i$Y$_i$		t / ha	Crop production from land i grown for crop first seeding i and second seeding g [1]
	L1st$_z$		ha	Total land first seeding for a first seeding crop z [2]
	L1stA2nd$_f$		ha	Total land first seeding allowing a first seeding allowing a second crop f [3]
	L2nd$_g$		ha	Total land second seeding for a second seeding crop g
L$_i$MIN x r	L$_i$	L$_i$MAX x R	ha	Hectares of land grown for the ith feed
	r			Minimum limit of the nutrients supply
	R			Maximum limit of the nutrients supply
	Y$_i$		t / year	The ith annual crop yield
	YHa$_i$		t DM / ha	The ith annual crop yield as t of dry matter per hectare
	TSSC$_i$	TSSC$_i$MAX	t DM / year	Total silages storage capacity considering land i grown for ensiled crop i
	THSC$_i$	THSC$_i$MAX	t DM / year	Total hay storage capacity considering land i grown for hay crop i
	MILK		€ / year	Annual milk income
	CP$_i$		€ / ha	Cost of production as € per hectare for crop i
	CPDM$_i$		€ / t DM	Cost of production as € per t of DM for crop i
	P$_i$		€ / t DM	Market price of the ith feed
	CC		€ / year	Cash crops net income
	IOFC		€ / year	Income Over feed Cost

[1] First seeding crop g as: corn silage first seeding, corn grain, high moisture ear corn first seeding, alfalfa hay, perennial grass hay, soybean grain first seeding, sorghum silage first seeding

[2] First seeding crop allowing a second seedind crop z as: small grains silage, mixed crop silage, ryegrass hay

[3] Second seeding crop f : corn silage second seeding, high moisture ear corn second seeding, sorghum silage second seeding, soybean grain second seeding

Table 2. Descriptive statistic (arithmetic mean ± SD) of farm characteristics of studied farms (n=29) and clusters of farms

Variable	**Cluster [1]**				**Mean**
	1 (n=7)	2 (n=11)	3 (n=9)	4 (n=2)	
Land					
Land 1st seeding, hectares	143.5 ± 80.4	163.2 ± 85.8	165 ± 102.7	65 ± 10	152.2 ± 92.5
Land 2nd seeding, hectares	42.6 ± 27.8	34.7 ± 23.7	54.5 ± 28.2	21.5 ± 3.5	41.8 ± 27.8
Crop plan					
Corn grain as cash crop, % total land [2]	6.38 ± 10.1	1.54 ± 4.87	0.16 ± 0.47	0 ± 0	2.17 ± 6.3
Corn grain, % total land	1.87 ± 2.2	7.79 ± 8.97	7.62 ± 6.92	3.0 ± 3.0	5.98 ± 7.34
Corn silage first seeding, % total land	19.64 ± 6.27	19.38 ± 6.99	9.93 ± 7.39	0 ± 0	15.17±10.04
Corn silage second seeding, % total land	18.37 ± 10.69	13.98 ± 6.99	22.41 ± 7.90	12.33 ± 12.53	17.54±9.5
High moisture ear corn first seeding, % total land	10.01 ± 12.32	12.33 ± 13.18	6.22 ± 5.76	7.53 ± 7.53	9.51±11.1
High moisture ear corn second seeding, % total land	2.99 ± 7.32	1.5 ± 4.74	0.69 ± 1.94	0 ± 0	1.50±4.85
Alfalfa hay, % total land	8.97 ± 8.98	16.67 ± 7.51	18.12 ± 2.46	11.5 ± 11.5	14.9±8.1
Small grains silage, % total land	12.34 ± 8.63	4.67 ± 6.5	3.41 ± 4.14	0 ± 0	5.81±7.36
Ryegrass hay, % total land	8.24 ± 9.3	0.35 ± 1.09	19.95 ± 10.24	24.83 ± 24.83	10.02±11.65
Perennial grass hay, % total land	0 ± 0	4.61 ± 9.31	1.43 ± 3.04	28.31 ± 28.31	4.14±9.28
Soybean grain first seeding, % total land	4.99 ± 9.68	1.99 ± 3.5	2.20 ± 4.16	0 ± 0	2.64±5.89
Soybean grain second seeding, % total land	0.3 ± 0.73	1.13 ± 1.93	3.44 ± 4.93	12.5 ± 12.5	2.43±5.38
Sorghum silage first seeding, % total land	2.79 ± 4.62	0.93 ± 2.93	0 ± 0	0 ± 0	1.03±3.10
Sorghum silage second seeding, % total land	1.14 ± 2.8	0.83 ± 2.19	0.62 ± 1.75	0 ± 0	0.78±2.18
Mixed crop silages, % total land	1.97 ± 3.17	12.42 ± 7.1	3.80 ± 3.03	0 ± 0	6.37±6.92
Herd composition					
Lactating cows, n	312.8 ± 92.3	343.3 ± 108.3	302.3 ± 166.4	162.7 ± 28.3	313.2 ± 144.1
Dry cows, n	48.5 ± 13.4	53.3 ± 17.3	47.34 ± 25.12	26.7 ± 3.4	48.8 ± 21.9
Heifers, n	318.1 ± 85.5	366.9 ± 110	366 ± 224.6	162.2 ± 21.8	347.7 ± 172.8
Herd performance					
Milk fat content, %	3.80 ± 0.1	3.89 ± 0.12	3.82 ± 0.13	3.93 ± 0.08	3.85 ± 0.12
Milk protein content, %	3.37 ± 0.07	3.39 ± 0.04	3.39 ± 0.08	3.40 ± 0.02	3.39 ± 0.07
ECM [3]	34.72 ± 2.44	34.72 ± 1.92	34.61 ± 2.45	35.88 ± 3.8	35.4 ± 2.86
Economics					
Milk price, Euro per 100 kg milk	38.7 ± 2.7	39 ± 2.5	38.1 ± 2.2	42 ± 3	38.8 ± 2.7
IOFC, Euro / lactating cow per d [4]	7.56 ± 1.55	7.85 ± 1.27	7.73 ± 1.24	8.35 ± 1.04	6.02 ± 1.5
Feed cost, Euro per 100 kg milk	21 ± 2	19 ± 1	20 ± 2	22 ± 4	20.4 ± 2.3
Self-sufficiency, Energy, % [5]	49.2 ± 10.7	57.1 ± 7.5	60.2 ± 10.3	36.4 ± 8.7	53.9 ± 11.8
Self-sufficiency, Protein, % [6]	31.4 ± 6.6	39.3 ± 5.5	43.3 ± 6.9	29.1 ± 1	37.4 ± 8

