Costs of Using Unmanned Aircraft on Crop Farms

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ABSTRACT

Excitement is high about the potential uses of unmanned aerial systems (UAS) in agriculture. We budgeted the costs of high-yield, non-irrigated corn production on two fields on a "representative" farm located in Northeastern Kansas. One complete pass over each field was completed. The representative farm will use a manned aerial system (MAS) or UAS and visual inspection and soil/tissue tests to determine whether and where a nitrogen deficiency is occurring. Our analysis suggests that UAS is less costly than MAS. The authors expect the costs of UAS and MAS to decrease in the future.

Introduction

Excitement is high in the agricultural community about the potential uses of unmanned aerial systems (UAS) in agriculture. UAS are one of the latest tools in the precision farmer's toolbox and farmers are eager to use them along with their other precision farming tools such as autosteer tractors, variable rate planters, and yield mappers.





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In spring 2014, the Applied Aviation Research Center at Kansas State University Polytechnic (at Salina, KS) had 35 students pursuing UAS degrees (Balthazor 2015).[1] The applications for UAS being discussed include a wide range of farm activities.

The purpose of this paper is to compare the costs resulting from using a UAS and a manned aerial system (MAS) for a crop survey of non-irrigated corn. (The acronyms UAS and MAS may be used for unmanned aerial or aircraft systems and manned aerial or aircraft systems. In this paper, for these two acronyms, the "A" may represent either aerial or aircraft.) We assume the farmer is using precision agriculture. At least one author questions whether precision agriculture will be as popular in the next decade (with lower commodity prices as several economists seem to be predicting) as it has been in the past. If this occurs, then precision agriculture will again become popular whenever commodity prices increase enough. In order to compare the costs associated with a similar farm situation, we investigate what the costs would be for a MAS and a UAS on a "representative" farm located in northeastern Kansas.

Regulations Regarding UAS

Recognizing the increasing demand for commercial use of UAS, Congress passed the Federal Aviation Administration (FAA) Modernization and Reform Act of 2012. Contained within was Public Law 112-95 (P.L. 112-95) which "mandated the safe and expedient integration of UAS" into the National Airspace System (NAS) and the establishment of rules for the use of small UAS. While the rules were being proposed and debated, the Secretary of Transportation was granted authority by Section 333 of P.L. 112-95 to allow certain UAS operations in the NAS by granting certain qualified applicants exemptions from FAA operating rules. In January 2015, the first Section 333 exemption was granted for use in commercial agriculture (Lowy, 2015).

In February 2015, the Federal Aviation Administration (FAA) released the long anticipated "Small UAS Notice of Proposed Rulemaking (NPRM)," a 195-page "proposal [offering] safety rules for small UAS (under 55 pounds) for non-recreational purposes (FAA, 2015b)." The 60-day comment period on this proposal closed on April 24, 2015 (FAA, 2015a). The NPRM and overview (as well as the comments on the small UAS NPRM proposal) can be found at the location cited (FAA, 2015b) in the references (as of Dec. 2015).

There is uncertainty how long it will be until the regulations are law. The FAA has said they want to have the rules finalized by June 2016.[2] Previous forecasts had predicted the rules might not be out until 2016 or 2017 (Morgan and Reuters, 2015). Until the new rules are finalized, it is only legal to use a UAS on one's own land under 400 feet for personal or hobby purposes. For example, it is legal for a gardener to use a UAS on a personal garden to check water conditions. However, a large corn producer cannot use a UAS, without a Section 333 exemption, on a commercial cornfield because it is a for-profit enterprise. To do so could expose the producer to a fine (Turner, 2014). In January 2015, the FAA and a videographer reached a settlement of $1,100 for allegedly operating a drone recklessly while he was filming the University of Virginia in 2011 (Nicas, 2015).

The Association for Unmanned Vehicle Systems published a report in March 2013, making projections about the potential economic benefit of unmanned aircraft systems on the United States economy. The projections included thousands of new, high paying manufacturing jobs, as well as large amounts of tax revenue. It was also predicted that public safety and precision agriculture would constitute most of the potential markets for the use of unmanned aircraft systems (Jenkins and Vasigh, 2013).

Due to the uncertainty surrounding the legal issues over the use of UAS for commercial purposes (as of December 9, 2015), we will not be including any licenses or fees in our budgets in this manuscript. We think it is reasonable to assume the new regulations will include additional fees.

What are UAS?

