Forage economics calculator web tool

1. Introduction

Nearly 90 % land area of North Dakota is in farms and ranches and the cattle (livestock) outnumbers population by a ratio of 3 to 1 [1]. Forages play a crucial role in livestock production since it provides all the necessary nutrients required for maintaining the animals. Sufficient and continuous supply of forage is vital in maintaining animal health, therefore producers grow and harvest forage crops specifically to store for seasonal shortfalls. Producing, harvesting, baling, and storing the forage crop represents a large proportion of annual livestock production cost [2, 3]. Making effective decisions on the selection of crops, fixing forage prices, and efficient management operations can bring down the risk involved in the agricultural enterprise. Performing economic analysis aids the forage growers make an educated decision on aspects such as forage purchase, machinery purchase, and determine forage prices.

Various parameters and complex calculations are involved in executing economic analysis of forage production including the costs such growing, harvesting, collecting, labor, fuel, and forage revenue. The following are existing spreadsheets tools developed to replace the manual method of analyzing the forage economics which can be tedious and time-consuming. Calculator spreadsheet was developed to calculate hay price for producers to compare net return between hay and corn production [4]. Another spreadsheet based calculator aimed at budgeting haying system enterprise, which allowed the producer using machinery and equipment information to determine the ownership and operating cost of specific type of haying system [5]. A hay decision support spreadsheet tool was developed which helped the producers to determine if it was profitable to produce or purchase hay, the hay types considered were alfalfa and grass [6].

However, these tools are available online the caveats are presented as follows, (i) the tools are scattered and a forage grower needs to use multiple spreadsheets to arrive at a decision; (ii) The available tools are in the format of spreadsheets and user needs to download and most likely enable macros option in order to run the calculations; (iii) all these tools mainly focussed on operations such as forage harvest and baling, while forage (bale) collection is often ignored. Bale collection is an intensive operation in the field, therefore cost associated with machinery, fuel, and labor needs to be included into the economic analysis in addition to harvest and baling operation.

Therefore, a user-friendly web-based tool namely “Forage Economics Calculator (FEC)” was developed using HTML, CSS, and JavaScript to perform economic analysis of forage production. Some of the advantages of using this tool includes, (i) FEC web tool serves as “one-stop” to aid decision making on major aspects such as growing or buying forage, purchasing machinery, and fixing forage prices based on net-return estimation; (ii) hassle-free access to FEC web tool from any internet-enabled computer (ipad/tablet or phone) with no download or installation of software required and can be used with different operating systems and browser applications; (iii) emphasis was given to bale collection operation using conventional tractor (collects maximum 2 bales/trip) and automatic bale picker (capable of collecting multiple bales/trip) while harvesting and baling were provided as direct inputs. Farmers, hay producers, custom hay operators, agricultural extension and financial personnel, and general users handling bales are the prospective users of the FEC web tool.

2. Description/overview of the web tool

Forage economics calculator (FEC) is a planning and management web tool to make an educated decision for ranchers and farmers on growing or buying forage, purchase machinery, and fixing forage prices. The tool performs standard economic analysis, with 24 user-inputs and 30 result outputs, including cost associated with harvest, baling, bale collection, bale transportation from field to storage, labor, fuel, revenue generated from selling the bales, and net return based on the cost and revenue (**??**). The tool emphasizes on the bale collection operation cost while harvesting, baling, and bale transportation are provided as direct inputs. Bale collection operation is commonly performed using a tractor with a spear or grapple attachment; or using an efficient "automatic bale picker" (ABP) which collects and transports multiple bales in a single trip. Both these bale collection machinery (tractor and ABP) are included in the tool for comparison. Cost associated with bale collection operation is based on the simulation (36,960 scenarios) performed in the previous study to estimate the logistics distance and fuel consumption of tractor and ABP during bale collection [7].

In addition to the standard economic analysis, the tool performs input sensitivity analysis for profit and as well as what-if and no-cost input scenario analysis. The tool generates dynamic/real-time results based on the user-input values and generates downloadable report and chart containing selected inputs and estimated results for future comparison and analysis. Though the calculator was developed based on the data (common crop type, bale sale price, and other costs inputs) collected from North Dakota, the tool can be extended to other states by changing the user-input values.

3. Web tool development

3.1. Web tool structure, styling, and development

FEC web tool was developed using the basic technologies, HTML [8], CSS [9], and JavaScript [10]. HTML was used to create the web tool's content structure, while CSS was used to design the web tool, including layout, visual effect, and background color. JavaScript programming language forms the basis of front-end web development and creates interactive elements that engage the user with the web tool. In addition to the basic web development technologies framework, the most popular front-end open-source toolkit called bootstrap was used to create responsive and mobile-first web tool [11]. Data visualization of the results was achieved using SVG elements from the basic HTML and supplemented by an open-source JavaScript library Chart.js that produces responsive, customizable, and downloadable charts [12]. Visual Studio Code (VS Code) text editor was used to write programming languages (HTML, CSS, and JavaScript) to develop the web tool. VS Code is free, open-source, and is equipped with IDE-like features that enable accessing aspects such as language-specific syntax highlighting, code indentation, plug-in, and add-on to capture code errors, etc. Code errors were additionally tested and captured by hosting the developed website onto the local server using Mac terminal commands.