[1] Cluster 1 could be described as dairy farms characterized by having a high stocking rate (4.09 cows per hectare, whereas the average of all the farms considered was 3.65 cows per hectare) and a medium level of land addressed to double cropping (i.e. 31.3% of the land, whereas the average of all the farms considered was 30.2% of the land). In the cluster 2 were grouped dairy farms with low incidence of double cropping strategies (i.e. 22,1% of the land). Cluster 3 can be described as dairy farms having a low stocking rate (3.2 cows per hectare) but with high usage of double cropping usage (i.e. 38.6% of the land). Cluster 4 can be ascribed as a small group of perennial grass based dairy farms with a high stocking rate (3.91 cows per hectare) and high usage on double cropping strategies (33% of the land)

[2] % Total land means the sum of the land used for a single crop and the land used for two crops within the same year

[3] Energy corrected milk = [12.82 x fat yield (kg)] + [7.13 x protein yield (kg)] + [0.323 x milk yield (kg)]

[4] Whole farm IOFC = Milk income over feed cost of the herd plus extra income from cash crops

[5] As percent of herd energy requirements (Mcal)

[6] As percent of herd protein requirement (CP)

Table 3. Descriptive statistic (arithmetic mean ± SD) of characteristics among studied farms (n=29) and clusters of farms

