Cost estimation of crop residue burning machine

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Abstract: The purpose of this study was to determine the cost of crop residue burning machine application based on several factors affecting its cost. Additionally, the cost was compared to the cost of prescribe burning practice. The total cost was determined by calculating fixed and variables costs. Those costs were computed mostly based on equations on ASAE EP496.2 DEC99 and ASAE D497.7 MAR2011(R2015). A Microsoft Windows® application was developed to systematically estimate the cost of the developed burning machine and to provide an additional tool for management decisions. Using the assumption of a-5 feet working width of the burning machine, the machine field efficiency of 60%, the travel speed of 1.9 mph, and a-20 acre of burn unit the total cost of burning practice using the developed burning machine was $164.78 which is comparable to prescribed burning cost on 134 acres of the burn unit. The important factor affecting the cost of the machine operation was the construction of firebreak and the acreage of machine use.

1. Introduction
Fire has been used for land management tool. In Agriculture, fire is set to remove post-harvest crop residues i.e., stubbles and straws, and weeds before the next planting season. Farmers would opt to burn when there was insufficient time to do a soil tillage because of late harvest. Incorporating the residue would not be an option because the freezing soil temperature will not allow the residue to decompose leading to difficulty in soil tillage. The whole process in the farm would be delayed which has an adverse effect for the next season’s crop.

The use of fire for crop residue management has been a long-standing topic of considerable debate whether it is beneficial in improving yield. Scientists have been comparing straw retention and straw burning in terms of improving soil properties. Some studies in three different continents...
show an advantageous effect of straw retention soil quality, soil organic matter and carbon storage, soil moisture retention, and enhanced nutrient cycling. However, the benefit of straw retention is vary depending on agroclimatic and socioeconomic factors [1]. Burning straw has shown a higher grain yield of winter durum wheat compared to straw retention. It is likely due to a higher N mineralization after the burning [2]. A similar study demonstrated for twenty years, straw burning did not result in a substantial reduction in grain yield, even though it elevated soil organic carbon losses [2].

In North America, fire is used for prescribed burning. Prescribed burning is one of fuel management tools to reduce the fuel build ups and suppress the risk of wildfires [3], [4]. Prescribe burning is the application of fire to forest fuels under the specific condition to attain expected management goals. Prescribed burning is conducted based on a burn plan. A burn plan is a safety measure as a guideline in performing burning activity. It describes burning weather condition, the fuel characteristics in term of quantity and quality, the number of people conducting the burn activity and the risk of the burn [5].

Fire has been used to control weeds on rangelands. A frequent fire reintroduction has been conducted to control woody plant species that are invading rangelands throughout the United States. This practice has shown the most effective method to control invasive, nonsprouting native juniper. This juniper causes a drastic decline in forage production, which in turn affects carrying capacity, stocking rate and livestock performance [6].

Fire exclusion in Ponderosa pine forests throughout the southwestern US has become dense with young trees, where the implementation of prescribed burning is difficult to carry out. Additionally, the exclusion contributes to uncharacteristically intense wildfires [7]. The effect of prescribed burning on stream and riparian vegetation shows a significant reduction in the burned vegetation [4]. The effect of fire on vegetation and soil properties depends on fire severity. Fire severity consists of two components: intensity and duration [8]. Severe fires, such as wildfires, can cause the removal of soil organic matter, loss of nutrients, leaching and erosion, structure, and porosity degradation [9]. Light to moderate fire temperatures have shown to be beneficial in increasing soil nutrients i.e. NO$_3$-N, NH$_4$-N, P, Ca, Mg, Na, and K, without significant difference in soil runoff and erosion [10]. In terms of promoting biodiversity, fire-based wildland management was compared to organic farming where both practices increase total organism abundance and evenness [11].

The cost of prescribed burning is relatively low, ranging from $10 to $15 per acre. However, it has a minimum charge of $300 per burn. Additionally, the minimum charge per contract is ranging from $300 to $250. For this amount, the tractor hours and hauling unit miles are not included. The actual tach hour would vary from $72 to $116; it depends on the tractor type [12], [13]. A small-scale burn that less than 30 acres would be costly since a typical prescribed fire requires a minimum charge per contract. A prototype machine for crop residues burning was developed and it is expected to use for a small-scale burn. The cost estimation of small-scale crop residue burn is important for producers to make decisions whether it is economically viable owning and operating this special machine. It is crucial to perform a thorough evaluation on field machinery cost on a whole-farm basis especially when more than one option available in a farm to do a certain production process to improve efficiency.