The web tool's functionality was built to work similarly as possible in major web browsers such as Firefox, Google Chrome, and Safari. The web tool was also made to accommodate mobile, tablet (iOS and Android), and desktop media screen sizes and provide a good visual and responsive web tool experience.

3.2. Webtool sections

The FEC web tool consists of three main sections (Fig. 1): (i) home or welcome, (ii) user instructions and manual, and (iii) calculator section. Each section consists of a collapsible navigation sidebar at the top-left corner that enables a smooth transition between the sections. The first section is the home page that welcomes the user to the forage economics web tool (Fig. 1. A). A visitor counter was added to the home page to track the number of times the web tool has been accessed and used. The second section consists of short 6-step user instructions and a detailed manual (Fig. 1. B). The user instructions include a friendly step-by-step guide for the user, while the detailed manual contains comprehensive information about the various inputs, region-specific forage and economics data, forage bale collection logistics models, standard economics calculations that run at the background of the web tool, and the generated outputs. The 6-step user instructions and detailed manual are downloadable and printable PDF documents. The third section is the actual forage economics calculator section that functions as a user interface that allows interaction between the user and the calculator (Fig. 1. C). The calculator consists of editable inputs, read-only result outputs, and a dynamic plot. More details on the FEC calculator's user interface and application features will be presented in the following section.

3.3. User interface and application features

The forage economics calculator is presented in a two column panel with inputs panel (24 input items) on the left and the results panel (30 result items) on the right (Fig. 2). The FEC

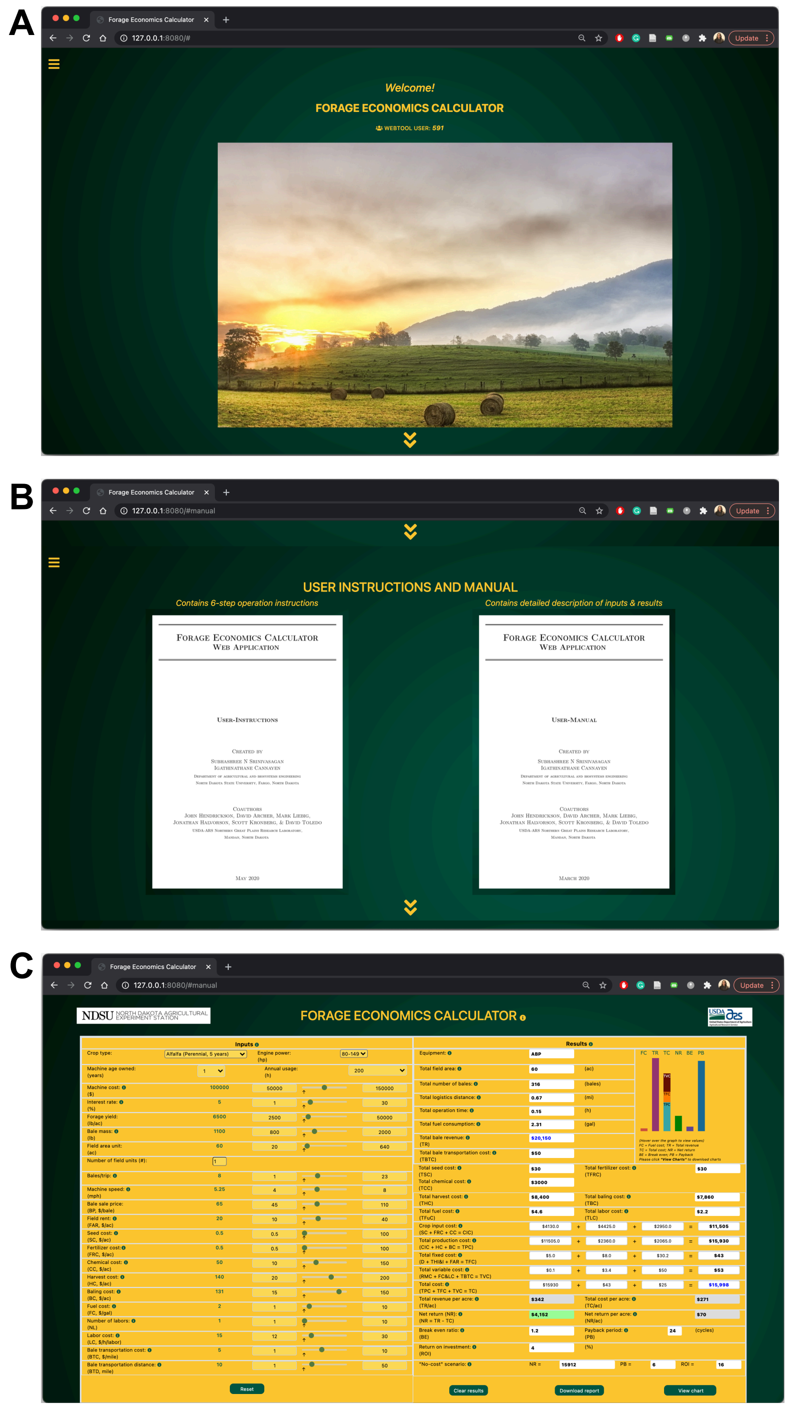

Fig. 1. Overview of the forage economics calculator web tool; A. Home or welcome of the forage economics calculator web tool with web tool user count feature; B. User instructions and manual section contains downloadable short 6-step user instructions and detailed user manual; C. Calculator section contains 24 inputs, 28 output results, and a dynamic plot

is the user-interface where human-computer interaction transpire; the user interacts with the calculator by choosing required inputs to estimate the results. The calculator is dynamic in nature; changing the inputs simultaneously changes the result values in real-time without any button actions. Input values are provided as default and can be modified by the user while the results are read-only. Tooltip feature is provided for the input and result items to display brief informative message with the user interacts with the tooltip icon, and is initiated by hovering the mouse over the icon (Fig. 2a).