UAS are small airplanes or helicopters that are radio controlled or operate on autopilot, making them unmanned. The two main types of UAS are fixed-wing and helicopter or multirotor (see Figures 1-3). Figure 1 is a picture of the X-8 fixed wing aircraft. This type is the most suitable to perform crop surveys. The helicopter and multirotor UAS use a lot of battery and can therefore, stay in the air for a short amount of time, making them ill-suited for most agriculture surveys and better suited for vertical surveys such as power poles or smokestacks. The X-8 UAS is a radio-controlled aircraft outfitted with a camera mount and with an integrated autopilot and ground control station (GCS). The farmer will be able to download free software from the Internet to program a flight plan for the crop survey. Both the MAS and the UAS will use a 34 millimeter (mm) camera. We decided to compare a MAS with a UAS because the images captured by the cameras will be similar in quality and will give users the same type of data to upload to a data processing website.

Before UAS, the most common way these photos were accessed by the farmer was satellite data imagery. However, data from satellite imagery tends to be less accurate than data from UAS.

Normalized Difference Vegetative Index (NDVI)

Figure 4 is an NDVI photograph of the United States from 1990 (USDA 2013). The reddish-brown area has a lower NDVI number and potentially correlated to lower photosynthetic activity. The areas in the green of the spectrum have more photosynthetic activity.

Both MAS and UAS cameras (see Tables 1 and 2 for cost estimates) will be able to convert the pictures to an image using the NDVI spectral imaging when taking the photos of the 500 and 2,000 acre cornfields. NDVI measures greenness, reflected as quantity and health or vigor of plants. The NDVI is sometimes utlized as an indicator of photosynthetic activity. This index is calculated as the ratio of the difference between near infrared (NIR) and red solar light and the sum of the two. This is done using the formula: NDVI = NIR-RED/NIR+RED (Price and Price, 2009), with the values falling between -1.0 and +1.0. High NDVI (closer to 1) means there is high photosynthetic activity. A lower NDVI value (closer to 0) means there is less photosynthetic activity. These pictures are able to tell a farmer where there is an area with lower photosynthetic activity. Lower photosynthetic activity indicates that there is some problem that needs to be addressed to help this crop be more productive. The NDVI picture does not necessarily show what is wrong (or the main causes responsible for the low photosynthetic activity). However, the NDVI picture identifies areas of low photosynthetic activity. The actual problem for crop producers could be pest infestation, nutrient deficiency, soil structure problems, etc. Further testing and visual inspection are required to determine what problem needs to be addressed.

Procedures

The Representative Farm

We budgeted the costs of high-yield, non-irrigated corn production on two fields of land on a "representative" farm located in Northeastern Kansas. We put "representative" in quotes because the farm will represent a current or future farm. Thus, the farm is not an average for the area. The two fields of land are a 500 acre corn field and a 2,000 acre corn field. These budgets will include the costs associated with a crop survey using a manned aerial or aircraft system (MAS) and compare them with the costs associated with an unmanned aerial or aircraft system (UAS) for use in precision agriculture. Using both UAS and MAS, one complete pass over each plot of land will be performed. After the data are analyzed, it is discovered through NDVI spectral imaging that low areas in the two fields exhibit lower photosynthetic activity compared to the rest of the two fields. After visual inspection and soil and tissue sampling, nitrogen (N) deficiency areas are identified as the cause of the low photosynthetic activity. Therefore, our budgets will include the additional costs associated with including an application of late-season N in corn (fromV10-V12).[3] In summary, the representative farm will use visual inspection along with MAS or UAS and soil/tissue tests to determine whether and where a nitrogen deficiency is occurring.

We plan on achieving average yields of 200 bushels per acre on our non-irrigated corn using a high-yielding hybrid corn seed and a seed drop rate of 34,000 seeds per acre. In order to achieve our yield goal of an average of 200 bushels per acre, we will need to apply the N at one pound of N for each bushel of corn yield ("close approximation"). Therefore, we will be applying N at the rate of 200 pounds per acre over the three applications of pre-survey N. For the first N application we will rent an anhydrous nitrogen tank from a local co-op (rental price is included in custom rate for anhydrous application) to apply 82 percent anhydrous-N at the beginning of March, pre-planting, at the rate of 100 pounds of N per acre. At the time of planting in Mid-April, we will perform a second application of N using Urea (46% N) at the rate of 15 pounds of N (elemental N) per acre. We assume that the farmer has access to the required equipment. We will apply a third application of nitrogen, using liquid Urea-Ammonium Nitrate (UAN) source, 28 percent N, at the rate of 85 pounds of N per acre at the V-6 growth stage of corn. The liquid N will be injected directly into the soil (assuming the farmer has this equipment). For other nutrients such as phosphorous (P) and potassium (K), soil testing reflected high levels; thus, application of these nutrients is not required at this point and will not be included in our budget calculations. If nutrients are not limiting, one pound of available N per acre (residual profile-N and applied fertilizer N) are adequate for producing 200 bushels per acre of corn (Ciampitti and Vyn, 2014).

