

SYSTEMS AND METHODS FOR ESTIMATING FEED EFFICIENCY AND CARBON FOOTPRINT FOR MILK PRODUCING ANIMAL

CROSS-REFERENCE TO RELATED APPLICATION(S)

5 **[0001]** This application is being filed on December 31, 2014, as a PCT International Patent application and claims priority to Canadian Patent Application Serial No. 2839027 filed on January 2, 2014, the disclosure of which is incorporated herein by reference in its entirety.

10 TECHNICAL FIELD

[0002] This application relates to a systems and methods for estimating and optimizing feed efficiency and carbon footprint for milk producing animal(s).

BACKGROUND

15 **[00003]** Milk is naturally produced in mammals, but certain types of mammals, referred to herein as milk producing animals, are commonly raised for the primary purpose of producing milk that will ultimately be used or sold to businesses or consumers as a source of food.

[0004] Milk producing animals obtain the nutrients needed for milk production through the food that they eat. The composition of animal feed is often selected in an attempt to provide the animals with the proper nutrition needed to support milk production. Any portion of the animal feed that is indigestible by the animal passes through the animal without benefitting milk production. The cost attributable to such portions of the animal feed is, at least in theory, an unnecessary expense. Accordingly, it would be beneficial if the composition of the animal feed could be evaluated and adjusted to reduce the portion of the animal feed that is indigestible by the milk producing animal.

[0005] Another consideration in the selection of animal feed is the extent of greenhouse gases generated and/or emitted from milk producing animals after they consume the animal feed. Some compositions of animal feed will cause the milk producing animal to generate more greenhouse gases than others. The greater the greenhouse gas emission, the greater the carbon footprint of the milk producing animal or collection of milk producing animals. Accordingly, it would be beneficial if the

composition of the feed could be evaluated and adjusted to reduce the resulting carbon footprint.

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SUMMARY

[0006] The present application relates to systems and methods for estimating milk producing animal feed conversion efficiency and carbon footprint, such as to allow adjustments to be made in the animals feed to improve milk production, reduce waste, and/or reduce the carbon footprint. In embodiments of the present application, a system is provided that integrates a digestion model of an animal feed with milk production efficiency and carbon footprint. Such systems and methods are useful to analyze and compare animal feed compositions that differ from one another in one or more components and/or to analyze the effect of the addition of a feed supplement on milk production efficiency and/or carbon footprint. In embodiments, the systems and methods described herein provide a feed parameter-carbon footprint compromise. A feed parameter-carbon footprint compromise is useful to adjust animal feed composition by balancing milk production efficiency with effects on carbon footprint. Different feed supplements or amounts of feed supplements, and/or different feed compositions are selected based on the desired feed parameter-carbon footprint compromise. The systems and methods can be used for a single animal or a plurality of animals.

[0007] The present application includes a method for estimating impact of a milk producing animal on carbon footprint, comprising providing one or more primary parameters associated with one or more of: a) a measure of microbial protein for a selected feed sample from a digestion model associated with the milk producing animal; b) a measure of total digestible nutrients for the selected feed sample from the digestion model associated with the milk producing animal; and c) an amount or a percent of components in the selected feed sample; producing with a computing device a baseline performance comprising milk production efficiency using at least one or more of the primary parameters and one or more secondary parameters for the milk producing animal, wherein the one or more secondary parameters are associated with one or more of: a measure of animal weight, a measure of animal milk production, a measure of animal milk protein, a measure of animal dry matter intake, a measure of animal milk price, and a measure of

animal dietary protein; and producing with the computing device a carbon footprint for the milk producing animal using the baseline performance.

[0008] Some embodiments further include displaying the carbon footprint for the milk producing animal. In some embodiments the displaying comprises displaying the carbon footprint for the milk producing animal as a function of feed intake of the animal. Further, in some embodiments the carbon footprint is displayed as a function of feed parameters to provide an optimal feed parameter-carbon footprint compromise.

[0009] In some embodiments, the one or more secondary parameters further include a measure of fat, a measure of fiber, a measure of calcium, a measure of phosphorous, or a measure of energy.

[0010] In embodiments of the present application, the digestion model is a chemical or biological fermentation model. In other embodiments the biological fermentation model is an *in vitro* biological model.

[0011] In some embodiments, a method for adjusting a feed composition, comprises a) digesting a feed sample in an *in vitro* fermentation system for a milk producing animal to generate a value for a primary parameter comprising a i) a measure of microbial protein for the feed sample; or ii) a measure of total digestible nutrients for the feed sample; b) measuring one or more secondary parameters selected from the group consisting of animal weight, animal milk production, animal milk protein, animal dry matter intake, animal milk price, and animal dietary protein to generate a value for the one or more secondary parameters; c) producing a baseline performance value comprising milk production efficiency using at least one or more of the values of the primary parameters and one or more of the values of the secondary parameters using a computing device; d) producing a carbon footprint for the milk producing animal using the baseline performance using a computing device; and e) adjusting a component of the feed sample to change the baseline performance, the carbon foot print or both.

[0012] In other embodiments, a method for adjusting a feed composition, comprises: a) determining a characteristic of a first feed sample to generate a value for a primary parameter; b) measuring one or more secondary parameters selected from the group consisting of animal weight, animal milk production, animal milk protein, animal dry matter intake, animal milk price, and animal dietary protein to generate a value for the one or more secondary parameters; c) producing a baseline performance value comprising milk production efficiency using the value of the primary parameter and one or more of

the values of the secondary parameters using a computing device; d) producing a carbon footprint for the milk producing animal using the baseline performance using a computing device; and e) adjusting a component of the first feed sample to change either the baseline performance, the carbon foot print or both.

- 5 [0013] In embodiments, the steps of methods as described herein are repeated until a feed composition is identified that maintains or increases milk production efficiency and decreases carbon footprint as compared to the first feed sample.

 [0014] In embodiments of the present application, the digestion model is a chemical or biological fermentation model. In other embodiments the biological fermentation model is
10 an *in vitro* biological model. In some embodiments, the *in vitro* digestion system comprises digesting the feed sample with one digestive enzymes in the presence of a microbial population.

 [0015] In embodiments, the characteristic of the feed sample is selected from the group consisting of a measure of protein, a measure of carbohydrate, a measure of fat, a
15 measure of dry matter, and a measure of gross energy. In some embodiments, determining the characteristics of the feed sample comprises measuring a characteristic of the feed sample. For example, measurements of characteristics can be made using a chemical method or near infrared spectroscopy. In other embodiments, characteristics of the feed sample are calculated.

20 [0016] In embodiments, adjusting a component of the feed sample comprises adding a feed supplement to the feed sample. In other embodiments adjusting a component of the feed sample comprises altering the form of protein or amount of protein in the sample. In further embodiments, adjusting a component of the feed sample comprises altering the digestibility of the feed sample.

25 [0017] In some embodiments according to the present application, producing with the computing device comprises calculating with the computing device. In embodiments, a baseline performance is calculated and/ or a carbon footprint is calculated. Some embodiments further include producing with the computing device feed efficiency in unit volume of milk produced per unit weight of feed consumed. Other embodiments further
30 include producing with the computing device NRC metabolizable protein required to support milk output in unit weight/time based on one or more of the secondary parameters. Further embodiments include producing with the computing device escape protein in units of weight. Additional embodiments include producing with the computing device a

change in milk production or feed efficiency for feed augmented with one or more feed supplements. In some embodiments, the producing with the computing device the change in milk production or feed efficiency comprises calculating an amount of the one or more feed supplements needed to obtain increased milk production or increased milk production efficiency.

[0018] The present application further includes a method for estimating impact of a plurality of milk producing animals on carbon footprint, comprising providing one or more primary parameters associated with one or more of: a) a measure of microbial protein based on a selected feed sample in a digestion model associated with at least one of the milk producing animals; b) a measure of total digestible nutrients based on the selected feed sample in the digestion model associated with at least one of the milk producing animals; and c) the amount or percent of components in the feed sample; producing with a computing device a performance for each animal comprising milk production efficiency using at least one or more of the primary parameters and one or more secondary parameters for each animal, wherein the one or more secondary parameters are associated with one or more of: a measure of animal weight, a measure of animal milk production, a measure of animal milk protein, a measure of animal dry matter intake, a measure of animal milk price, and a measure of animal dietary protein; producing with the computing device a carbon footprint per animal using the baseline performance; and aggregating the carbon footprint per animal for each animal of the plurality of milk producing animals to provide an aggregate carbon footprint.

[0019] Some embodiments further include displaying the carbon footprint for each animal of the plurality of milk producing animals. Other embodiments include displaying the aggregate carbon footprint for the milk producing animals as a function of feed intake of the animals. In some embodiments, the aggregate carbon footprint is displayed as a function of feed parameters to provide an optimal feed parameter-aggregate carbon footprint compromise.

[0020] In some embodiments, the plurality of milk producing animals includes animals of different species or from different phylogenetic families. Further, in some embodiments the plurality of milk producing animals are animals of the same species or from same phylogenetic family.

[0021] In some embodiments, the one or more secondary parameters further include one or more of a measure of fat, a measure of fiber, a measure of calcium, a measure of phosphorous, and a measure of energy.

5 [0022] The present application includes embodiments in which the digestion model is a chemical or biological fermentation model. In some embodiments the fermentation model is an *in vitro* biological model.

[0023] In further embodiments of the present application, the producing with the computing device comprises calculating with the computing device. Some embodiments further include producing with the computing device feed efficiency in unit volume of milk produced per unit weight of feed consumed. Some embodiments further include producing with the computing device NRC metabolizable protein required to support milk output in unit weight/time based on one or more of the secondary parameters. Other embodiments further include producing with the computing device a change in milk production or feed efficiency for feed augmented with one or more feed supplements. In some embodiments, producing with the computing device a change in milk production or feed efficiency comprises calculating an amount of the one or more feed supplements needed to obtain an increase in milk production or an increase in milk production efficiency. In some embodiments, the producing with the computing device a carbon footprint per animal includes producing a carbon footprint per animal using the increased milk production or increased milk production efficiency.