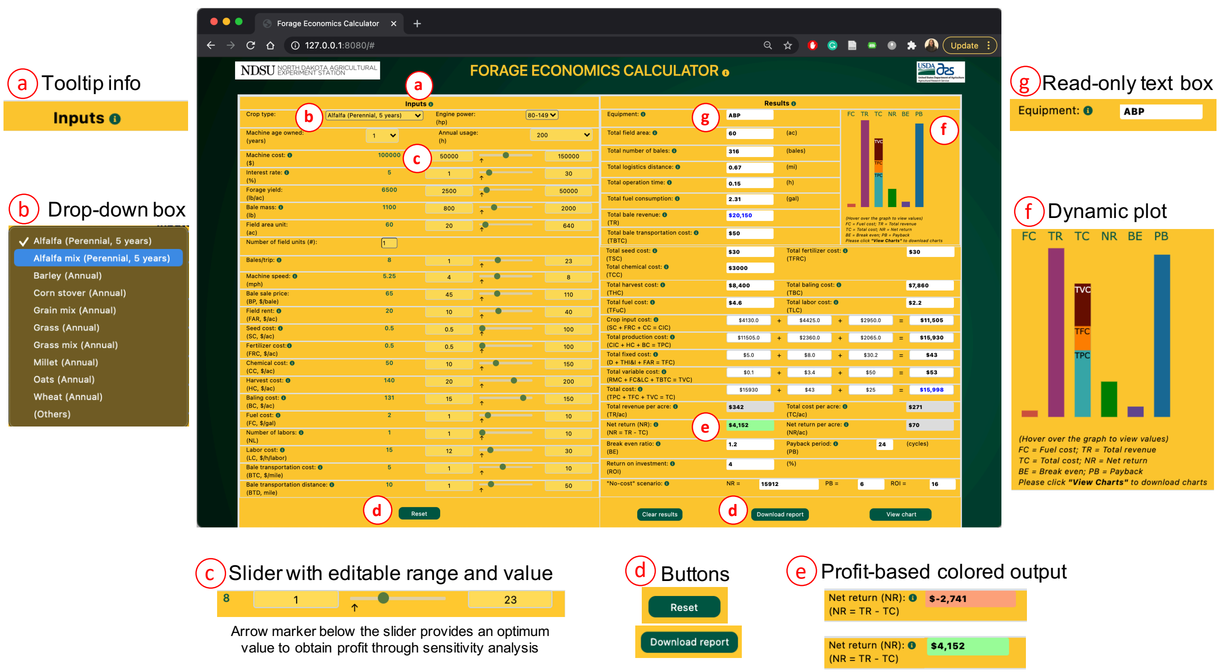

Fig. 2. Forage economics calculator user interface and application features showing input column, results column, tooltip info, drop-down box, slider option, editable text box, button option, read-only text box, dynamic plot, and colored text boxes.

Default values are provided for all the input items and can be changed by the user through four different input options such as, drop-down box, slider, and editable text boxes. Among the 24 user-input items, 4 are fixed inputs in the form of a drop-down box containing a defined list, while the remaining are variable inputs in the form of sliders and editable text boxes. Drop-down options displays a specific list of items from which the user can choose one item from the list (Fig. 2b). Sliders are versatile design tools that can be used to select a value between a range (Fig. 2c). The slider consists of a minimum, maximum, and a selected value which are provided by default, however the minimum and maximum value for each slider item can be changed using editable text-boxes and the value can be changed by adjusting the position of the slider. Arrow markers are provided under each slider which provides sensitivity analysis, the position of these arrow markers informs the value to the user at which a loss or profit is incurred. Reset button option is provided at the bottom of the input items, which resets all the input items to the set default value(Fig. 2d).

The results column consists of read-only text boxes displaying the estimated results(Fig. 2g). The dynamic plot in the results column displays various estimated result items in the form of a bar chart; the chart changes with the changing results based on the user inputs (Fig. 2f). Hovering over the bars in the graph displays a tooltip with their respective result value information. Colored text box for "Net return" result item aids in enhanced visualization; background color green indicates profit and red indicates loss(Fig. 2e). There are three different button operations in the results panel; Clear results, Download report, and View chart. Clear results button clears all the generated results and changes the value at the input panel to the default values. Download report button generates a printable document in PDF format consisting of selected user-inputs and the generated result items. View chart button allows user to visualize generated economic results such as total cost, total revenue, and the net return in a responsive bar chart format.

3.4. Web tool inputs

A total of 24 input items are arranged on the left panel, among which 4 are drop-down options with a pre-defined list, while the remaining are the slider and editable input box options which are customizable based on the user requirement. Among the total inputs, 11 are cost-based inputs, while the remaining are based on the forage crop, equipment, and operation. Detailed description of each input item is presented in Table 1. Most forage crop types prevalent in North Dakota have been listed under the "Crop type" drop-down input. However, suppose the desired forage crop is not listed, the user can select "Others" from the list and provide relevant range values in the editable minimum and maximum input boxes for the sliders. In the event of zero inputs, the user can change the value in the minimum editable input box to zero and adjust the slider to the left-most position to select the zero value.