The objectives of this paper were to determine the cost of crop residue burning machine application based on several factors affecting its cost. Those factors were then used to develop software for estimating the machine cost. Additionally, the cost was compared to the cost of prescribe burning practice.

2. Methods

The machine cost is categorized into two categories: ownership cost (fixed cost) and operating cost (variable cost). Fixed costs include depreciation, interest (opportunity cost), taxes, insurance, and maintenance facilities [14]. The assumption of the economic life of the machine and salvage
value is needed for annual depreciation calculation. Salvage value and total depreciation was calculated equation (1) and (2) [14], [15].

\[ D = P_p - S_v \]  \hspace{1cm} (1)
\[ S_v = L_p R_v \]  \hspace{1cm} (2)

Where:
- \( D \) : total depreciation, $
- \( P_p \) : purchase price, $
- \( L_p \) : current price list, $
- \( R_v \) : remaining value factor,
- \( S_v \) : salvage value, $.

The current price list, which is used to determine the salvage value, is assumed that a new machine is purchased at a discount from purchase price [16].

\[ L_p = \frac{P_p}{0.9} \]  \hspace{1cm} (3)

Where
- \( L_p \) : list price, $
- \( P_p \) : purchase price for a new machine, $
- 0.9 \) : discount factor for a new machine.

Remaining value was determined using a table for “other machine” as reported in Table 1.

**Table 1. Remaining salvage value as a percent of new list price** [14].

| Machine Age (Year) | Remaining Value (%) | Machine Age (Year) | Remaining Value (%) |
|--------------------|---------------------|--------------------|---------------------|
| 1                  | 69                  | 11                 | 33                  |
| 2                  | 62                  | 12                 | 31                  |
| 3                  | 56                  | 13                 | 29                  |
| 4                  | 52                  | 14                 | 28                  |
| 5                  | 48                  | 15                 | 26                  |
| 6                  | 45                  | 16                 | 25                  |
| 7                  | 42                  | 17                 | 24                  |
| 8                  | 40                  | 18                 | 22                  |
| 9                  | 37                  | 19                 | 21                  |
| 10                 | 35                  | 20                 | 20                  |

The joint cost of depreciation and interest was calculated by using a capital recovery factor (R). A capital recovery was calculated using equation (4) [15], [17].

\[ R = \left\{ D x \left[ \frac{i}{a} x (1 + \frac{i}{a})^n \right] \right\} + \frac{S_n}{a} \]  \hspace{1cm} (4)
Where:

- \( R \): one of series of equal payments due at the end of each compounding period, $
- \( D \): Total depreciation, $
- \( i \): interest rate as compounded \( q \) times per year, decimal
- \( S_v \): salvage value, $
- \( n \): life of the investment in year.

The ASAE standard EP496.2 provides the estimated value of taxes, insurance, and housing (TIH) as percentages of the purchase price. To simplify the calculation, the TIH was calculated as 2% of the purchase price. Another approach to estimate fixed cost is to combine salvage value factor, machine life, interest rate, and TIH cost into an annual fixed cost percentage as shown in equation (5). The fixed annual cost was determined by multiplying the purchase price of the machine by this equation (5) [15], [17].

\[
C_0 = 100 \left[ \frac{1-S_v}{L} + \frac{1+S_v}{2} i + K_2 \right] \tag{5}
\]

Where,

- \( C_o \): fixed cost percentage, in %
- \( S_vf \): salvage value factor, in % (percent of salvage value compared to purchase price)
- \( L \): machine life, in year
- \( K_2 \): fixed cost for taxes, housing, and insurance, in decimal

Variable costs should be taken into consideration when machine is operated. Repair and maintenance costs depend on hours of annual use and length of ownership. Annual hours of use were determined by dividing the total acres of operation with effective field capacity (\( C_a \)). \( C_a \) was calculated using (6) [15], [17].

\[
C_a = \frac{swE_f}{825} \tag{6}
\]

Where,

- \( s \): field speed, mile/h
- \( w \): working width, ft
- \( E_f \): field efficiency, decimal.