Crops	**Cluster**								**Mean**	
	1		2		3		4			
	Yield	Cost	Yield	Cost	Yield	Cost	Yield	Cost	Yield	Cost
	t DM / ha	€ t DM	t DM / ha	€ t DM	t DM / ha	€ t DM	t DM / ha	€ t DM	t DM / ha	€ t DM
Farm grown feeds										
Alfalfa hay	9.46±1.55	184.3±45	9.9±0.6	149.9±22.6	9.57±0.87	161.24±38.6	9.8±0.65	173.5±31.9	9.7±1.1	163.2±37.3
Mixed crops silage [1]	9.23±0.8	119.9±33.2	9.1±0.6	109.3±12.1	9.62±0.33	108.5±30	9.52±0.17	149.6±39.6	9.3±0.6	114.1±28.2
Corn grain [2]	10.9±1.1	220.1±23.9	10.5±0.6	218.5±15.1	10.11±0.6	225.45±32.1	10.35±0.55	240.9±17.4	10.5±0.8	222.6±24.5
Corn silage first seeding	20.2±2.15	115.9±20.7	19.9±1.35	109.1±7.3	20.2±1.51	106.64±14.2	20.13±0.99	117.9±15.9	20.1±1.6	110.6±14.5
Corn silage second seeding	17.8±2.03	135.7±24.4	16.4±1.38	134.8±12.7	17.3±1.21	129.5±13.8	17.7±0.8	126.6±14.9	17.1±1.6	132.8±17
High moisture ear corn 1st [3]	11.8±1.2	192.7±25.5	12.1±0.95	163.6±18.5	11.7±0.47	169.6±24.8	11.65±0.5	188.3±36.1	11.8±0.9	174.4±26
High moisture ear corn 2nd [4]	9.9±0.9	244.9±37.4	9.49±0.6	224.9±24.65	9.41±0.17	224.4±30.6	9.88±0.44	243.9±52.4	9.6±0.7	234.0±33.7
Perennial grass hay	8.65±1.1	148.2±43.2	9.1±0.8	128.9±26.5	8.62±0.51	112.7±40.9	10.01±0.9	164.4±37.3	8.9±0.9	129.6±39.5
Ryegrass hay	5.93±0.45	157.3±30.2	5.92±0.2	144.1±21.2	5.98±0.23	151.7±26.8	5.57±0.1	197.4±48.6	5.9±0.3	153.3±30.8
Soybean grain first seeding	2.91±0.5	513.7±148.1	3.3±0.25	384.9±71.1	3.32±0.28	384±110.4	3.61±0.21	414.4±113.6	3.2±0.4	417.8±121.9
Soybean grain second seeding	2.53±0.38	543.3±104.4	2.85±0.19	461.4±56.93	2.87±0.25	434.9±84.6	2.97±0.6	466.1±84.5	2.8±0.3	473.3±91
Sorghum silage first seeding	12.2±0.9	127.1±19.7	12.7±0.7	112.1±14.6	12.8±0.47	110.8±28.1	12.24±0.7	138.9±28.3	12.6±0.7	122.7±25.1
Sorghum silage second seeding	10.96±0.94	134.1±15	11.8±1.05	121.4±15.8	11.8±0.6	116.4±22.1	11.20±1.1	136.4±0.21	11.7±0.9	127.5±20.9
Small grains silage	9.6±1	108.1±13.8	9.22±1.2	108.4±15.8	9.4±1.4	105.5±28.6	10.37±1.3	112.2±18.9	9.5±1.2	105.9±20.4

[1] Mixed crop silage = small grains and vetch / pea harvested as wilted silage

[2] This crop can be a cash crop, can be sold or used as fee

[3] High moisture ear corn first seeding

[4] High moisture ear corn second seeding

[5] The same market prices has been used for all the farm considered, reflecting the average market price of year 2017 and taken from (CLAL S.r.l., 2018; https://www.clal.it).

Table 4. Differences in cropping plan, feed cost and income over feed cost (IOFC) between baseline and optimized scenario by farms' clusters. Simple data average has been used.