20 [0024] Some embodiments further include calculating with the computing device escape protein in units of weight. In some embodiments, the aggregating the carbon footprint per animal for each animal of a plurality of animals includes aggregating a carbon footprint per animal for each animal of the plurality of animals with feed augmented with the one or more feed supplements, to provide an aggregate carbon footprint as a function of an amount of the one or more feed supplements or milk production. Some embodiments further include displaying the aggregate carbon footprint as a function of the selected amount of the one or more feed supplements or milk production. Other embodiments further include producing with the computing device a required protein level or protein savings.

30 [0025] The present application also includes a method for estimating an increase in one or more of milk production and milk production efficiency in a milk producing animal provided with animal feed containing one or more feed supplements, comprising

providing a baseline performance comprising one or more of milk production and milk production efficiency for the milk producing animal; providing a selected amount of one or more feed supplements; and calculating with the computing device an increase in one or more of milk production and milk production efficiency in the milk producing animal fed
5 using the selected amount of the one or more feed supplements relative to the baseline performance.

[0026] Some embodiments further include calculating with the computing device a carbon footprint for the animal. Additionally, some embodiments include displaying the carbon footprint as a function of the selected amount of the one or feed supplements or
10 milk production. Some embodiments also include calculating with the computing device a required dietary protein or protein savings.

[0027] The present application also includes a method for estimating an increase in one or more of milk production and milk production efficiency in a plurality of milk producing animals provided with animal feed containing one or more feed supplements,
15 comprising: providing a baseline performance comprising one or more of milk production and milk production efficiency for the plurality of milk producing animals; providing a selected amount of one or more feed supplements; and calculating with a computing device an increase in one or more of milk production and milk production efficiency per animal in the plurality of milk producing animals fed using the selected amount of the one
20 or more feed supplements relative to the baseline performance.

[0028] Some embodiments further include calculating with the computing device a carbon footprint per animal for each animal of the plurality of animals. Other embodiments also include aggregating the carbon footprint per animal for each animal of the plurality of animals to provide an aggregate carbon footprint as a function of the
25 selected amount of the one or more feed supplements or milk production. Additionally, some embodiments include displaying the carbon footprint as a function of the selected amount of the one or more feed supplements or milk production.

[0029] The present application also includes a system for estimating the impact of a milk producing animal on carbon footprint, the system comprising at least one processing device; and at least one computer readable storage device, the at least one computer
30 readable storage device storing data instructions. The data instructions, when executed by the at least one processing device cause the at least one processing device to generate a baseline performance engine configured to receive one or more primary parameters

associated with one or more of a measure of microbial protein and a measure of total digestible nutrients, and to produce a baseline performance comprising one or more of milk production and milk production efficiency using at least one of the primary parameters and one or more secondary parameters, wherein the one or more secondary
5 parameters are associated with a measure of one or more of animal weight, animal milk production, animal milk protein, animal dry matter intake, animal milk price, and animal dietary protein; and a carbon footprint engine configured to use the baseline performance to produce a carbon footprint for the animal.

[0030] Some embodiments further include a display device, wherein the carbon
10 footprint for the animal is displayed on the display device as a function of feed intake of the animal.

[0031] Some embodiments also include a plurality of computing devices, wherein a first processing device is part of a first computing device and a second processing device is part of a second computing device.

15 [0032] In some embodiments, the baseline performance engine operates on the first computing device to produce the baseline performance and the carbon footprint engine operates on the second computing device to produce the carbon footprint. In other embodiments, the first computing device is in data communication with the second computing device across one or more data communication networks. In another
20 embodiment, the baseline performance engine is configured to calculate the baseline performance and the carbon footprint engine is configured to calculate the carbon footprint.

[0033] The present application also includes a system for estimating the impact of a plurality of milk producing animals on carbon footprint, the system comprising: at least
25 one processing device; and at least one computer readable storage device, the at least one computer readable storage device storing data instructions that, when executed by the at least one processing device cause the at least one processing device to generate a baseline performance engine configured to receive one or more primary parameters associated with one or more of a measure of microbial protein and a measure of total digestible nutrients,
30 the baseline performance engine further configured to produce a baseline performance comprising milk production efficiency using at least one of the primary parameters and one and or more secondary parameters, wherein the one or more secondary parameters are associated with a measure of one or more of: animal weight, animal milk production,

animal milk protein, animal dry matter intake, animal milk price, and animal dietary protein; and a carbon footprint engine configured to use the baseline performance to produce a carbon footprint for each animal in the plurality of animals and aggregate the carbon footprint produced for each animal in the plurality of animals to provide an aggregate carbon footprint.

[0034] Some embodiments further include a display device, wherein the display device displays the aggregated carbon footprint for the plurality of animals as a function of feed intake of the plurality of animals.

[0035] In some embodiments the baseline performance engine is configured to calculate the baseline performance and the carbon footprint engine is configured to calculate the carbon footprint.

[0036] Some embodiments further include a plurality of computing devices, wherein a first processing device is part of a first computing device and a second processing device is part of a second computing device. In some embodiments the first computing device is in data communication with the second computing device across one or more data communication networks.

[0037] In some embodiments the plurality of milk producing animals includes animals of different species or from different phylogenetic families. In other embodiments the plurality of milk producing animals are animals of the same species or from same phylogenetic family.

BRIEF DESCRIPTION OF THE DRAWINGS

[0038] FIG. 1 is a schematic block diagram illustrating an example system for estimating the impact of a milk producing animal on carbon footprint.

[0039] FIG. 2 is a schematic block diagram illustrating an example system for estimating the impact of a feed supplement on production and/or carbon footprint of a milk producing animal.

[0040] FIG. 3 is a screen shot of an example user interface display 300 according to some embodiments of the present disclosure.

DETAILED DESCRIPTION

[0041] **Definitions**

[0042] The following detailed description refers to subject matter in the accompanying drawings which show, by way of illustration, specific aspects and embodiments in which the present subject matter may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the present subject matter.

5 References to “an”, “one”, or “various” embodiments in this application are not necessarily to the same embodiment, and such references contemplate more than one embodiment.

[0043] As used in this application, the term “animal(s)” refers to non-human animals raised or used as a source of food. For example, animals include, but are not limited to, 10 domesticated livestock such as cattle, goats, sheep, buffalo, camel, horse, and water buffalo. A “milk producing animal(s)” is an animal raised or used for milk production.

[0044] As used in this application, the term “baseline performance” refers to various aspects of a milk producing animal when the milk producing animal is fed animal feed without one or more optional feed supplements. Examples of baseline performance 15 include a milk producing animal’s milk production and/or milk production efficiency. The term “baseline performance engine” refers to a machine or portion of a machine that produces and/or calculates a baseline performance associated with a milk producing animal. In some embodiments, the baseline performance engine includes data instructions, which when executed by a processing device cause the processing device to 20 produce and/or calculate a baseline performance.

[0045] As used in this application, the term “carbon footprint” refers to the generation and/or emission of a set of greenhouse gases. As used herein, carbon footprint is primarily focused on the generation and/or emission of greenhouse gases by a milk producing animal. Typical greenhouse gases generated by an animal include carbon dioxide and 25 methane. Carbon footprint can refer to the generation and/or emission of gases by an individual animal or a collection of animals. The term “aggregate carbon footprint” refers to the sum of the carbon footprints of a collection of animals. A collection of animals can be part of a single farm or distributed across a collection of one or more farms or other locations. A collection of one or more animal locations is referred to herein as an 30 “enterprise.” The term “carbon footprint engine” refers to a machine or portion of a machine that produces and/or calculates a carbon footprint associated with a milk producing animal or collection of milk producing animals. In some embodiments the

carbon footprint engine includes data instructions, which when executed by a processing device cause the processing device to produce and/or calculate a carbon footprint.

[0046] As used herein in this application, the term “dry matter intake” (DMI) refers to the amount of a feed an animal consumes per day on a moisture free basis.

5 [0047] As used in this application, the term “estimating” refers to producing, determining, and/or calculating one or more values that predict or approximate an actual value.

[0048] As used in this application, the term “fermentation model(s)” or “digestion model(s)” refers to an in vitro digestion model that mimics in vivo digestion of an animal.

10 In embodiments of the present application, the animal is a ruminant animal. The gastrointestinal tract of ruminant animals is characterized by multi-compartment stomachs and microbial fermentation of components of the feed. An example of a fermentation or digestion model is a batch-culture, rumen-fluid, gas-fermentation system combined with mathematical analysis to allow for the differentiation of rapid and slowly-fermenting
15 carbohydrate pools in individual feedstuffs or TMR samples. The rate and extent of organic matter degradation, can be determined with such system by monitoring gaseous fermentation products (CO₂, methane) of microbial metabolism in addition to CO₂ produced by the buffering of microbial produced short-chained fatty acids (SCFA, primarily acetate and butyrate).

20 [0049] As used in this application, the term “feed(s)” or “animal feed(s)” refers to material(s) that are consumed by animals and contribute energy and/or nutrients to an animal’s diet. Animal feeds typically include a number of different components that may be present in forms such as concentrate(s), premix(es) co-product(s), or pellets. Examples of feeds and feed components include, but are not limited to, Total Mixed Ration (TMR),
25 corn, soybean, forage(s), grain(s), distiller grain(s), sprouted grains, legumes, vitamins, amino acids, minerals, molasses, fiber(s), fodder(s), grass(es), hay, straw, silage, kernel(s), leaves, meal, soluble(s), and supplement(s). As used herein the term “selected animal feed(s)” refers to an animal feed selected for analysis using the methods and systems described herein.