3.5. Web tool generated results

The result panel is located on the right of the forage economics calculator with a total of 30 generated result items. All the items are displayed in read-only text box and cannot be edited by the user. Among the total result items, 16 are cost-based and the rest are standard economic results such as net return, revenue, break even ratio, payback period, etc. Three non-linear regression models ($R^2 = 0.98$) developed in our previous study that estimate the total logistics distance, operation time, and fuel quantity consumed during bale collection operation runs in the background of the calculator web tool [7]. Eight standard economic analysis equations were included to generate the rest of the results (economics-based). Though, calculator is represented in imperial units for the ease of use by farmers and ranchers, the models are developed using SI units, therefore, a conversion factor is accounted in estimating the results values. The result panel also includes "No-cost scenario" analysis where net return, payback period, and return on investment results are estimated assuming field area rent, fertilizer cost, chemical cost, and labor cost input items are zero. More information on the result items are presented in the subsequent sections.

3.5.1. Equipment type

The equipment type result displays tractor or ABP. In our previous study we considered different scenarios comparing tractor and ABP for bale collection operation through kinematic simulation. Calculator determines the equipment type based on the input value bales/trip (Table 1, #11). The conditions for equipment type is as follows:

$$\text{Equipment} = \begin{cases} \text{Tractor,} & \text{bales/trip} \leq 2 \\ \text{Automatic bale picker,} & \text{bales/trip} > 2 \end{cases}$$

Table 1
Brief description of forage economics calculator web tool input options.

Inputs	Description
1. Crop type	The types of forage crops listed are curated based on forage crops available for sale as bales in commercial markets present in North Dakota, such as NDSU feedlist [13] and BisManonline [14]. The list consisted of perennial and annual forage crop types.
2. Engine power (hp)	Engine power ranges of commercially available tractors (applicable directly with attachments or automatic bale picker). The engine power influences the bale load-carrying capacity [15, 16, 17].
3. Machine age owned (years)	Number of years the tractor is owned by the farmer/rancher.
4. Annual usage (h)	Average annual operation of the tractor in hours (h).
5. Machine cost ($)	The listed cost of the machine during the purchase. The machine cost is based on the engine power.
6. Interest rate (%)	Interest rate at which machine was purchased.
7. Forage yield (lb/ac)	Production of forages from the field of a specified area. The range accommodates possible yield variation of the potential forages and bioenergy feedstocks.
8. Bale mass (lb)	The weight of a single large round bale (dimension 5 × 5 or 5 × 6 ft) in pounds (lb). The range limits are fixed based on the bale mass sold at the commercial markets of North Dakota.
9. Field area unit (ac)	Expressed as fractions of a "section" (1 square mile = 640 acres = 259 ha) as a standard US land unit. Range includes from the smallest (8 ha) to the largest (259 ha) fraction of the field area unit.
10. Number of field units (#)	Number of field area sections.
11. Bales/trip	Bales/trip less than 3 was considered for conventional tractor bale collection, while bales/trip greater than 2 were considered based on the available commercial carrying capacity of automatic bale picker.
12. Machine speed (mph)	Machine speed (mph) is the operating speed of the machine in the field during bale collection operation.
13. Bale sale price ($/bale)	Specific to bale crop types and the price range limit was fixed based on the data collected from commercial markets in North Dakota. The price range values changes based on the selected crop type [13, 14].
14. Field area rent ($/ac)	The cost of average rent of field area per acre. The range limit values are based on the data from the 2020 North Dakota Department of Trust Lands survey [18].
15. Seed cost ($/ac)	Seed cost per acre was direct or annualized that differs based on the selected forage crop type.
16. Fertilizer cost ($/ac)	Fertilizer cost per acre, which is the total cost of fertilizers such as nitrogen, phosphorous, potassium, sulfur, limestone, and others based on the forage crop.
17. Chemical cost ($/ac)	Chemical cost is the cost of herbicide, fungicide, and insecticide per acre.
18. Harvest cost ($/ac)	Involves machinery and labor cost (overhead) for harvesting the forages and is provided as direct input.
19. Baling cost ($/ac)	Involves machinery and labor cost (overhead) for baling the forages and is provided as direct input.
20. Fuel cost ($/gal)	Fuel (diesel) cost per gallon was fixed based on 10-year average fuel cost per gallon.
21. Number of labors	Number of labors involved during bale collection operation.
22. Labor cost ($/h/labor)	Labor cost per hour is the cost of labor operating the equipment during bale collection.
23. Bale transportation cost ($/mile)	Fuel and labor cost of transporting the bale from field to storage facility.
24. Bale transportation distance (mile)	Distance between the field and the storage facility.

Inputs #1 – #4 are drop-down options, #10 is an input box, and the rest are slider options with editable range values.

3.5.2. *Total field area*

Total field area is estimated as a product of the two following inputs: field area unit and number of units (Table 1, #9 and #10).