Variables	**Unit**	**Cluster**				**Mean**	**MSE**	**P**
		1	2	3	4			
Corn grain as cash crop	% total land [1]	-1.10 ± 2.82	-1.35 ±4.28	-0.16 ± 0.47	0 ± 0	-0.83 ± 3.1	3.410	0.719
Corn grain	“	0.29 ± 4.94	-5.52 ±6.13	-6.12 ± 6.65	-3 ± 3	-4.13 ± 6.5	7.670	<0.05
Corn silage first seeding	“	-2.96 ±8.43	12.78 ±8.46	16.76 ± 7.05	39.41 ± 0.55	12.05 ± 13.4	8.046	<0.05
Corn silage second seeding	“	3.94 ± 9.05	1.87 ± 5.53	-9.33 ± 6.4	4.59 ± 11.74	-0.9 ± 9.45	7.818	<0.05
High moisture ear corn first seeding	“	1.41 ± 8.37	5.01 ± 8.24	4.98 ± 4.82	-7.3 ± 7.77	3.3 ± 8.2	7.648	0.169
High moisture ear corn second	“	-2.99 ± 7.32	-1.5 ± 4.74	2.24 ± 4.62	0 ± 0	-0.6 ± 5.8	5.651	0.309
seeding	“	-2.79 ± 10.78	-10.18 ± 8.49	-14.96 ± 5.52	-6.52 ± 6.52	-9.63 ± 9.6	8.628	0.086
Alfalfa hay	“	-12.34 ± 8.63	-3.2 ± 5.91	-3.41 ± 4.14	10.41 ± 7.98	-4.53 ± 8.7	6.951	<0.05
Small grains silage	“	-8.24 ± 9.3	-0.35 ± 1.09	-19.95 ±10.24	-24.83 ± 0.17	-10.2 ± 11.9	7.891	<0.05
Ryegrass hay	“	0 ± 0	-2.48 ± 6.71	-0.53 ± 1.09	-20.81 ± 0.19	-3.5 ± 8.2	4.503	<0.05
Perennial grass hay	“	-2.03 ± 9.91	-0.03 ± 2.78	4.11 ± 5.76	5.01 ± 5.01	-2.1 ± 4.9	6.796	0.251
Soybean grain first seeding	“	0.76 ± 1.85	0.17 ± 3.19	4.69 ± 10.22	-12.50 ± 12.50	0.85 ± 8.2	7.379	0.051
Soybean grain second seeding	“	-0.03 ± 0.17	-0.93 ± 2.93	0 ± 0	0 ± 0	-0.4 ± 1.9	1.907	0.674
Sorghum silage first seeding	“	1.77 ± 6.98	0.82 ± 3.27	0.36 ± 2.80	4.51 ± 4.51	1.2 ± 4.65	4.763	0.690
Sorghum silage second seeding	“	24.30 ± 11.03	4.90 ± 4.9	21.32 ± 2.90	11.02 ± 4.05	15.1 ± 10.9	7.216	<0.05
Mixed crop silages [2]	% land [3]	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0.458	0.674
Land 1st seeding	% land [3]	86.4 ± 198.3	56.2 ± 88.8	6.3 ± 24.3	2.5 ± 21.7	31.3 ± 116.9	55.714	0.881
Land 2nd seeding	% land [3]	5.7 ± 12.3	6.2 ± 9.2	-2.9 ± 8	0.7 ± 5.9	1.2 ± 10.5	10.560	0.456
Land 1st + Land 2nd seeding	€ per 100 kg milk	0.51 ± 0.67	0.72 ± 0.57	-0.05 ± 0.61	0.67 ± 0.47	0.41 ± 0.68	0.799	0.242
Feed Cost from Homegrown feeds	€ per 100 kg milk	-1.84 ± 1.49	-1.63 ± 0.76	-1.68 ± 0.95	-2.59 ± 2.49	-1.81 ± 1.46	1.358	0.055
Feed Cost from Purchased feeds	€ 100 kg milk	-1.33 ± 0.94	-0.91 ± 0.29	-1.73 ± 0.70	-2.06 ± 1.94	-1.39 ± 1.09	1.042	<0.05
Total Feed Cost	% herd requirement	6.5 ± 4.9	9.3 ± 4.7	6.4 ± 4.1	13.1 ± 9	8.47 ± 6.32	5.465	<0.05
NE$_l$ farm produced	% herd requirement	5.6 ± 2.7	2.9 ± 2.9	3 ± 2.1	5.2 ± 2.7	3.57 ± 3.11	2.655	<0.05
CP farm produced	€ per cow per d	0.36 ± 0.26	0.26 ± 0.09	0.47 ± 0.17	0.61 ± 0.42	0.38 ± 0.29	23.923	0.057
IOFC [4]								

[1] % Total land means the sum of the land used for a single crop and the land used for two crops within the same year