30 [0050] As used in this application, the term “sample(s) of animal feed” or “feed sample(s)” refers to a representative portion of an animal feed. In embodiments of the present application, a representative portion of an animal feed contains the same

components in similar proportions to that of the animal feed. A representative sample is preferably homogenous or substantially homogenous.

[0051] As used in this application, the term “feed efficiency” refers to a ratio of an amount of animal feed or component of animal feed that needs to be consumed by an animal to obtain a unit of production, such as weight gain, milk production, or egg production. The term “milk production efficiency” refers to a ratio of an amount of animal feed or component of animal feed that needs to be consumed by a milk producing animal to obtain a unit of milk production. In some embodiments, milk production efficiency is represented as a ratio of milk produced to the amount of feed or a feed component consumed over a period of time.

[0052] As used in this application, the term “feed parameter(s)” refers to one or more qualities or characteristics associated with an animal feed sample. One example of a feed parameter is a cost of the feed, such as per unit weight or per unit volume.

[0053] As used in this application, the term “feed parameter-carbon footprint compromise” refers to a solution determined by balancing one or more feed parameters against one or more carbon footprint parameters. The term “optimal feed parameter-carbon footprint compromise” refers to a most preferred solution determined by balancing one or more feed parameters against one or more carbon footprint parameters.

[0054] As used in this application, the term “feed supplement” refers to an animal feed additive that, when combined with an animal feed, causes an increased milk production or increased milk production efficiency.

[0055] As used in this application, the term “in vivo” refers to processes occurring within a living biological organism.

[0056] As used in this application, the term “in vitro” refers to processes occurring in an artificial environment outside the living organism and to biological processes or reactions that would normally occur within an organism but are made to occur in an artificial environment. In vitro environments can include, but are not limited to, test tubes and cell culture.

[0057] As used in this application, the term “measure” refers to a quantifiable unit.

[0058] As used in this application, the term “nutrient(s)” refers to a substance that is needed for an organism to live and/or grow. Nutrients include, but are not limited to, components such as protein, fat, carbohydrates (e.g., sugars), fiber, vitamins, calcium, iron, niacin, nitrogen, oxygen, carbon, phosphorus, potassium, sodium chloride, and

mixtures thereof. The term “total digestible nutrients” refers to a sum of the digestible nutrients in an animal feed, often determined from a digestion model as defined herein.

[0059] As used in this application, the term “primary parameter(s)” refers to data or information relating to nutritional content of a feed sample. Examples of primary

5 parameters include a) a measure of microbial protein for a selected feed sample from a digestion model associated with the milk producing animal; b) a measure of total digestible nutrients for the selected feed sample from the digestion model associated with the milk producing animal; and c) an amount or a percent of components in the selected feed sample.

10 [0060] As used in this application, the term “secondary parameter(s)” refers to data or information relating to factors that may influence an animal’s milk production or carbon footprint, or the value or cost of same. Examples of secondary parameters include a measure of animal weight, a measure of animal milk production, a measure of animal milk protein, a measure of animal dry matter intake, a measure of animal milk price, and a
15 measure of animal dietary protein.

[0061] As used in this application, the term “microbial protein” refers to the protein provided by rumen microbes in a ruminant, or generated through a digestion model of a ruminant. Microbial protein is one of the sources of metabolizable protein for a milk producing animal. As used in this application, the term “metabolizable protein” refers to a
20 sum of protein and amino acids reaching the small intestine from ruminally undegraded protein (RUP) and microbial protein, in ruminants. The term “NRC metabolizable protein” refers to how much protein is required to support the desired milk production. The NRC metabolizable protein requirements in gms/day are provided by the National Research Council of the United States (such as available at the National Academies Press
25 website) or the National Research Council of Canada.

[0062] As used in this application, the term “escape protein” or “rumen – undegradable protein” (RUP) refers to a portion of protein in an animal feed that resists rumen degradation and can be digested directly in the other stomachs or small intestine of a milk producing animal.

30 [0063] As used in this application, the term “rumen degradable protein” (RDP) refers to a portion of protein in an animal feed that is degraded in the rumen.

[0064] As used in this application, the term “protein savings” refers to an amount or percent of protein in excess of a baseline performance. For example, the protein savings is

an additional amount of protein digested by a milk producing animal when fed a feed supplement along with an animal feed.

[0065] Detailed Description

5 **[0066]** The present application relates to systems and methods for estimating and optimizing milk producing animal feed conversion and carbon footprint.

10 **[0067]** In embodiments of the present application, a system is provided that integrates a digestion model of an animal feed with milk production efficiency and carbon footprint. Such systems and methods are useful to analyze and compare different animal feed compositions that differ from one another in one or more components and/or to analyze the effect of the addition of a feed supplement on milk production efficiency and/or carbon footprint.

15 **[0068]** In embodiments, an animal feed sample is digested using an in vitro fermentation model to generate a microbial protein output (g/mg). The microbial protein output is combined with one or more secondary parameters, such as animal weight (kg), milk production (L), milk protein(%), dry matter intake (kg), milk price (\$/L), or dietary protein (%) to produce a baseline performance of milk production efficiency. The baseline performance and other parameters are entered into a carbon footprint engine. Such parameters comprise farm variables and/or milk production efficiency measure of the baseline performance. Farm variables include but are not limited to number of animals in herd, average live weight, average base milk price, farm size, and combinations thereof. Other parameters include but are not limited to milk yield, herd culling rate, calving interval, first calving age, total feed use per liter, diet soya inclusion rate, nitrogen use per ha, diesel use per cow, electric use per liter and combinations thereof. The output of carbon footprint includes grams CO₂

25 **[0069]** In embodiments, the systems and methods described herein provide feed parameter-carbon footprint compromise. A feed parameter-carbon footprint compromise is useful to adjust animal feed composition by balancing milk production efficiency with effects on carbon foot print. Different feed supplement or amounts of feed supplements, and/or different feed compositions are selected based on the desired feed parameter-carbon footprint compromise. The systems and methods can be used for a single animal or a plurality of animals.

[0070] Method For Estimating Impact of Milk Producing Animal(s) on Carbon Footprint

[0071] The present application includes a method for estimating impact of a milk producing animal on carbon footprint, comprising providing one or more primary parameters associated with one or more of: a) a measure of microbial protein for a selected feed sample from a digestion model associated with the milk producing animal; b) a
5 measure of total digestible nutrients for the selected feed sample from the digestion model associated with the milk producing animal; and c) an amount or a percent of components in the selected feed sample; producing with a computing device a baseline performance comprising milk production efficiency using at least one or more of the primary parameters and one or more secondary parameters for the milk producing animal, wherein
10 the one or more secondary parameters are associated with one or more of: a measure of animal weight, a measure of animal milk production, a measure of animal milk protein, a measure of animal dry matter intake, a measure of animal milk price, and a measure of animal dietary protein; and producing with the computing device a carbon footprint for the milk producing animal using the baseline performance. Secondary parameters include but
15 are not limited to animal weight (kg), milk production (L), milk protein(%), dry matter intake (kg), milk price (\$/L), or dietary protein (%).

[0072] The present application further includes a method for estimating impact of a plurality of milk producing animals on carbon footprint, comprising providing one or more primary parameters associated with one or more of: a) a measure of microbial protein
20 based on a selected feed sample in a digestion model associated with at least one of the milk producing animals; b) a measure of total digestible nutrients based on the selected feed sample in the digestion model associated with at least one of the milk producing animals; and c) the amount or percent of components in the feed sample; producing with a computing device a performance for each animal comprising milk production efficiency
25 using at least one or more of the primary parameters and one or more secondary parameters for each animal, wherein the one or more secondary parameters are associated with one or more of: a measure of animal weight, a measure of animal milk production, a measure of animal milk protein, a measure of animal dry matter intake, a measure of animal milk price, and a measure of animal dietary protein; producing with the computing
30 device a carbon footprint per animal using the baseline performance; and aggregating the carbon footprint per animal for each animal of the plurality of milk producing animals to provide an aggregate carbon footprint.

[0073] The present application further includes in some embodiments, a method for adjusting a feed composition, comprises a) digesting a feed sample in an in vitro fermentation system for a milk producing animal to generate a value for a primary parameter comprising a i) a measure of microbial protein for the feed sample; or ii) a
5 measure of total digestible nutrients for the feed sample; b) measuring one or more secondary parameters selected from the group consisting of animal weight, animal milk production, animal milk protein, animal dry matter intake, animal milk price, and animal dietary protein to generate a value for the one or more secondary parameters; c) producing a baseline performance value comprising milk production efficiency using at least one or
10 more of the values of the primary parameters and one or more of the values of the secondary parameters using a computing device; d) producing a carbon footprint for the milk producing animal using the baseline performance using a computing device; and e) adjusting a component of the feed sample to change the baseline performance, the carbon foot print or both.

15 [0074] In other embodiments, a method for adjusting a feed composition, comprises: a) determining a characteristic of a first feed sample to generate a value for a primary parameter; b) measuring one or more secondary parameters selected from the group consisting of animal weight, animal milk production, animal milk protein, animal dry matter intake, animal milk price, and animal dietary protein to generate a value for the one
20 or more secondary parameters; c) producing a baseline performance value comprising milk production efficiency using the value of the primary parameter and one or more of the values of the secondary parameters using a computing device; d) producing a carbon footprint for the milk producing animal using the baseline performance using a computing device; and e) adjusting a component of the first feed sample to change either the baseline
25 performance, the carbon foot print or both.

[0075] **Primary parameters**

[0076] Some embodiments include providing or calculating one or more primary parameters. In some embodiments, the primary parameters include, but are not limited to, data or information relating to the nutritional content of an animal feed sample. Once
30 provided or calculated, the primary parameters can be used to produce or calculate a baseline performance associated with an animal feed, for example, as described herein.