3.5.3. *Total number of bales*

The total number of bales generated depended on the input values, field area, bale mass, and biomass yield (Table 1, #7, #8, #9, and #10). A random variation of 10% in the crop stand uniformity was assumed [19]. Any change in these input values is reflected in the result value of total number of bales.

$$\text{Number of bales} = \frac{A_\mathrm{F} \times Y_\mathrm{B}}{M_\mathrm{B}} \tag{1}$$

where, A_F = field area (ha); Y_B = biomass yield (Mg/ha); and M_B = bale mass (Mg) .

3.5.4. *Total logistics distance*

Logistics distance during bale collection is estimated using the prediction model developed [7] with the input values of field area, bales/trip, and biomass yield (Table 1, #7, #9, and #11).

$$D_\mathrm{L} = \left[\frac{A_\mathrm{F} Y_\mathrm{B}}{17.879 \times (B_\mathrm{T} + 0.895)} \right]^{1.377} \quad (R^2 = 0.98) \tag{2}$$

where, D_L = total bale aggregation logistics distance (km).

3.5.5. *Total operation time*

The bale collection operational time is estimated using the developed multivariate model [7] with the user input values of field area, bales/trip, biomass yield, and equipment speed (Table 1, #7, #9, #11, and #12).

$$T_\mathrm{L} = \left[\frac{A_\mathrm{F} Y_\mathrm{B}}{-8.650 + 15.141 B_\mathrm{T} + 2.836 S_\mathrm{P}} \right]^{1.381} \quad (R^2 = 0.98) \tag{3}$$

where, T_L = bale collection operation time (h) and S_P = equipment operation speed (km/h).

3.5.6. *Total fuel consumption*

The fuel (diesel) consumption (gallons) is estimated using the multivariate prediction model developed [7] with the input values field area, bales/trip, biomass yield, and equipment speed (Table 1, #7, #9, #11, and #12). Different prediction models based on standard fuel consumption methods (ASABE Standards [20] and fuel efficiency [21]) were used to estimate the fuel consumption of the equipment tractor and ABP. These methods estimated fuel consumption based on the horse power of the engine and bale load.

$$\text{Tractor (1 to 2 bales):} \qquad Q_{\mathrm{F}} = \left[\frac{A_{\mathrm{F}} Y_{\mathrm{B}}}{-1.155 + 2.548 B_{\mathrm{T}} + 0.544 S_{\mathrm{P}}}\right]^{1.414} \qquad (R^2 = 0.98) \tag{4}$$

$$\text{ABP (8 to 23 bales):} \qquad Q_{\mathrm{F}} = \left[\frac{A_{\mathrm{F}} Y_{\mathrm{B}}}{-0.782 + 0.184 B_{\mathrm{T}} + 0.759 S_{\mathrm{P}}}\right]^{1.243} \qquad (R^2 = 0.98) \tag{5}$$

where, Q_{F} is the fuel quantity (L) consumed during bale collection operation.

3.5.7. *Total bale revenue*

Total bale revenue ($) is based on the input values, crop type and price per bale (Table 1, #1 and #13), and the number of bales generated (Eq. 1). In North Dakota, it is observed that the forage crop Alfalfa has the highest price per bale while the grain bales has the least; however this may vary with other locations.

3.5.8. *Crop input cost*

Crop input cost is the sum of total seed cost, fertilizer cost, and chemical cost.

$$\mathrm{CIC}\ (\$) = \mathrm{TSC} + \mathrm{TFRC} + \mathrm{TCC} \tag{6}$$

where, CIC = crop input cost ($), TSC = total seed cost ($), TFRC = total fertilizer cost ($), and TCC = total chemical cost ($). Total seed, fertilizer, and chemical cost is estimated based on the inputs, field area unit (ac), number of units, and seed, fertilizer, and chemical cost ($/ac), respectively (Table 1, #9, #10, #15, #16, and #17).

3.5.9. *Total production cost*

Total production cost is the sum of crop input cost (Eq. 6), harvest, and baling cost.

$$\text{TPC (\$)} = \text{CIC} + \text{THC} + \text{TBC} \tag{7}$$

where, TPC = total production cost ($), THC = total harvest cost ($), and TBC = total baling cost ($). Total harvest and baling cost are estimated using harvest cost ($/ac), baling cost ($/ac), field area unit, and number of field units (Table 1, #9, #10, #18, #19).

3.5.10. *Total fixed cost*

Total fixed cost ($) is the sum of total depreciation, taxing, housing, and insurance, interest cost, and total field area rent and is estimated using the inputs, machine cost, interest rate, field area, and field area rent (Table 1, #5, #6, #9, #10).

$$\text{TFC (\$)} = \text{D} + \text{THI} + \text{I} + \text{TFAR} \tag{8}$$

where, TFC = Total fixed cost ($), D = total depreciation cost ($), THI = total taxing, housing, and insurance cost ($), I = total interest cost ($), and TFAR = total field area rent($).

Depreciation (D)

The average annual depreciation cost expressed in US Dollars ($) is calculated based on the machine cost, salvage value, and useful life of the machine [22].

$$\text{Average annual depreciation cost} = \frac{\text{Machine cost} - \text{Salvage value}}{\text{Useful life of machine (years)}} \tag{9}$$

Salvage value ($) is the value of the machine at disposal and can be calculated as the percent of the machine cost. The salvage percent value for three different range of machine engine (30–79 hp, 80–149 hp, and > 150 hp) and annual usage hours (200, 400, and 600 h) is presented as a table in a study conducted by the Iowa State University, extension and outreach

[23]. The following second order polynomial models with a good fit ($R^2 > 0.99$) were developed using the data provided in the study by the Iowa State University for determining the salvage value percentage using the inputs engine capacity (hp), annual usage (h), and machine age (years).