[2] Mixed crop silage = small grains and vetch / pea harvested as wilted silage

[3] % Land = the physical land availability of the farm

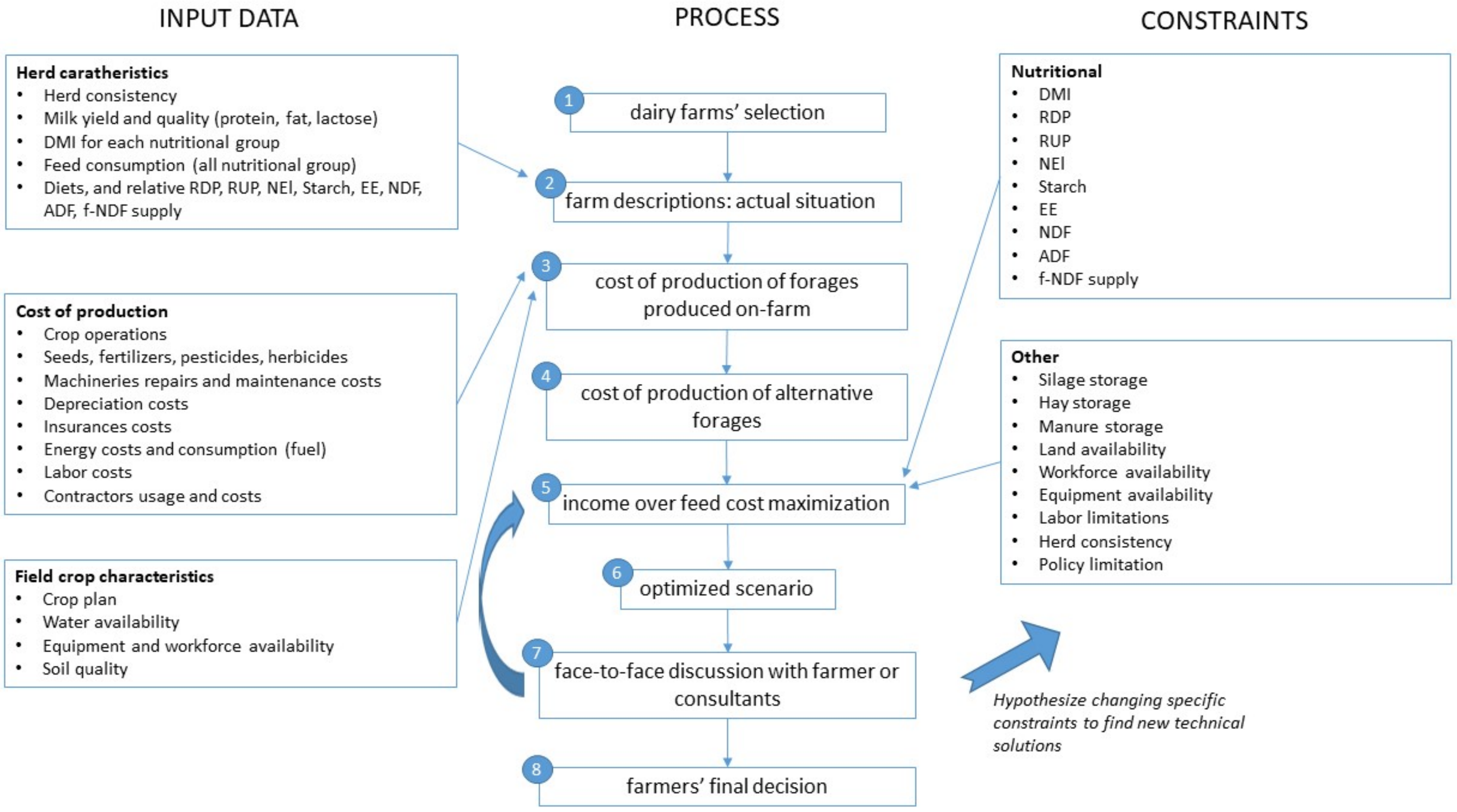
[4] Whole farm IOFC = Milk income over feed cost of the herd plus extra income from cash crops

Table 5. Differences in diets feed allocation between baseline and optimized scenario by farms' clusters. Simple data average has been used.