The accumulated repair and maintenance cost was estimated using equation (7) that based on ASAE standard EP496.2 [15], [17]

\[
C_{rm} = RF1)P_{p-inf}[\frac{h}{1000}]^{RF2} \tag{7}
\]

Where,

- \( C_{rm} \): Accumulated repair and maintenance cost, $
- \( P_{p-inf} \): Adjusted purchase price for inflation, $
- \( h \): accumulated use of the machine, hour
- \( RF1, RF2 \): repair, and maintenance factors. These factors can be found in ASAE standard D497.7 clause 5 [18].

The price of the machine was corrected for inflation as shown in equation (8) was used [15].
\[ P_{p-inf} = P_p (1 + inf)^n \] (8)

Where,

- \( P_p \): purchase price, $ 
- \( inf \): inflation, decimal 
- \( n \): machine life, year

Fuel cost was determined by operation time (h) and the size of the tractor or power unit. Hourly fuel consumption was determined by multiplying the tractor PTO by a constant (m) that provided value in gallon per hour. The value was 0.06 for gasoline engines and 0.044 for diesel engines. The annual fuel cost ($/year) was calculated using equation (9) [14]. This annual fuel cost was also including the annual fuel cost for burning operation.

\[ Fuel Cost = Gas Consumption \times Gas Price \times h \] (9)

The total cost to have and to operate the machine is the total fixed cost per hour and variable cost per hour.

A Microsoft Windows® application was developed to systematically estimate the cost of the developed burning machine and to provide an additional tool for management decisions. This application was built using Microsoft Visual Studio® 2017. The software has the capability to develop a Windows-based application with a relatively user-friendly programming environment.

3. Results and discussion

Figure 1 and Figure 2 illustrate the application layout that consists of two parts, fixed cost, and variable cost. Each part has two columns, the first column is for data entry and the second column is the calculated results. The calculation of fixed and variable costs was created as a “command button calculate” with an “event click”. This event activates hardware such as keyboard and mouse to execute the cost calculation. As soon as the user inputs the required variables and hit the calculate button, the value of fix and variable costs appears. The example of the application coding is displayed in Figure 3.

Figure 1. Windows app layout for determining fixed cost for the developed burning machine.
Figure 2. Window app for determining variable cost and total annual cost for the developed burning machine ($/year).

Figure 3. The screenshot of command button calculate and event click in Windows-based application to calculate machine cost

For the fixed cost, the purchase price was obtained by using the purchase price of Red Dragon® vegetable and bed flamer that was produced by Flame Engineering Inc. This bed flamer is used for burning down/pre-emerged treatment. The price of a 5 ft working width of the bed flamer is $3700. Discount factor value, which is used to calculate the machine current price list, was set to 0.9 as the
default value. User has the flexibility to change this factor value. The economic life was obtained based on the economic life of the mounted flaming machine which is 8 years[19]. The economic life value was designed as a dropdown menu. Each option of the economic life is assigned to a certain remaining salvage value as shown in Table 1. The annual inflation rate for the United State for 2019 was 1.7% and the interest rate for operating loans in Oklahoma based on Farm Service Agency USDA is 2.625% [20].

The annual fixed cost was calculated based on two different approaches. The first approach was using capital recovery as shown in equation (4) and the second approach was using the ownership cost percentage in equation (5). Figure 4 reports the first approach gave a higher ownership cost, which is $561.21 compared to the second approach ($401.09). It is because the extra $160.12 for the first approach is assumed to be set aside each year to just repay the value lost due to depreciation and pay interest costs. In other words, the first approach takes into consideration the annual cost of ownership and the time value of money. While the second approach is a simple estimate of the total annual ownership cost by multiplying the purchase price of the machine by the ownership cost percentage [18].

![Figure 4. The machine’s fixed cost calculation scenario.](image)

The estimation of the variable cost was based on the developed burning machine mounted behind the tractor. The tractor for the burning operation was assumed to be rented. Based on Oklahoma Farm and Ranch custom rates in 2017-2018, the tractor rent cost was categorized into two categories based on its rated power, less than 100 hp, and 100-150 hp [21]. The rent cost was set to $31.71 and $32.16 as default for tractor power less than 100 hp and 100-150 hp, respectively. The rent cost can also be entered manually. The determination of fuel consumption was divided into two groups. The first was fuel consumption for the tractor (gasoline or diesel) and the second was fuel consumption for machine burning (LPG). The fuel consumption data was obtained during the experiment. The average fuel consumption was 0.7 Gal/hour with working pressure and width 20 PSI and 25”, respectively. If the prototype machine was manufactured with a working width of 5 ft, the fuel consumption would be approximately 1.75 Gal/hour.