[0077] One example of a primary parameter is a measure of microbial protein for a selected feed sample from a digestion model associated with the milk producing animal.

Another example of a primary parameter is a measure of total digestible nutrients for the selected feed sample from the digestion model associated with the milk producing animal. A further example of a primary parameter is an amount or a percent of components in the selected feed sample. Each of these example primary parameters are described in further detail herein.

[0078] Feed samples

[0079] One of the examples of a primary parameter, discussed above, is an amount or a percent of components in a selected feed sample. Once an animal feed of interest has been identified, a characteristic of the feed sample such as an amount or a percent of one or more components in the selected animal feed can be identified. In some embodiments of the present application, the amount or percent of components can be determined analytically using wet chemistry or using spectroscopic methods such as NIR. In some embodiments, the amount or the percent is obtained from, retrieved from, or looked up in a table providing the amount or a percent of components or characteristics of the selected feed sample including but not limited to dry matter, crude protein, crude digestible fiber, acid digestible fiber, neutral digestible fiber, minerals, vitamins, digestible energy, net energy and combinations thereof. Examples of such tables are available for example, at the website for National Research Council of the United States or Canada.

[0080] Digestion Models

[0081] A drawback with using data identifying the components in a selected feed sample, however, is that there are numerous variables that can impact the digestion of animal feed by a milk producing animal. As a result, some embodiments utilize one or more digestion models to obtain a more accurate understanding of how a feed sample will be digested by milk producing animals.

[0082] In embodiments, the digestion model is a chemical or biological fermentation model. In other embodiments the biological fermentation model is an *in vitro* biological model.

[0083] Some embodiments involve digesting a feed sample to generate a value for a primary parameter, or providing or calculating a measure of microbial protein or total digestible nutrients for a selected feed sample from an *in vitro* digestion model associated with the milk producing animal. Example of a suitable digestion model is the *In Vitro* Fermentation Model (IFM) (Alltech of Nicholasville, KY, US) or the Fermentrics™ Gas Fermentation System (the “Fermentrics System”), (see the Fermentrics website). An in

vitro digestion model comprises contacting a feed sample with one or more digestive enzymes and/or microbial population under conditions of pH, time and temperature that simulates the in vivo digestive process of the animal. Adjustments in the digestive process such as pH, time, and temperature are adjusted depending on the animal.

5 [0084] Specific examples of fermentation digestion models include IFM and Fermentrics™. The IFM process involves the fermentation of a feed sample (typically a total mixed ration (TMR)) by incubating the feed sample in buffered rumen fluid for 48 hours, which simulates the in vivo digestive process of a milk producing animal. During the process, volatile fatty acids and microbial biomass are produced, along with
10 greenhouse gases such as carbon dioxide and methane. The IFM determines, for example, how carbohydrates and protein are fermented and as a result the amount or percent of nutrients that are available for digestion by a milk producing animal. In particular, in some embodiments, the IFM provides a measure of microbial protein for the selected feed sample. The Fermentrics™ System utilizes a rumen-fluid batch culture, gas fermentation
15 system to evaluate a feed sample and generate gas fermentation data, including carbohydrate (B_1 , B_2 , B_3) digestion rates.

[0085] Other embodiments involve providing or calculating a measure of total digestible nutrients for the selected feed sample from the digestion model associated with the milk producing animal. Total digestible nutrients can be calculated based on feed
20 analysis.

[0086] **Secondary parameters**

[0087] Some embodiments of the present disclosure, involve one or more secondary parameters. In some embodiments the secondary parameters include, but are not limited to, data or information relating to factors that may influence an animal's milk production or carbon footprint, or the value or cost of same. In some embodiments, the one or more
25 secondary parameters are measured. In some embodiments, the secondary parameters are provided or calculated, and can be used along with the primary parameters to produce or calculate a baseline performance associated with an animal feed.

[0088] One example of a secondary parameter is a measure of animal weight, such as
30 a weight of a milk producing animal (such as 600 Kg).

[0089] Another example of a secondary parameter is a measure of animal milk production. In some embodiments the measure of animal milk production is expressed as a volume over a period of time (such as 35 Liters per day).

[0090] Another example of a secondary parameter is a measure of animal milk protein. In some embodiments the measure of animal milk protein is expressed an amount of protein per unit volume. In another embodiment, the measure of animal milk protein is expressed as a percent (such as 3.2%).

5 [0091] Another example of a secondary parameter is a measure of animal dry matter intake (DMI). In some embodiments the measure of animal dry matter intake is the weight of animal feed excluding water content. In some embodiments the measure of animal dry matter intake is expressed as a weight over a period of time (such as 22 Kg per day).

10 [0092] A further example of a secondary parameter is a measure of animal milk price. In some embodiments the measure of animal milk price is the value at which the milk can be sold per unit volume (such as \$0.32 per Liter).

[0093] Another example of a secondary parameter is a measure of animal dietary protein. In some embodiments the measure of dietary protein is expressed as an amount, 15 while in other embodiments it is expressed as a percent (such as 16%).

[0094] Other secondary parameters include but are not limited to measure of fat, a measure of fiber, a measure of calcium, a measure of phosphorous, or a measure of energy.

[0095] Any one or more of the secondary parameters, or other secondary parameters, 20 can be used in various embodiments.

[0096] **Producing a baseline performance**

[0097] Some embodiments include producing a baseline performance comprising milk production efficiency using at least one or more of the primary parameters and one or more secondary parameters for the milk producing animal. The baseline performance 25 indicates one or more aspects of a performance of an animal feed absent the presence of optional feed supplements, for example.

[0098] In some embodiments of the present application, producing a baseline performance involves producing or calculating an estimate of a milk producing animal's milk production when fed the animal feed sample, based upon one or more of the primary 30 and secondary parameters. In some embodiments, producing a baseline performance involves producing or calculating an estimate of the milk producing animal's milk production efficiency when fed the animal feed sample, such as a measure of a volume of milk produced per unit weight of feed consumed. Some embodiments produce or

calculate a measure of NRC metabolizable protein required to support milk output for the milk producing animal given the one or more secondary parameters. Some embodiments produce or calculate a measure of escape protein, such as an estimate of an amount of protein that escapes the rumen with the selected feed sample.

5 [0099] In some embodiments the baseline performance includes a measure of milk production. In some embodiments the milk production is a number input by a user (such as in liters / day). In another embodiments, the milk production is calculated based on an estimate of the animal's daily metabolizable protein intake, such as can be computed by the product of the dry matter intake (kg) and the percentage dietary protein contained in
10 the animal feed. The metabolizable protein can be estimated to be equal to the sum of the animal's metabolizable protein required for maintenance and the metabolizable protein available for lactation. An estimate of the metabolizable protein can be computed based on the animal's weight and the amount of dry matter intake. By subtracting the metabolizable protein required for maintenance from the total metabolizable protein, the
15 protein required for lactation can be obtained. This value can then be used to generate an estimated milk production based on the amount or percent of protein per unit of milk.

[00100] In some embodiments the baseline performance includes an estimate of feed efficiency. Feed efficiency (liters per kg) can be computed by dividing the milk production (liters) by the dry matter intake (kg).

20 [00101] Other values are included in the baseline performance in some embodiments.

[00102] Producing a carbon footprint

[00103] Some embodiments include producing a carbon footprint for the milk producing animal using the baseline performance. In some embodiments, the carbon footprint is produced or calculated using a carbon footprint engine. One suitable example
25 of a carbon footprint engine is the E-CO₂ carbon footprint software discussed herein. In some embodiments, the carbon footprint is produced or calculated using the baseline performance. In some embodiments the carbon footprint includes an estimated amount of greenhouse gas emissions that would be generated by one or more milk producing animals over a period of time. In some embodiments the estimate is a weight of the emissions over
30 a period of time, and in other embodiments the estimate is a weight of the emissions per unit weight of milk producing animal over a period of time (such as kg CO₂ / kg weight). In some embodiments the carbon footprint includes other aspects in addition to greenhouse gas emissions.

[00104] In some embodiments of the present application, the carbon footprint is displayed as a function of feed parameters to provide a feed parameter-carbon footprint compromise. A feed parameter-carbon footprint compromise is useful for selecting a feed composition or adjusting a feed composition in order to balance feed parameters with a
5 desired carbon footprint. Feed parameters include one or more qualities or characteristics associated with an animal feed sample. One example of a feed parameter is a cost of the feed or feed component, such as a cost of the feed per unit weight or per unit volume. Another example of a feed parameter is the feed efficiency or milk production efficiency. Similarly, some embodiments include carbon footprint parameters. Carbon footprint
10 parameters include one or more characteristics of a carbon footprint. One example of a carbon footprint parameter is a cost associated with the carbon footprint, such as a cost per unit weight.

[00105] In some cases, a more expensive animal feed may provide a reduced carbon footprint than a less expensive feed. As a result, the feed parameters and the carbon
15 footprint parameters can be used to provide or calculate an optimal feed parameter-carbon footprint compromise. In some embodiments, the optimal value is the value that has the lowest cost feed to achieve a carbon footprint having reduced carbon footprint as compared to a reference feed sample or other feed sample under consideration, for example.

[00106] Another example feed parameter-carbon footprint compromise includes determining a baseline carbon footprint for a feed using the methods and systems as described herein and then determining the effect of altering a component of the feed composition on carbon footprint and selecting the feed composition that provides a decrease in carbon footprint from the baseline carbon footprint. For example, if it is
20 desired to obtain a certain revenue per cow based on price of milk per liter, an initial feed composition is selected that has a level of microbial protein that provides for milk production in liters sufficient to attain the desired revenue per cow. In embodiments, the milk production can be input into a carbon footprint engine to produce a baseline carbon footprint for that level of microbial protein. The effect of changes to the animal feed
25 composition, such as adding at least one feed supplement, is assessed on milk production and carbon footprint. The process of changing the animal feed composition can be repeated until the feed supplement or combination of animal feed changes achieve the
30 optimal feed parameter-carbon footprint compromise. In embodiments, the animal feed

composition is adjusted to maintain milk production at a desired level while decreasing the carbon footprint from the baseline carbon footprint. Such analysis can be conducted in a single cow or plurality of cows. Such analysis can be conducted on an annual basis, and feed composition adjusted to decrease carbon footprint on an annual basis.