30–79 hp

$$200\,\text{h:} \quad V_S = 0.09(A_M)^2 - 3.88(A_M) + 66.03 \quad (R^2 = 0.99)$$

$$400\,\text{h:} \quad V_S = 0.09(A_M)^2 - 3.76(A_M) + 60.73 \quad (R^2 = 0.99)$$

$$600\,\text{h:} \quad V_S = 0.09(A_M)^2 - 3.61(A_M) + 56.86 \quad (R^2 = 0.99)$$

80–149 hp

$$200\,\text{h:} \quad V_S = 0.10(A_M)^2 - 4.23(A_M) + 69.89 \quad (R^2 = 0.99)$$

$$400\,\text{h:} \quad V_S = 0.10(A_M)^2 - 4.25(A_M) + 69.45 \quad (R^2 = 0.99)$$

$$600\,\text{h:} \quad V_S = 0.10(A_M)^2 - 4.23(A_M) + 68.89 \quad (R^2 = 0.99)$$

$>$150 hp

$$200\,\text{h:} \quad V_S = 0.12(A_M)^2 - 4.95(A_M) + 70.17 \quad (R^2 = 0.99)$$

$$400\,\text{h:} \quad V_S = 0.12(A_M)^2 - 4.87(A_M) + 68.23 \quad (R^2 = 0.99)$$

$$600\,\text{h:} \quad V_S = 0.12(A_M)^2 - 4.79(A_M) + 66.81 \quad (R^2 = 0.99)$$

where, V_S is the salvage value percentage (%) and A_M is the machine age in years (1–15 years).

$$\text{Salvage value (\$)} = V_S \times \text{Machine cost} \tag{10}$$

The useful life of machine in years is calculated using the hours of use until wear-out and the annual usage (h). The hours of use until wear-out is assumed to be 10,000 and the assumption is based on the probability that the machine will be obsolete after 10,000 hours.

$$\text{Useful life of machine (years)} = \frac{10{,}000}{\text{Annual usage}} \tag{11}$$

Substituting Eq. 10 and Eq. 11 in Eq. 9 determines the average annual depreciation cost.

$$\text{Depreciation hourly cost (\$/h)} = \frac{\text{Average annual depreciation cost}}{\text{Annual usage}} \tag{12}$$

$$\begin{aligned}\text{Total depreciation cost (\$)} = \text{Depreciation hourly cost} \times \\ \text{Total operation time}\end{aligned} \tag{13}$$

Hourly depreciation cost (\$/h) is determined using average annual depreciation cost (\$) and annual usage (h) (Eq. 12). Total depreciation cost is determined using hourly depreciation cost (\$/h) and total operational time (h) (Eq. 13) .

Taxing, Housing, and Insurance (THI)

The annual property tax, housing, and insurance (THI) cost determined by multiplying the THI percentage fixed for the specific type of machine by the average investment in the machine. The average investment is the average value of machine cost and salvage value (Eq. 14). The total Taxing (0.0%), Housing (1.0%), and Insurance (0.33%) percentage is considered as 1.33% for tractor [22].

$$\text{Average annual THI cost} = \frac{\text{Machine cost} + \text{Salvage value}}{2} \times 1.33\% \tag{14}$$

$$\text{THI hourly cost (\$/h)} = \frac{\text{Average annual THI cost}}{\text{Annual usage}} \tag{15}$$

$$\text{Total THI cost (\$)} = \text{THI hourly cost} \times \text{Total operation time} \tag{16}$$

THI hourly cost (\$/h) is determined using average annual THI cost (\$) and annual usage (h) (Eq. 15). Total depreciation cost is determined using hourly THI cost (\$/h) and total operational time (h) (Eq. 16) .

Interest (I)

The machine when purchased using loan, the interest rate is charged against the average value of the machine cost and salvage value. This amount is the money paid to the lender as interest payments for the borrowed capital [22]. The interest rate is fed by the user into the calculator (Table 1, #6).

$$\text{Average annual interest cost} = \frac{\text{Machine cost} + \text{Salvage value}}{2} \times \text{Interest rate\%} \tag{17}$$

$$\text{Interest hourly cost (\$/h)} = \frac{\text{Average annual interest cost}}{\text{Annual usage}} \tag{18}$$

$$\text{Total interest cost (\$)} = \text{Interest hourly cost} \times \text{Total operation time} \tag{19}$$

Interest hourly cost (\$/h) is determined using average annual interest cost (\$) and annual usage (h) (Eq. 18). Total interest cost is determined using hourly interest cost (\$/h) and total operational time (h) (Eq. 19) .

Total field area rent (TFAR)

Total field area rent cost is the product of field area unit, number of field units, and field area rent per acre, (Table 1, #9, #10, #14).

Substituting equations, Eq. 14, Eq. 17, and Eq. 20 along with total field area rent in Eq. 9 determines the total fixed cost.