The cost of site preparation for fireguards varies depends mostly on the topographical region. The average cost for site preparation for burning purposes is $36.51/acre [22]. In most cases, the greatest direct cost of prescribed burning is preparing a firebreak around the perimeter of the burn unit.
Often, firebreak preparation is a one-time cost and can be maintained indefinitely to keep the long-term cost down [23].

For a small farm, the site preparation for firebreak construction was assumed to be $0. The $0 cost assumption was based on the assumption that for firebreak fixed costs are prohibitive for a small farm. Besides, the firebreak would take up a larger percentage of the small farm’s acreage; thereby taking away too much productive ground. Therefore, the burning practices using the developed burning machine would need more labor to patrol the perimeter and spend less on constructing the firebreak. The backing fire techniques would need to implement first before conducting the actual burning practices to reduce the fuel along the burn unit perimeter and contain the fire within the boundary of the burning.

The total annual cost for the burning machine ($/year) is shown on the same window as the variable cost. The two values of the total annual costs because of the two different methods in calculating the machine fixed cost as previously described (Figure 5).

Based on the survey from 1985 to 1994 of the USDA Forest Service’s National Forests System, the average cost for all type of prescribed burning were $101.48 per acre with 134 acres of average burn size. The unit size is the crucial factor to be used in calculating per-acre costs, where larger units have smaller costs. This cost included site preparation, ignition, and maintenance, mop-up, post-fire monitoring, contractor costs. Considering the inflation and consumer price index, the value of $101.48 in 2019 is $175.82.

Using the assumption of a 5 feet working width of the burning machine, the machine field efficiency of 60%, the travel speed of 1.9 mph, and a 20 acre of the burn unit, the total cost of burning practice using the developed burning machine was comparable to prescribed burning cost on 134 acres of the burn unit.

Figure 5. The machine’s variable cost calculation scenario.

Figure 6 illustrates the effect of burn acreage changes on the machinery cost. More acres of use lower per acre costs as depreciation and interest costs are spread over more acre. However, it might also mean that there would be some issues getting the burning practices done in a timely manner if a 5-ft working width of the machine were used to burn large size farm. In general, the increase in machinery size would lower the machinery cost. However, Figure 6 shows A 15-ft working width of the machine has the highest total cost, while the 10 ft working width has the lowest total cost. It is
because of the assumptions of the purchase price for different working width was not the same. It was assumed the purchase prices for a 10-ft and 15-ft working width were $5,200 and $7,700, respectively. This assumption was based on the purchase price of the vegetable and bed flaming machine with the same working width.

Field efficiency (FE) considers failure to utilize the full operating width of the machine and many other interruptions such as turning, waiting, etc. Effective field capacity (EFC) is one of several factors affecting the FE values. Figure 7 illustrates the increase in EF’s effect on the machine total cost. As the EF increases, the annual hour of use decreases which in turn would lower the total cost.

![Figure 6. The effect of increasing more acres of use and the machine size on machine cost](image)

![Figure 7. The effect of increasing field efficiency on machine total cost.](image)

4. Conclusions

Employing the developed Windows® based application to determine the cost of the burning activity and using the assumption of a 5 feet working width of the burning machine, the machine field efficiency of 60%, the travel speed of 1.9 mph, and a 20 acre of the burn unit, the total cost of burning practice using the developed burning machine was $164.78. This amount of cost is comparable to the prescribed burning cost on 134 acres of the burn unit.

The most significant factor that affects the cost of the machine burning was the preparation of the fireguard. The fireguard for the machine burning application was seen as unnecessary because the fireguard construction would take up a larger percentage of the small farm’s acreage.

More acres of use lower per acre costs as depreciation and interest costs are spread over more acre. However, it might also mean that there would be some issues getting the burning practices
done in a timely manner if a 5-ft working width of the machine was used to burn large-sized farms.

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