Variables[1]	**Cluster**				**Mean**	**MSE**	**P**
	1	2	3	4			
Lactating cows diet							
Corn grain	-1.7 ± 2.75	-0.33 ± 4.1	-3.38 ± 4.02	-3.24 ± 3.24	-2.02 ± 4.05	4.11	*0.628*
Corn silage first seeding	5.02 ± 15.23	14.24 ± 12.41	17.29 ± 11.40	27.64 ± 11.83	13.91 ± 15	14.3	*0.102*
Corn silage second seeding	1.28 ± 7.81	3.37 ± 11.1	-3.16 ± 10.76	9.53 ± 1.75	-0.24 ± 10.6	11.5	*0.659*
High moisture ear corn first seeding	2.05 ± 7.8	3.04 ± 8.5	3.73 ± 9.86	0.17 ± 0.17	3.36 ± 9.04	9.16	*0.931*
High moisture ear corn second	-0.53 ± 1.29	0 ± 0	-0.1 ± 5.83	0 ± 0	-0.06 ± 3.43	3.49	*0.991*
seeding	1.57 ± 7.24	-4.22 ± 6.6	-12.20 ± 3.83	-1.6 ± 1.6	-5.71 ± 6.83	5.9	*<0.05*
Alfalfa hay	-3.98 ± 4.02	-2.76 ± 6.15	-1.2 ± 2.92	-0.04 ± 3.02	-3.12 ± 3.91	3.98	*0.276*
Small grains silage	-0.58 ± 1.41	0.25 ± 2.81	-.042 ± 1.18	-4.28 ± 4.28	-0.5 ± 1.41	1.84	*0.06*
Ryegrass hay	-1.64 ± 4.01	0.22 ± 3.5	0 ± 0	-11.65 ± 1.46	-1.04 ± 2.91	3	*<0.05*
Perennial grass hay	0.43 ± 0.9	-0.43 ± 1.5	0.68 ± 1.94	0.98 ± 0.98	0.06 ± 1.55	1.62	*0.449*
Soybean grain first seeding	0.32 ± 0.78	-1.25 ± 2.8	1.56 ± 1.7	-2.33 ± 2.33	-0.08 ± 2.45	2.26	*<0.05*
Soybean grain second seeding	5.90 ± 5.88	4.63 ± 5.2	9.48 ± 6.23	2.12 ± 2.12	6.48 ± 6.05	5.90	*0.313*
Mixed crops silage	-8.14 ± 4.97	-10.56 ± 9.9	-11.76 ± 7.15	-17.37 ± 5.08	-11.04 ± 6.8	7.23	*0.422*
Total feeds purchased on the market							
Dry cows diet	-0.67 ± 1.65	0 ± 0.86	0 ± 0	0 ± 0	-0.18 ± 1.1	1.03	*0.531*
Corn grain	-0.7 ± 1.88	3.77 ± 5.46	1.18 ± 2.91	5.78 ± 5.78	1.97 ± 4.6	4.43	*0.09*
Corn silage first seeding	2.06 ± 3.99	2.45 ± 4.47	0.72 ± 2.25	10.43 ± 1.13	2.30 ± 4.2	3.82	*<0.05*
Corn silage second seeding	0.62 ± 3.05	-1.76 ± 6.37	0.14 ±1.53	0 ± 0	0.04 ± 4	4.51	*0.323*
High moisture ear corn first seeding	0 ± 0	0 ± 0	0.57 ± 1.07	0 ± 0	0.20 ± 0.7	0.63	*0.253*
High moisture ear corn second	-1.59 ± 3.89	-3.51± 7.86	0 ± 0	0 ± 0	-2.05 ± 5.9	5.66	*0.467*
seeding	-0.14 ± 0.34	-1.36 ± 4.50	-14.27 ± 13.35	0 ± 0	-4.90 ± 10.3	8.83	*<0.05*
Small grains silage	-6.74 ± 11.89	1.07 ± 2.76	0.64 ± 1.8	-8.51 ± 3.35	-1.17 ± 7.3	6.51	*<0.05*
Ryegrass hay	-2.89 ± 14.77	-1.02 ± 3.4	0 ±0	0 ± 0	-2.11 ± 6.6	7.91	*0.900*
Perennial grass hay	6.85 ± 16.03	9.5 ± 12.7	0 ± 14.63	18.1 ± 18.1	7.62 ± 16.3	15.9	*0.66*
Sorghum silage first seeding	3.68 ± 10.19	11.54 ±14.3	25.76 ± 16.91	0 ± 0	13.03 ± 15.4	15.2	*<0.05*
Sorghum silage second seeding	-0.48 ± 12.98	20.69 ± 16.2	-14.74 ± 11.56	-25.81 ± 21.65	-14.75 ± 16.8	15.9	*0.08*
Mixed crops silage							
Total feeds purchased on the market	-0.15 ± 0.37	-1.34 ± 3.12	0 ± 0	0 ± 0	-0.62 ± 2.22	2.12	*0.388*
Heifers diet	-0.72 ± 1.71	9.89 ± 6.1	5.61 ± 6.57	15.6 ± 0.06	7.23 ± 7.3	5.45	*<0.05*
Corn grain	0.65 ± 2.57	6.63 ± 9.75	0.94 ± 1.92	10.03 ± 5.64	3.81 ± 7.37	6.89	*0.07*
Corn silage first seeding	0.26 ± 0.65	0.27 ± 0.6	-0.14 ± 0.59	0 ± 0	0.21 ± 0.54	0.64	*0.659*
Corn silage second seeding	-5.79 ± 8.08	-5.85 ± 12.1	-2.52 ± 4.19	12.9 ± 12.9	-3.69 ± 11.23	10.28	*0.152*
High moisture ear corn first seeding	-4.38 ± 7	-7.4 ± 8.23	-14.46 ± 8.77	0 ± 0	-9.44 ± 9.17	8.71	*0.131*
Small grains silage	-6.58 ± 11.01	-2.06 ± 9.8	0.06 ± 0.16	-17.7 ± 15.1	0.02 ± 0.1	9.84	*0.159*
Ryegrass hay	-3.41 ± 9.73	-1.03 ±3.43	0 ± 0	0 ± 0	-1.69 ± 5.43	5.55	*0.649*
Perennial grass hay	3.2 ± 7.83	1.14 ± 3.34	0.55 ± 3.16	4.12 ± 4.12	1.98 ± 5.2	5.13	*0.647*
Sorghum silage first seeding	18.36 ± 8.6	16.8 ± 13.15	19.72 ± 12.63	11.9 ± 11.9	16.38 ± 11.43	12.51	*0.549*
Sorghum silage second seeding	-1.44 ± 4.14	-17.05 ± 11.54	-8.6 ± 9.41	-36.8 ± 25.9	-13.12 ± 14.8	12.53	*0.092*
Mixed crops silage							
Total feeds purchased on the market							