5 **[00107]** In embodiments, adjusting a component of the feed sample to change the baseline performance, the carbon foot print or both involves adding a feed supplement. In embodiments, adjusting a component of the feed sample comprises altering the form of protein or amount of protein in the sample. In embodiments, adjusting a component of the feed sample comprises altering the digestibility of the feed sample.

10 **[00108]** Some embodiments include aggregating the carbon footprint per animal for each animal of the plurality of milk producing animals to provide an aggregate carbon footprint. As one example, the aggregate of the carbon footprint per animal is the sum of the individual milk producing animal carbon footprints among a collection of milk producing animals in an enterprise, for the selected feed sample.

15 **[00109]** In embodiment of the present application, the plurality of milk producing animals includes animals of different species or from different phylogenetic families. In other embodiments, the plurality of milk producing animals is animals of the same species or from same phylogenetic family. Typically the plurality of animals are of the same species and from the same herd. Herds range in size from about 5 to 500 animals or more.

20 **[00110] Producing feed efficiency**

[00111] Some embodiments include producing or calculating feed efficiency. In some embodiments the feed efficiency is produced or calculated in unit volume of milk produced per unit weight of feed consumed. In some embodiments the feed efficiency is computed by dividing the estimated milk production (with or without feed supplements)

25 by the animal dry matter intake.

[00112] Additional embodiments include producing a change in milk production or feed efficiency for feed augmented with one or more feed supplements, as discussed in further detail herein. In some embodiments, producing the change in milk production or feed efficiency comprises calculating an amount of the one or more feed supplements

30 needed to obtain increased milk production or increased milk production efficiency.

[00113] Producing NRC metabolizable protein

[00114] Some embodiments include producing NRC metabolizable protein required to support milk output in unit weight/time based on one or more of the secondary parameters.

In some embodiments the NRC metabolizable protein requirement is obtained from a lookup table or chart, such as available from the National Research Council, as discussed herein, such as based at least in part on the weight of the animal, and additional of the secondary parameters, or other parameters.

5 **[00115] Producing escape protein**

[00116] Further embodiments include producing escape protein in units of weight. In embodiments, it is desirable to increase escape protein so that more protein can be absorbed in the small intestine.

[00117] In some embodiments the escape protein is computed by subtracting the rumen digestible protein from the total metabolizable protein. In some embodiments the rumen digestible protein is determined based on the results of a digestion model. For example, if the digestion model determines the total digestible nutrients as a percentage of the feed, the total digestible nutrients (grams) can be computed based on the animal's dry matter intake to determine rumen digestible protein. As another example, if the digestion model
10 determines the microbial protein, the rumen digestible protein can be computed based on the microbial protein and the dry matter intake.

[00118] Routing

[00119] Some embodiments include or involve a routing mode of operation. The routing mode of operation involves fixing the animal's milk production at a constant
20 amount, and determining a reduction in the required dry matter intake or required dietary protein that can be accomplished by including one or more feed supplements as part of the animal's feed. The feed supplements can be used to increase the animal's production of microbial protein, for example, so that the required dry matter intake and/or required dietary protein contained in the feed can be reduced without reducing the total amount of
25 metabolizable protein that the animal receives. In some embodiments of the present application, an appropriate decrease in dry matter intake or in required dietary protein is produced or computed. In some embodiments a cost savings is determined based on the use of one or more feed supplements, as a result of the reduction in required dry matter intake or required dietary protein.

30 **[00120] Increased milk production**

[00121] In some embodiments, feed supplements are used to increase milk production. The feed supplements can provide additional protein, or can include components that enhance the production of microbial protein, thereby in either case (or both) increasing the

animal's metabolizable protein intake. The increase in milk production can be estimated based on the amount or percent of protein per unit of milk produced.

[00122] Increased milk production efficiency

5 **[00123]** Some embodiments produce an estimate of an increase in milk production efficiency that can be obtained by the use of one or more feed supplements. The increase in milk production efficiency can be computed, for example, by computing the total increased milk production (the sum of the baseline milk production and the increased milk production, and dividing the total increased milk production by the dry matter intake.

[00124] Increased revenue

10 **[00125]** Some embodiments produce an estimate of an amount of increased revenue that can be obtained by the use of one or more feed supplements. In some embodiments an estimate of the increased revenue is computed as the product of the increased milk production and the milk price.

15 **[00126] Method For Estimating Impact of Feed Supplement on Production of Milk Producing Animal(s)**

[00127] The present application also includes a method for estimating an increase in one or more of milk production and milk production efficiency in a milk producing animal provided with animal feed containing one or more feed supplements, comprising providing a baseline performance comprising one or more of milk production and milk production efficiency for the milk producing animal; providing a selected amount of one or more feed supplements; and calculating with the computing device an increase in one or more of milk production and milk production efficiency in the milk producing animal fed using the selected amount of the one or more feed supplements relative to the baseline performance.

25 **[00128]** In embodiments of the present application, a method comprises producing with the computing device a change in milk production or feed efficiency for feed augmented with one or more feed supplements. In embodiments, the change in milk production or feed efficiency comprises calculating an amount of the one or more feed supplements needed to obtain increased milk production or increased milk production efficiency.

30 **[00129]** The present application provides A method for adjusting a feed composition, comprising: a) digesting a feed sample in an in vitro fermentation system for a milk producing animal to generate a value for a primary parameter comprising i) a measure of microbial protein for the feed sample; or ii) a measure of total digestible nutrients for the

- feed sample; b) measuring one or more secondary parameters selected from the group consisting of animal weight, animal milk production, animal milk protein, animal dry matter intake, animal milk price, and animal dietary protein to generate a value for the one or more secondary parameters; c) producing a baseline performance value comprising
- 5 milk production efficiency using at least one or more of the values of the primary parameters and one or more of the values of the secondary parameters using a computing device; d) producing a carbon footprint for the milk producing animal using the baseline performance using a computing device; and e) adjusting a component of the feed sample to change the baseline performance, the carbon foot print or both.
- 10 **[00130]** In other embodiments, a method for adjusting a feed composition further comprises Digesting a feed sample comprising a feed supplement in an in vitro fermentation system for a milk producing animal to generate a value for a primary parameter comprising a) a measure of microbial protein for the feed sample; or b) a measure of total digestible nutrients for the feed sample; Holding a value for one or more
- 15 of the secondary parameters constant, wherein the secondary parameters selected from the group consisting of animal weight, animal milk production, animal milk protein, measuring animal dry matter intake, animal milk price, animal dietary protein and combinations thereof; producing a supplement performance value comprising milk production efficiency using at least one or more of the values of the primary parameters
- 20 and one or more of the values of the secondary parameters using a computing device; producing a supplement carbon footprint for the milk producing animal using the supplement performance using a computing device; and comparing the supplement performance to the baseline performance and/or comparing the supplement carbon footprint to the carbon footprint and selecting the feed supplement that changes milk
- 25 production efficiency, carbon foot print or both.
- [00131]** Such methods are useful to select a feed composition and/or a feed supplement in order to increase feed efficiency, and/or to balance any increase in feed efficiency with effects on carbon footprint. The methods may be repeated any number of times using different feed compositions and/or different feed supplements or amounts, and the results
- 30 compared to one another to allow a selection of a feed composition and/or supplement that achieves the desired feed parameter-carbon footprint compromise.

[00132] Feed Efficiency / Milk Production Efficiency

[00133] In some embodiments the feed or milk production efficiency can be improved by feeding a milk producing animal one or more feed supplements along with an animal feed. Some embodiments involve estimating an increase in, or calculating an improvement in, feed efficiency or milk production efficiency between the baseline
5 performance and the supplement performance. The supplement performance refers to the an estimate of a performance associated with the milk producing animal when the milk producing animal is fed one or more feed supplements along with a selected animal feed.

[00134] Feed Supplements

[00135] Feed supplements as used herein refer to components that are added to a feed
10 composition in order to change the characteristics of the feed composition. Feed characteristics include but are not limited to, a residual component after digestion, microbial protein, total digestible nutrients, nitrogen source, protein source, and neutral detergent fiber. Feed supplements can include components that adjust digestibility of feed components such as protein, neutral detergent fiber, and non protein nitrogen. Feed
15 supplements include but are not limited to, protein, amino acids, non protein nitrogen sources, enzymes, microbial protein, and microbial derived components. Specific examples of feed supplements include DEMP™, Optigen®, and Fibrozyme™ (all available from Alltech, Inc. Nicholasville, KY).

[00136] Baseline Performance

[00137] In embodiments, of the present application a method provides a baseline
20 performance comprising one or more of milk production or milk production efficiency as described herein. A baseline of milk production for a particular feed sample can be determined by calculating the amount of milk produced per unit of feed fed to the animal. In embodiments, a baseline performance comprising milk production efficiency is
25 produced using at least one of the primary parameters and one or more secondary parameters, wherein the one or more secondary parameters are associated with a measure of one or more of animal weight, animal milk production, animal milk protein, animal dry matter intake, animal milk price, and animal dietary protein as described above. Baseline performance results can be displayed and/or stored as described herein.