3.5.11. Total variable cost

Total variable cost is the sum of total repair and maintenance, total fuel, total labor cost, and total bale transportation cost. Inputs used to estimate the total variable cost are machine age, fuel cost, labor cost, bale transportation distance, bale transportation cost (Table 1, #20, #21, #22, #23, and #24) and operation time (Eq. 3) .

$$\text{TVC (\$)} = \text{RMC} + \text{TFC} + \text{TLC} + \text{TBTC} \tag{20}$$

where, TVC = total variable cost ($), RMC = total repair and maintenance cost ($), FC = fuel cost ($), LC = labor cost ($), and TBTC = total bale transportation cost ($).

Repair and maintenance (RMC)

The accurate predictions of repair and maintenance cost ($) is difficult since the repair cost of the machine depends on the other external factors such as purpose of use, terrain, soil, etc. The annual repair and maintenance cost can be determined using the machine cost ($), total accumulated repair (TAR), machine age (years), and annual usage (h).

$$\text{Average annual RMC} = \text{Machine cost} \times \frac{\text{TAR}}{\text{Machine age}} \tag{21}$$

A series of varying total accumulated repairs (TAR) equations based on the type of equipment has been developed by University of Idaho, Washington State University, and Oregon State University [24]. The TAR equation for 4-wheel drive tractor is as follows:

$$\text{Total accumulated repairs} = 0.003 \times \left(\frac{\text{Annual usage} \times \text{Machine age}}{1000}\right)^{2.0} \tag{22}$$

Substituting Eq. 22 in Eq. 21 estimates the annual repair and maintenance cost.

$$\text{RMC hourly (\$/h)} = \frac{\text{Average annual RMC}}{\text{Annual usage}} \tag{23}$$

$$\text{Total RMC (\$)} = \text{RMC hourly cost} \times \text{Total operation time} \tag{24}$$

RMC hourly (US Dollars, $/h) is determined using average annual RMC($) and annual usage (h) (Eq. 23). Total RMC cost is determined using hourly RMC ($/h) and total operational time (h) (Eq. 24).

Total fuel cost (TFC)

Total fuel cost ($) is calculated as a product of input fuel cost per gallon (Table 1, #20) and the calculated fuel consumption (Eqs. 4 and 5).

Total labor cost (TLC)

Total labor cost ($) is the product of number of labors, labor cost per hour (Table 1, #21 and #22) and the estimated operation time (Eq. 3).

Total bale transportation cost (TBTC)

Total cost for transporting the bales from the field to a storage unit is estimated as a product of the following inputs, bale transportation cost per unit mile and distance (Table 1, #23 and #24).

Substituting equation Eq. 24 along with total fuel cost, total labor cost, and total bale transportation cost in Eq. 20 determines the total variable cost.

3.5.12. Total cost

Total cost is the sum of total production (Eq. 7), total fixed (Eq. 8), and total variable costs (Eq. 20).

$$\text{TC (\$)} = \text{TPC} + \text{TFC} + \text{TVC} \tag{25}$$

where, TC = total cost ($).

3.5.13. Net return

Net return refers to the income from an investment after all the costs are deducted. The net return can be calculated using the total bale revenue (Section 3.5.7) and the total cost (Eq. 25).

$$\text{Net return (\$)} = \text{Total bale revenue} - \text{Total cost} \tag{26}$$

A net return value greater than zero indicates profit and lesser than zero indicates loss.

3.5.14. Break even ratio

Break even ratio is the ratio of total bale revenue (Section 3.5.7) to total cost (Eq. 26).

$$\text{Break even ratio} = \frac{\text{Total bale revenue}}{\text{Total cost}} \tag{27}$$

Break even ratio value greater than 1 indicates profit and value less than 1 indicates loss.

3.5.15. Payback period

Payback period is the length of time required to recover the initial investment (machine price) through profit. The payback period is estimated in cycles, a year can have one or many cycles depending on the frequency of forage crop harvest and bale aggregation.

$$\text{Payback period (cycles)} = \frac{\text{Machine cost}}{\text{Net return (profit)}} \tag{28}$$

The payback period is only calculated if the outcome of net return is profit.

3.5.16. Return on investment

Return on investment (ROI) is expressed as a percentage and is the ratio of profit to the machine cost (Eq. 29).

$$\text{Return on investment (\%)} = \frac{\text{Net return (profit)}}{\text{Machine cost}} \times 100 \tag{29}$$

The return on investment is calculated only if the outcome of net return is profit.

4. Case study and scenario analysis

A case study was carried out to demonstrate the functionality and applicability of the forage economics calculator web tool on a real field scenario. A local farmer was contacted to apply real-field input values and compare the estimated results with their existing records. The farm (80 ac) is located at 4 miles West of Mandan, North Dakota, where the perennial alfalfa forage crop was produced. The tool was temporarily hosted on a local server on developers' machine for the farmer. Input values for field parameters, bale collection operation, and crop input cost were fed into the calculator by the farmer using the user-friendly input options. Some of the default input options were left as such while others were appropriately modified by the farmer according to their field and operation data, discussed subsequently. Selected inputs and the generated results are presented in Table 3.

4.1. Case study inputs

The inputs were fed to the calculator using drop-down options, sliders, and editable input boxes. The case study focused on estimating the economics of the Alfalfa, a perennial forage crop, in a field area of 80 ac. The calculator estimated the cost for collecting the bales using a tractor with 2 bales/trip capacity. The annualized seed cost was fixed at \$25/ac, while the fertilizer and chemical cost was set at the minimum (0\$). Harvest and baling costs are provided as direct inputs. Other costs include machinery, field rent, fuel, and labor.