[1] Expressed as DM % of total die

Figure 1. Linear program optimization model framework for finding maximum farm income over feed cost



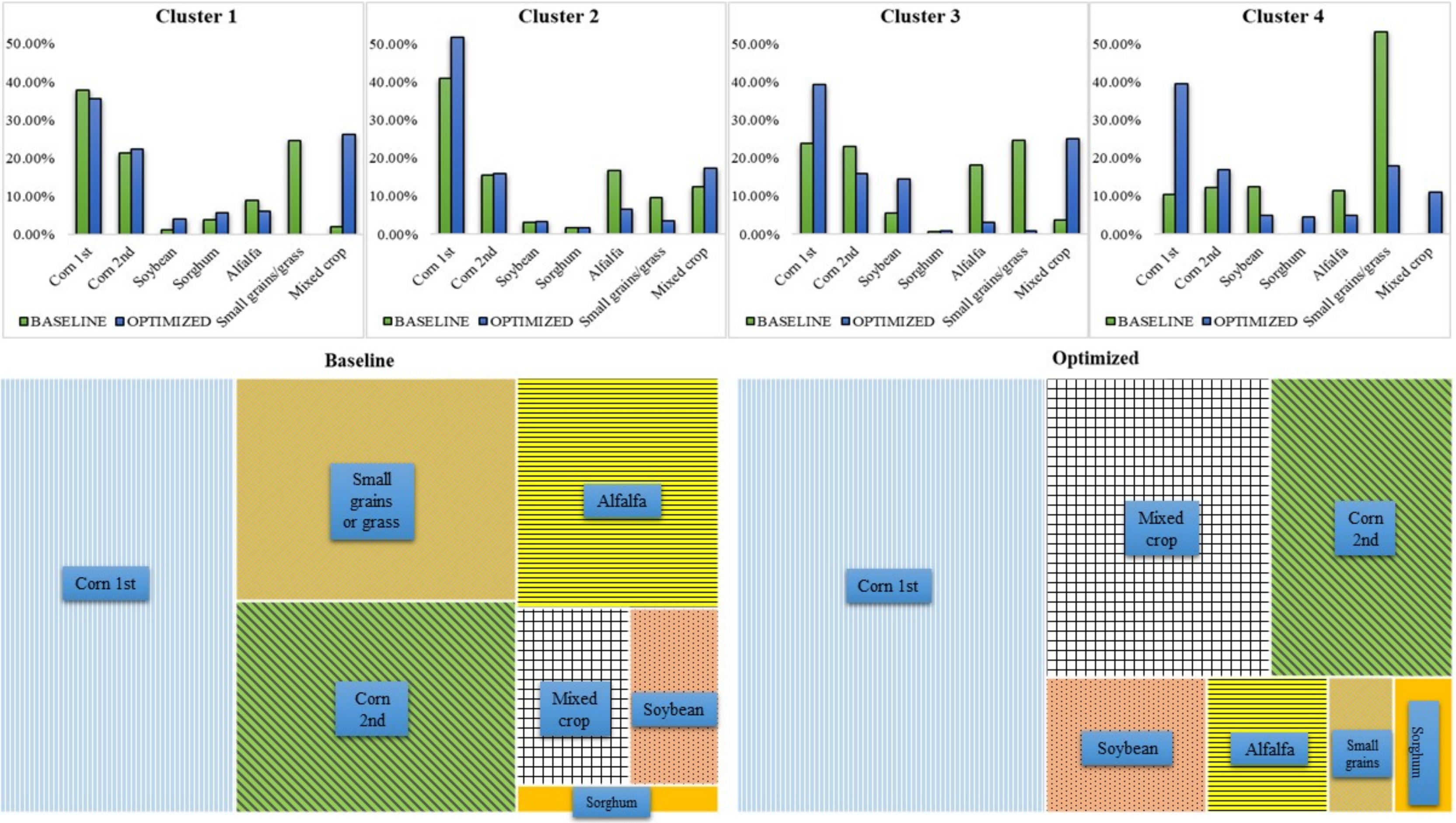


Figure 2. Average crop plan distribution by farms' clusters (top graphs) and all farms (n=29) in the Baseline and Optimized scenarios. Corn 1st is the aggregated area for corn silage first seeding, high moisture ear corn first seeding, corn grain. Corn 2nd is the aggregated area for corn silage second seeding, high moisture ear corn second seeding. Mixed crop is mixed crop silage small grains and vetch / pea harvested as wilted silage. Small grains/grass are the aggregated area for perennial grass hay, ryegrass hay, small grains silage. Sorghum is the aggregated area for sorghum silage first seeding and sorghum silage second seeding. Soybean is the aggregated area for soybean grain first seeding, soybean grain second seeding. Alfalfa is alfalfa hay.