[00138] Supplement Performance

[00139] In embodiments, of the present application a method provides a supplement
30 baseline performance comprising one or more of milk production or milk production efficiency for a feed composition with at least one added feed supplement as described

herein. A baseline of milk production for a particular feed sample can be determined by calculating the amount of milk produced per unit of feed fed to the animal in the presence of one or more supplements. In embodiments, a supplement baseline performance comprising milk production efficiency is produced using at least one of the primary
5 parameters and one or more secondary parameters, wherein the one or more secondary parameters are associated with a measure of one or more of animal weight, animal milk production, animal milk protein, animal dry matter intake, animal milk price, and animal dietary protein as described above.

[00140] Once a supplement performance is generated, it is compared to a baseline
10 performance for the feed composition without any added feed supplement. The effect of the supplement on performance is determined by identifying whether the presence or amount of the supplement results in a change from the baseline performance. In embodiments, a feed supplement is selected that increases the milk production or milk production efficiency. In embodiments, the feed supplement is selected that that increases
15 milk production or milk production efficiency while maintaining or decreasing a carbon foot print.

[00141] **Carbon footprint**

[00142] As described above, the systems and methods of the present application comprise producing with the computing device a carbon footprint for the milk producing
20 animal using the baseline performance or the supplement performance. In some embodiments the carbon footprint is produced or calculated using a carbon footprint engine. One suitable example of a carbon footprint engine is the E-CO₂ carbon footprint software, also known as the Alltech® “What-If” Tool available at
“alltech.eco2project.com” through a cooperative effort of E-CO₂ of Crewe, Cheshire East,
25 UK, and Alltech of Nicholasville, KY, US. In some embodiments the carbon footprint includes an estimated amount of greenhouse gas emissions that would be generated by one or more milk producing animals over a period of time. In some embodiments the estimate is a weight of the emissions over a period of time, and in other embodiments the estimate is a weight of the emissions per unit weight of milk producing animal over a period of
30 time (such as kg CO₂ / kg weight). In some embodiments the carbon footprint includes other aspects in addition to greenhouse gas emissions.

[00143] In embodiments, as described above, milk production or milk production efficiency can be determined for a plurality of animals and a carbon foot print for the

plurality of animals can be aggregated to provide an aggregated carbon footprint for feed samples with or without a supplement.

[00144] In some embodiments of the present application, the carbon footprint is displayed as a function of feed parameters to provide a feed parameter-carbon footprint compromise in the presence or absence of a feed supplement. A feed parameter-carbon footprint compromise is useful for selecting a feed composition or adjusting a feed composition in order to balance feed parameters with a desired carbon footprint. Feed parameters include one or more qualities or characteristics associated with an animal feed sample. One example of a feed parameter is a cost of the feed or feed component, such as a cost of the feed per unit weight or per unit volume. Another example of a feed parameter is the feed efficiency or milk production efficiency. Similarly, some embodiments include carbon footprint parameters. Carbon footprint parameters include one or more characteristics of a carbon footprint. One example of a carbon footprint parameter is a cost associated with the carbon footprint, such as a cost per unit weight. In embodiments, the carbon footprint associated with the supplement performance is compared to that of the baseline performance and the feed supplement is selected that adjusts the characteristic of a carbon footprint parameter.

[00145] In some cases, a more expensive animal feed may provide a reduced carbon footprint than a less expensive feed. As a result, the feed parameters and the carbon footprint parameters can be used to provide or calculate an optimal feed parameter-carbon footprint compromise. In some embodiments the optimal value is the value that has the lowest cost feed to achieve a reduced carbon footprint as compared to a reference feed sample or other feed composition under consideration, for example, a feed composition having a feed supplement.

[00146] **Implementation and display using one or more computing devices**

[00147] Some embodiments are implemented or include at least one processing device and at least one computer readable storage device. Computer readable storage devices store data instructions that, when executed by the at least one processing device cause the at least one processing device to implement the methods as described herein.

[00148] In embodiments, a computer readable storage device contains data instructions that, when executed by the at least one processing device cause the at least one processing device to generate a baseline performance engine configured to receive one or more primary parameters associated with one or more of a measure of microbial protein and a

measure of total digestible nutrients, and to produce a baseline performance comprising one or more of milk production and milk production efficiency using at least one of the primary parameters and one or more secondary parameters, wherein the one or more secondary parameters are associated with a measure of one or more of animal weight, animal milk production, animal milk protein, animal dry matter intake, animal milk price, and animal dietary protein; and a carbon footprint engine configured to use the baseline performance to produce a carbon footprint for the animal. In other embodiments, a carbon foot print is generated for a plurality of animals and aggregated as described herein.

[00149] In embodiments, a computer readable storage device contains data instructions that, when executed by the at least one processing device cause the at least one processing device to a method for estimating an increase in one or more of milk production and milk production efficiency in a milk producing animal provided with animal feed containing one or more feed supplements, comprising providing a baseline performance comprising one or more of milk production and milk production efficiency for the milk producing animal; providing a selected amount of one or more feed supplements; and calculating with the computing device an increase in one or more of milk production and milk production efficiency in the milk producing animal fed using the selected amount of the one or more feed supplements relative to the baseline performance. A baseline performance engine configured to receive one or more primary parameters associated with one or more of a measure of microbial protein and a measure of total digestible nutrients, and to produce a baseline performance comprising one or more of milk production and milk production efficiency using at least one of the primary parameters and one or more secondary parameters, wherein the one or more secondary parameters are associated with a measure of one or more of animal weight, animal milk production, animal milk protein, animal dry matter intake, animal milk price, and animal dietary protein in the presence of one or more feed supplements(supplement performance) and/or absence of the one or more feed supplements(baseline performance); and a carbon footprint engine configured to use the baseline and/or supplement performance to produce a carbon footprint for the animal. In other embodiments, a carbon foot print is generated for a plurality of animals and aggregated as described herein.

[00150] An example of a processing device is a central processing unit. A wide variety of other processing devices can also be used in other embodiments, such as a microprocessor, or other device capable of processing data instructions. Some

embodiments include multiple processing devices. The multiple processing devices can be part of a common device, or parts of separate devices. In some embodiments the processing devices include or are in data communication with a data communication device, which permit data communication between the processing devices. In some
5 embodiments the processing devices can communicate with each other across one or more networks, such as the Internet, a cellular communication network, a local area network, or other communication network that supports data communication.

[00151] Some embodiments include one or more computer readable storage devices storing data instructions that, when executed by the at least one processing device cause
10 the at least one processing device to perform one or more of the methods, operations, or functions disclosed herein. The computer readable storage device is a physical, tangible device. A computer readable storage device is or includes a non-transitory computer readable medium.

[00152] In some embodiments a processing device is, or is a part of, a computing
15 device. An example of a computing device is a computer, such as a server, a desktop computer, a laptop computer, a tablet computer, a smartphone, and a wearable computing device. In some embodiments a computer readable storage device is part of the computing device, while in other embodiments it is separate from the computing device.

[00153] Some embodiments include a first processing device and a second processing
20 device, wherein the first processing device is part of a first computing device and the second processing device is part of a second computing device. In some embodiments the first and second computing devices are local and in other embodiments the first and second computing devices are remote. Some embodiments include three or more computing devices. In some embodiments the first processing device operates to produce
25 the baseline performance and the second processing device operates to produce the carbon footprint, as described herein.

[00154] Some embodiments further include a display device. In some embodiments the display device is part of or in data communication with a processing device. The display device can be a display device connected with a computing device, or may be a remote
30 display device connected to another computing device.

[00155] **The Drawings**

[00156] FIG. 1 is a schematic block diagram illustrating an example system 100 for estimating the impact of a milk producing animal on carbon footprint. In this example the

system includes a feed sample evaluation engine 102, a baseline performance engine 104, and a carbon footprint engine 106. In some embodiments the system also involves a feed sample 101, primary parameters 103, secondary parameters 105, a baseline performance 107, and a carbon footprint 109.

5 [00157] In some embodiments the feed sample evaluation engine 102 receives a feed sample 101 or data or information related to a feed sample. Examples of the feed sample evaluation engine 102 include a digestion model. In another example, the feed sample evaluation engine 102 operates to evaluate an amount or a percent of one or more components in the selected feed sample 201, such as based on the information related to
10 the feed sample.

[00158] The feed sample evaluation engine 102 generates one or more primary parameters 103 for the selected feed sample 101.

[00159] The baseline performance engine 104 utilizes the one or more primary and secondary parameters 103 and 105 to produce the baseline performance 107. In some
15 embodiments the baseline performance engine 104 executes a set of data instructions to perform one or more computations of the primary and secondary parameters 103 and 105 to compute one or more baseline performance 107 values.

[00160] The baseline performance 107 is provided to the carbon footprint engine 106, which operates to produce a carbon footprint 209 for one or more milk producing animals.

20 [00161] In some embodiments the baseline performance 107 and/or the carbon footprint 109 are used to adjust the selected feed sample 101, and the process is repeated to determine a baseline performance 107 and a carbon footprint for the adjusted selected feed sample 101.

[00162] In some embodiments the selection of the feed sample is automated by a
25 computing device to determine an optimal feed parameter-carbon footprint compromise based on the baseline performance 107 and/or the carbon footprint 109.

[00163] FIG. 2 is a schematic block diagram illustrating an example system 200 for estimating the impact of a feed supplement on production and/or carbon footprint of a milk producing animal. In this example the system includes a feed sample evaluation
30 engine 202, a baseline performance and supplement performance engine 204, and a carbon footprint engine 206. In some embodiments the system also involves a feed sample 201, primary parameters 203, secondary parameters 205, a baseline performance 207, a carbon footprint 209, and an optional feed supplement 211.

[00164] In some embodiments the feed sample evaluation engine 202 receives a feed sample 201 or data or information related to a feed sample. In some embodiments the selected feed sample 201 also includes an optional feed supplement 211. Examples of the feed sample evaluation engine 202 include a digestion model. In another example, the feed sample evaluation engine 202 operates to evaluate an amount or a percent of one or more components in the selected feed sample 201 and the feed supplement 211, such as based on the information related to the feed sample.