The calculator by default performs sensitivity and "no-cost" scenario analysis. Additionally, an automatic bale picker scenario analysis was conducted with 8 bales/trip was considered to compare bale collection with the conventional tractor using 2 bales/trip, while other inputs remained the same. Changing the bales/trip input from 2 to 8 alone affects bale collection logistics distance, fuel consumption, operation time, and net return.

4.2. Case study results

Non-linear regression models and economic equations were used to estimate the field operation and economic analysis result values. Various economic analysis results include net return, break-even ratio, payback period, and return on investment. The estimated results for the inputs values fed are represented in the results panel and through data visualization (Fig. 3). The calculator evaluated the net return for the inputs at \$ 8,271 and the return per acre at \$103 which corroborated with the existing farmer's field data.

Sensitivity analysis for the fed user-inputs exhibited that in the event of harvest or baling cost is greater than \$120 or \$115, the farmer would incur a loss at net return. The result

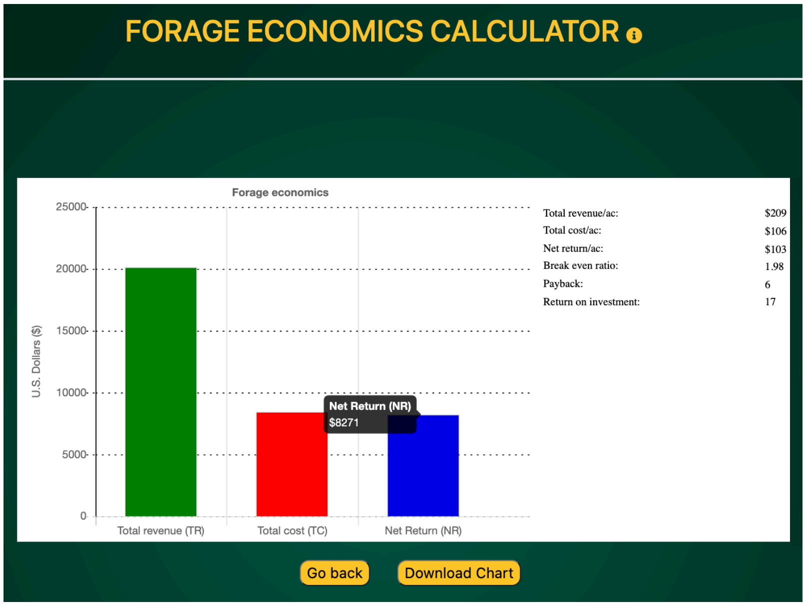

Fig. 3. Downloadable graphical visualization chart comparing total revenue, total cost, and net return. Other prominent economics outputs are presented in text.

values of "no-cost" scenario analysis revealed that the net return increased by 44 %, payback period decreased by 2 cycles, and the return on investment increased by 6 % when field area rent, fertilizer, chemical, and labor costs are zero.

Results of ABP scenario analysis indicated that the total logistics distance for bale collection decreased by 4.6 times and the operation time decreased by 82 % using 8 bales/trip in comparison to the traditional 2 bales/trip. Since total labor cost is based on the operation time, a considerable reduction in cost by using ABP was observed as well. However, fuel consumption of carrying 8 bales/trip decreased by 5 % when compared to 2 bales/trip since the fuel consumption is proportional to the bale load. Therefore, the net return increased only by 0.2 % by using ABP instead of traditional tractor.

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Table 3
Real field case study and scenario analyis using forage economics calculator

Inputs		Results	
Parameter	Value	Parameter	Value (2 bal
Crop type	Alfalfa (Perennial, 5 years)	Equipment	Tractor
Engine power (hp)	80–149	Total field area (ac)	80
Machine age owned (years)	10	Total number of bales (bales)	223
Annual usage (h)	200	Total logistics distance (miles)	2.99
Machine cost ($)	50,000	Total operation time (h)	0.78
Interest rate (%)	5	Total fuel consumption (gal)	2.30
Forage yield (lb/ac)	5,000	Total bale revenue ($)	20,150
Bale mass (lb)	1,500	Total bale transportation cost ($)	15
Field area unit (ac)	80	Total fuel cost ($)	4.6
Number of field units (#)	1	Total labor cost ($)	11.7
Bales/trip	2 and 8	Total production cost ($)	5,600
Machine speed (mph)	5	Total fixed cost ($)	2,822
Bale sale price ($/bale)	75	Total variable cost ($)	32
Field rent ($/ac)	35	Total cost ($)	8,454
Seed cost ($/ac)	25	Net return ($)	8,271
Fertilizer cost ($/ac)	0	Total revenue per acre ($/ac)	209
Chemicial cost ($/ac)	10	Total cost per acre ($/ac)	106
Harvest cost ($/ac)	20	Net return per acre ($/ac)	103
Baling cost ($/ac)	15	Break even ratio	1.98
Fuel cost ($/gal)	2	Payback period (cycles)	6
Number of labors	1	Return on investment (%)	17
Labor cost ($/h)	2	No-cost scenario net return ($)	11,909
Bale transportation cost ($/mile)	3	No-cost scenario payback (cycles)	4
Bale transportation distance (miles)	5	No-cost scenario return on investment (%)	24

hp - horsepower, h - hours, lb - pounds, ac - acre, $ - US Dollars, mph - miles per hour, gal - gallons.

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