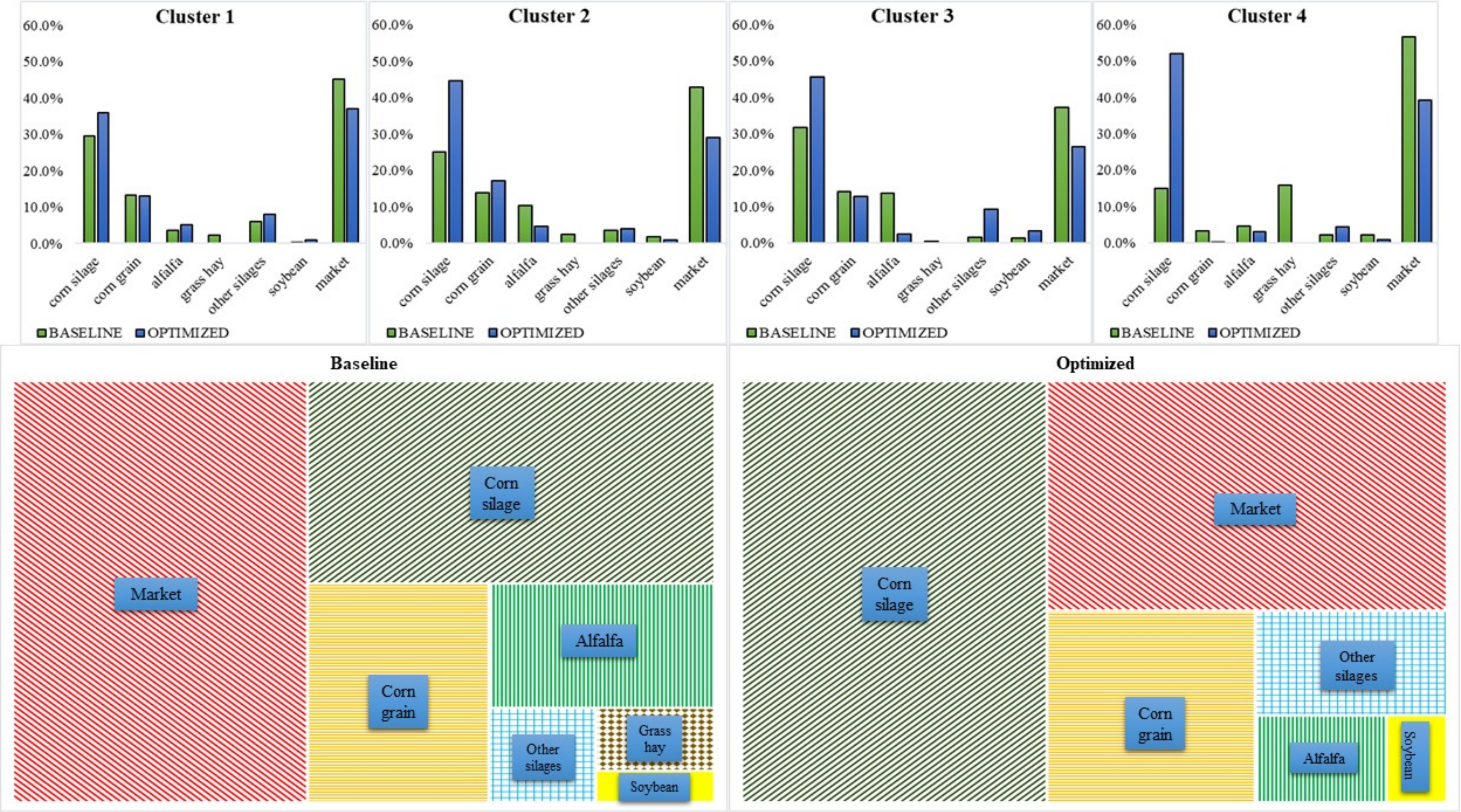


Figure 3. Average distribution of the diets components by farms' clusters (top graphs) and all farms (n=29) in the Baseline and Optimized scenarios. Corn silage 1st is the aggregated area for corn silage first seeding and corn silage in second seeding, corn grain is the aggregated area for high moisture ear corn first seeding and high moisture ear corn in second seeding. Other silages is the aggregated area for small grains silage, sorghum first and second seeding silage, mixed crop silage (small grains + vetch/pea harvested as wilted silage). Grass hay is the aggregated area of ryegrass hay and perennial grass hay. Soybean is the aggregated area for soybean grain first seeding, soybean grain second seeding. Alfalfa is alfalfa hay. Market is the aggregated area for all the diet components purchased on the market.