[00165] The feed sample evaluation engine 202 generates one or more primary parameters 203 for the selected feed sample 201 and for the selected feed sample with the feed supplement 211.

[00166] The baseline performance and supplement performance engine 204 utilizes the one or more primary and secondary parameters 203 and 205 to produce the baseline performance or supplement performance 207. The baseline performance involves the performance without the optional feed supplement 211, while the supplement performance involves the performance with the optional feed supplement 211. In some embodiments the baseline performance engine 204 executes data instructions, such as with one or more processing devices, to perform one or more computations of the primary and secondary parameters 203 and 205 to compute one or more baseline performance and supplement performance 207 values.

[00167] The impact of a feed supplement on production can be determined by comparing the baseline performance with the supplement performance.

[00168] The baseline and supplement performance 207 is provided to the carbon footprint engine 206, which operates to produce a carbon footprint 209 for one or more milk producing animals based on either or both of the baseline performance or the supplement performance 207.

[00169] In some embodiments the baseline performance 207 and/or the carbon footprint 209 are used to adjust the selected feed sample 201 and/or the optional feed supplement 211, and the process is repeated to determine a baseline performance 207 and a carbon footprint for the adjusted selected feed sample 201 and optional feed supplement 211.

[00170] In some embodiments the selection of the feed sample is automated by a computing device to determine an optimal feed parameter-carbon footprint compromise based on the baseline performance 207 and/or the carbon footprint 209.

[00171] FIG. 3 is a screen shot illustrating an example user interface display 300 according to the present disclosure. In some embodiments, the user interface display 300 is generated by the baseline performance engine 104, shown in FIG. 1. In other embodiments, the user interface display 300 is a display generated by the baseline and supplement performance engine 204, shown in FIG. 2.

[00172] In the illustrated example, the display 300 includes a primary parameters section 302, a secondary parameters section 304, a feed supplements section 306, a supplement effect section 308, a routing effect section 310, and a protein data section 312.

[00173] In some embodiments the primary parameters section 302 displays one or more primary parameters received from another source, such as from a digestion model. In another possible embodiment, the primary parameters section 302 is an input section into which a user can enter one or more primary parameters. In this examples, the primary parameters include a measure of microbial protein for a selected feed sample from a digestion model associated with the milk producing animal, a measure of total digestible nutrients for the selected feed sample from the digestion model associated with the milk producing animal, and an amount or a percent of components in the selected feed sample.

[00174] The secondary parameters section 304 is provided in some embodiments to display one or more secondary parameters, such as received from another source. In other embodiments, the secondary parameters section 304 is an input section into which a user can enter one or more secondary parameters. In this example, the secondary parameters section includes input fields into which one or more secondary parameters can be provided, such as animal weight (kg), milk production (L), milk protein (%), dry matter intake (kg), milk price (\$/L), and dietary protein (%).

[00175] The feed supplements section 306 is provided in some embodiments to permit the selection of one or more feed supplements. In this example the user interface display 300 includes three selectable and/or adjustable controls that the user can manipulate to adjust the amounts of one or more feed supplements to be included in the animal feed. In this example the feed supplements are Demp™, Optigen®, and Fibrozyme™, for example. Other embodiments include other feed supplements. In this example the Demp™ feed supplement is selected for inclusion in the feed, and the Optigen® and Fibrozyme™ feed supplements are not included.

[00176] Some embodiments include a supplement effect section 308. In some embodiments the supplement effect section graphically displays an effect that the supplement has on the milk production and/or feed efficiency.

5 [00177] In the illustrated example, the supplement effect section 308 includes a milk production display 320, a feed efficiency display 322, an increased milk production display 324, a total milk production display 326, an improved feed efficiency display 328, and an additional revenue display 330.

[00178] The milk production display 320 displays a baseline milk production (35 liters), and also includes the feed efficiency display 322 that shows a baseline feed
10 efficiency (1.59), in this example.

[00179] The supplement effect display 324 displays the increased milk production (3.8 liters / day) obtained through the use of the one or more selected feed supplements, such as the Demp™ feed supplement in this example.

[00180] The total milk production display 326 displays the total milk production (38.8
15 liters / day), and also includes the improved feed efficiency display 328 that displays the improved feed efficiency (1.76) achieved through the inclusion of one or more of the feed supplements, for example.

[00181] The additional revenue display 330 shows an increased revenue (\$1.07) obtained through the use of the one or more feed supplements.

20 [00182] In some embodiments the displays 320, 324, 326, and 328 include circular meter displays, having the appearance of a speedometer, that allow the associated information to be quickly and easily understood by the user viewing the displays. In some embodiments the displays 322 and 328 are displayed within the displays 320 and 326, respectively.

25 [00183] As discussed herein, some embodiments include a routing mode of operation. As one example, the routing mode can be selectively turned on or off using the “routing” control within the secondary parameters section 304. During the routing mode of operation, the milk production can be fixed at a desired level, while the dry matter intake (kg), and/or the dietary protein (%) are adjusted based on the inclusion of one or more
30 supplements. The results are displayed in the routing effect section 310. In this example, the routing effect section 310 includes a required dietary protein (%) display and a protein savings (%) display. When one or more feed supplements are included, the required dietary protein (%) shows the reduced dietary protein of the feed that can be used while

continuing to provide the milk producing animal with the appropriate metabolizable protein. The protein savings display shows the difference between the baseline required dietary protein (%) and the improved required dietary protein (%).

5 [00184] The protein data display 312 displays other protein-related data, such as the amount of protein supplied to the milk producing animal by the inclusion of the one or more feed supplements, the escape protein with the feed supplement, the escape protein without the feed supplements, and the NRC metabolizable protein required by the milk producing animal.

10 [00185] The various embodiments described above are provided by way of illustration only and should not be construed to limit the claims attached hereto. Those skilled in the art will readily recognize various modifications and changes that may be made without following the example embodiments and applications illustrated and described herein, and without departing from the true spirit and scope of the following claims.

WHAT IS CLAIMED IS:

1. A method for estimating impact of a milk producing animal on carbon footprint, comprising:

providing one or more primary parameters associated with one or more of: a) a measure of microbial protein for a selected feed sample from a digestion model associated with the milk producing animal; b) a measure of total digestible nutrients for the selected feed sample from the digestion model associated with the milk producing animal; and c) an amount or a percent of components in the selected feed sample;

producing with a computing device a baseline performance comprising milk production efficiency using at least one or more of the primary parameters and one or more secondary parameters for the milk producing animal, wherein the one or more secondary parameters are associated with one or more of: a measure of animal weight, a measure of animal milk production, a measure of animal milk protein, a measure of animal dry matter intake, a measure of animal milk price, and a measure of animal dietary protein; and

producing with the computing device a carbon footprint for the milk producing animal using the baseline performance.

2. The method of claim 1 further comprising:

displaying the carbon footprint for the milk producing animal.

3. The method of claim 2 wherein the displaying comprises displaying the carbon footprint for the milk producing animal as a function of feed intake of the animal.

4. The method of claim 2 wherein the carbon footprint is displayed as a function of feed parameters to provide an optimal feed parameter-carbon footprint compromise.

5. The method of claim 1 wherein the one or more secondary parameters further include a measure of fat, a measure of fiber, a measure of calcium, a measure of phosphorous, or a measure of energy.

6. The method of claim 1 wherein the producing with the computing device comprises calculating with the computing device.
7. The method of claim 1 wherein the digestion model is a chemical or biological fermentation model.
8. The method of claim 7 wherein the biological fermentation model is an *in vitro* biological model.
9. The method of claim 1, wherein producing a baseline performance comprises producing or calculating an estimate of the milk production efficiency by calculating a measure of a volume of milk produced per unit weight of feed consumed.
10. The method of claim 1, wherein producing a baseline performance comprises producing or calculating an estimate of the milk production efficiency by calculating a NRC metabolizable protein requirements to achieve a desired milk output in unit weight/time using one or more of the secondary parameters.
11. The method of claim 1, wherein producing a baseline performance comprises producing or calculating an estimate of the milk production efficiency by calculating escape protein.
12. The method of claim 1 further comprising:
producing with the computing device a change in milk production or feed efficiency for feed augmented with one or more feed supplements.
13. The method of claim 12 wherein the producing with the computing device the change in milk production or feed efficiency comprises calculating an amount of the one or more feed supplements needed to obtain increased milk production or increased milk production efficiency.
14. A method for estimating impact of a plurality of milk producing animals on carbon footprint, comprising:

providing one or more primary parameters associated with one or more of: a) a measure of microbial protein based on a selected feed sample in a digestion model associated with at least one of the milk producing animals; b) a measure of total digestible nutrients based on the selected feed sample in the digestion model associated with at least one of the milk producing animals; and c) the amount or percent of components in the feed sample;

producing with a computing device a performance for each animal comprising milk production efficiency using at least one or more of the primary parameters and one or more secondary parameters for each animal, wherein the one or more secondary parameters are associated with one or more of: a measure of animal weight, a measure of animal milk production, a measure of animal milk protein, a measure of animal dry matter intake, a measure of animal milk price, and a measure of animal dietary protein;

producing with the computing device a carbon footprint per animal using the baseline performance; and

aggregating the carbon footprint per animal for each animal of the plurality of milk producing animals to provide an aggregate carbon footprint.

15. The method of claim 14 further comprising:

displaying the carbon footprint for each animal of the plurality of milk producing animals.

16. The method of claim 14 further comprising:

displaying the aggregate carbon footprint for the milk producing animals as a function of feed intake of the animals.

17. The method of claim 14 wherein the plurality of milk producing animals includes animals of different species or from different phylogenetic families.

18. The method of claim 14 wherein the plurality of milk producing animals is animals of the same species or from same phylogenetic family.

19. The method of claim 14 wherein the producing with the computing device comprises calculating with the computing device.

20. The method of claim 14 wherein the aggregate carbon footprint is displayed as a function of feed parameters to provide an optimal feed parameter-aggregate carbon footprint compromise.
21. The method of claim 14 wherein the one or more secondary parameters further include one or more of: a measure of fat, a measure of fiber, a measure of calcium, a measure of phosphorous, and a measure of energy.
22. The method of claim 14 wherein the digestion model is a chemical or biological fermentation model.
23. The method of claim 22 wherein the biological fermentation model is an *in vitro* biological model.
24. The method of claim 14 further comprising:
producing with the computing device feed efficiency in unit volume of milk produced per unit weight of feed consumed.
25. The method of claim 14 further comprising:
producing with the computing device NRC metabolizable protein required to support milk output in unit weight/time based on one or more of the secondary parameters.
26. The method of claim 14 further comprising:
calculating with the computing device escape protein in units of weight.
27. The method of claim 14 further comprising:
producing with the computing device a change in milk production or feed efficiency for feed augmented with one or more feed supplements.
28. The method of claim 27 wherein producing with the computing device a change in milk production or feed efficiency comprises calculating an amount of the one or more feed supplements needed to obtain an increase in milk production or an increase in milk production efficiency.

29. The method of claim 28 wherein the producing with the computing device a carbon footprint per animal includes producing a carbon footprint per animal using the increased milk production or increased milk production efficiency.

30. The method of claim 29 wherein the aggregating the carbon footprint per animal for each animal of a plurality of animals includes aggregating a carbon footprint per animal for each animal of the plurality of animals with feed augmented with the one or more feed supplements, to provide an aggregate carbon footprint as a function of an amount of the one or more feed supplements or milk production.

31. The method of claim 30 further comprising:
displaying the aggregate carbon footprint as a function of the selected amount of the one or more feed supplements or milk production.

32. The method of claim 14 further comprising:
producing with the computing device a required protein level or protein savings.

33. A method for estimating an increase in one or more of milk production and milk production efficiency in a milk producing animal provided with animal feed containing one or more feed supplements, comprising:
providing a baseline performance comprising one or more of milk production and milk production efficiency for the milk producing animal;
providing a selected amount of one or more feed supplements; and
calculating with the computing device an increase in one or more of milk production and milk production efficiency in the milk producing animal fed using the selected amount of the one or more feed supplements relative to the baseline performance.

34. The method of claim 33 further comprising:
calculating with the computing device a carbon footprint for the animal.

35. The method of claim 34 further comprising:
displaying the carbon footprint as a function of the selected amount of the one or feed supplements or milk production.

36. The method of claim 33 further comprising:
calculating with the computing device a required dietary protein or protein savings.
37. A method for estimating an increase in one or more of milk production and milk production efficiency in a plurality of milk producing animals provided with animal feed containing one or more feed supplements, comprising:
providing a baseline performance comprising one or more of milk production and milk production efficiency for the plurality of milk producing animals;
providing a selected amount of one or more feed supplements; and
calculating with a computing device an increase in one or more of milk production and milk production efficiency per animal in the plurality of milk producing animals fed using the selected amount of the one or more feed supplements relative to the baseline performance.
38. The method of claim 37 further comprising:
calculating with the computing device a carbon footprint per animal for each animal of the plurality of animals.
39. The method of claim 38 further comprising:
aggregating the carbon footprint per animal for each animal of the plurality of animals to provide an aggregate carbon footprint as a function of the selected amount of the one or more feed supplements or milk production.
40. The method of claim 39 further comprising:
displaying the carbon footprint as a function of the selected amount of the one or more feed supplements or milk production.
41. A system for estimating the impact of a milk producing animal on carbon footprint, the system comprising:
at least one processing device; and
at least one computer readable storage device, the at least one computer readable storage device storing data instructions that, when executed by the at least one processing device cause the at least one processing device to generate:

a baseline performance engine configured to receive one or more primary parameters associated with one or more of a measure of microbial protein and a measure of total digestible nutrients, and to produce a baseline performance comprising one or more of milk production and milk production efficiency using at least one of the primary parameters and one or more secondary parameters, wherein the one or more secondary parameters are associated with a measure of one or more of animal weight, animal milk production, animal milk protein, animal dry matter intake, animal milk price, and animal dietary protein; and

a carbon footprint engine configured to use the baseline performance to produce a carbon footprint for the animal.

42. The system of claim 41 further comprising a display device, wherein the carbon footprint for the animal is displayed on the display device as a function of feed intake of the animal.

43. The system of claim 41 further comprising a plurality of computing devices, wherein a first processing device is part of a first computing device and a second processing device is part of a second computing device.

44. The system of claim 41 wherein the baseline performance engine operates on the first computing device to produce the baseline performance and the carbon footprint engine operates on the second computing device to produce the carbon footprint.

45. The system of claim 43 wherein the first computing device is in data communication with the second computing device across one or more data communication networks.

46. The system of claim 41 wherein the baseline performance engine is configured to calculate the baseline performance and the carbon footprint engine is configured to calculate the carbon footprint.

47. A system for estimating the impact of a plurality of milk producing animals on carbon footprint, the system comprising:

at least one processing device; and

at least one computer readable storage device, the at least one computer readable storage device storing data instructions that, when executed by the at least one processing device cause the at least one processing device to generate:

a baseline performance engine configured to receive one or more primary parameters associated with one or more of a measure of microbial protein and a measure of total digestible nutrients, the baseline performance engine further configured to produce a baseline performance comprising milk production efficiency using at least one of the primary parameters and one and or more secondary parameters, wherein the one or more secondary parameters are associated with a measure of one or more of: animal weight, animal milk production, animal milk protein, animal dry matter intake, animal milk price, and animal dietary protein; and

a carbon footprint engine configured to use the baseline performance to produce a carbon footprint for each animal in the plurality of animals and aggregate the carbon footprint produced for each animal in the plurality of animals to provide an aggregate carbon footprint.

48. The system of claim 47, further comprising a display device, wherein the display device displays the aggregated carbon footprint for the plurality of animals as a function of feed intake of the plurality of animals.

49. The system of claim 47 wherein the baseline performance engine is configured to calculate the baseline performance and the carbon footprint engine is configured to calculate the carbon footprint.

50. The system of claim 47 further comprising a plurality of computing devices, wherein a first processing device is part of a first computing device and a second processing device is part of a second computing device.

51. The system of claim 50 wherein the first computing device is in data communication with the second computing device across one or more data communication networks.

52. The system of claim 49 wherein the plurality of milk producing animals includes animals of different species or from different phylogenetic families.
53. The system of claim 49 wherein the plurality of milk producing animals is animals of the same species or from same phylogenetic family.
54. A method for adjusting a feed composition, comprising:
- a) digesting a feed sample in an in vitro fermentation system for a milk producing animal to generate a value for a primary parameter comprising a i) a measure of microbial protein for the feed sample; or ii) a measure of total digestible nutrients for the feed sample;
 - b) measuring one or more secondary parameters selected from the group consisting of animal weight, animal milk production, animal milk protein, animal dry matter intake, animal milk price, and animal dietary protein to generate a value for the one or more secondary parameters;
 - c) producing a baseline performance value comprising milk production efficiency using at least one or more of the values of the primary parameters and one or more of the values of the secondary parameters using a computing device;
 - d) producing a carbon footprint for the milk producing animal using the baseline performance using a computing device; and
 - e) adjusting a component of the feed sample to change the baseline performance, the carbon foot print or both.
55. A method for adjusting a feed composition, comprising:
- a) determining a characteristic of a first feed sample to generate a value for a primary parameter;
 - b) measuring one or more secondary parameters selected from the group consisting of animal weight, animal milk production, animal milk protein, animal dry matter intake, animal milk price, and animal dietary protein to generate a value for the one or more secondary parameters;

- c) producing a baseline performance value comprising milk production efficiency using the value of the primary parameter and one or more of the values of the secondary parameters using a computing device;
- d) producing a carbon footprint for the milk producing animal using the baseline performance using a computing device; and
- e) adjusting a component of the first feed sample to change either the baseline performance, the carbon foot print or both.

56. The method of claim 54 or claim 55, wherein the steps are repeated until a feed composition is identified that maintains or increases milk production efficiency and decreases carbon footprint as compared to the first feed sample.

57. The method of claim 54, wherein the in vitro digestion system comprises digesting the feed sample with one or more digestive enzymes in the presence of a microbial population.

58. The method of claim 55, wherein the characteristic of the feed sample is selected from the group consisting of a measure of protein, a measure of carbohydrate, a measure of fat, a measure of dry matter, and a measure of gross energy.

59. The method of claim 55, wherein the step of determining the characteristic of the feed sample comprises measuring a characteristic of the feed sample.

60. The method of claim 55, wherein the step of determining the characteristic of the feed sample comprises calculating a characteristic of the feed sample.

61. The method of claim 59, wherein the characteristic of the feed sample is determined by a chemical method or by near infrared spectroscopy.

62. The method of any one of claims 54-61, wherein adjusting a component of the feed sample comprises adding a feed supplement to the feed sample.

63. The method of claim 62, wherein adjusting a component of the feed sample comprises altering the form of protein or amount of protein in the sample.
64. The method of claim 62 or claim 63, wherein adjusting a component of the feed sample comprises altering the digestibility of the feed sample.
65. The method of claim 54 or claim 55, wherein the step of producing a baseline performance comprises calculating a baseline performance.
66. The method of claim 54 or claim 55, wherein the step of producing a carbon footprint comprises calculating a carbon footprint.
67. The method of claim 54 or claim 55, wherein the step of producing a baseline performance comprises measuring a baseline performance.