We are assuming the farmer experiences a wet year and some of the nitrogen applied, during the first three N applications, leaches out of the soil or is lost to the atmosphere as a N_2O gas in the low areas of the fields (more saturated areas). Therefore, the farmer decides to purchase the equipment in order to take aerial photographs of the 500-acre and 2,000-acre fields, using MAS or UAS. These passes are done to calculate NDVI that could be potentially used as an estimator of the "photosynthetic activity" throughout the two fields. The information gathered will be used to identify where the low productive areas are. When the areas with low NDVI activity are identified, if there are no other apparent problems, (e.g., pests) then soil and plant tissue testing will be completed to determine whether there is an N deficiency. Costs of soil and plant tissue tests would be the same for MAS and UAS and are therefore not included in our budgets.

The One-Pass over the 500 and 2,000 Acre Cornfields

For our MAS budget (Table 1), the farmer decides to purchase a manned aerial vehicle system (MAS) to complete the pass at the V-10 corn stage. A Cannon 6D digital single-lens reflex (DLSR) camera with near infrared conversion will need to be purchased. The camera is able to provide NDVI spectral images. A camera mount to attach the camera to the underside of the plane will need to be purchased, then it must be installed by a FAA certified Airframe and/or Powerplant mechanic (FAA certified A&P mechanic). After the flight the camera mount can easily be taken off and kept. The pilot will complete one pass over the field; we estimate the 500 acre MAS survey to take approximately 20 minutes to complete the one pass; for the 2,000 acre field, approximately 45 minutes (Balthazor, 2015). (See Table 1 footnote 19 for flight time calculations for the 500 acre corn-field). The farmer then uploads the NDVI data collected to a data processing site to be analyzed. (See the section on data analysis below for further explanation.)

For the budget using UAS (Table 2), the farmer decides to purchase a X-8 fixed-wing UAS, a S100 digital camera (with NDVI integration), and a UAS launcher. The pass will happen at the V-10 corn stage. We estimate the time to complete one pass using the UAS over 500 acres will take approximately 45 minutes and the pass over 2,000 acres will take approximately 173 minutes (Balthazor, 2015). (See Table 2 footnote 19 for flight time calculations for the 500 acre cornfield). The farmer will download onto their home device free software off the internet, which incorporates Google Maps in order to program the route the UAS will fly (i.e., over the 500 and 2,000 acre cornfields). The X-8 Fixed-Wing UAS does not require a launcher (with practice it can be launched by hand). However, in Table 2 the farmer will purchase a launcher for $200 because it makes the process easier.

The Data Analysis

Analyzing the NDVI spectral images takes special knowledge and expertise; therefore in both of the budgets in Tables 1 and 2 the farmer will probably not be doing the data analysis on site. (Most farmers probably do not have the knowledge and expertise.) In this paper, we assume the farmer does not have the special knowledge and expertise to perform the NDVI spectral images analysis. Instead the farmer will upload the NDVI photos taken using the MAS or UAS to an appropriate website. This website will create an NDVI map of the fields using the photos (See Figure 5).

It is, however, possible for the data-analyzing software to be purchased by the farmer if the farmer has expertise for doing this kind of data analysis. The photo processing software used commonly retails for approximately $3,499. This software is able to create not only NDVI images; but several different types of field maps as well. The farmer will also need data management software, which takes raw data collected from several types of precision agriculture tools and processes the data; so that the data may be used in decision making. Such software retails for approximately $500. We are expecting the price of the software to go down in the future.

Because of concerns regarding the sharing of big-data sets, a producer may decide to purchase the data processing software in order to avoid some of the big data issues. If a producer decides to share information with another entity or website, then the producer needs to ensure that farm related big data issues are handled in an acceptable manner.

The data analysis shows that the low points of the 500 and 2,000 acre corn fields (approximately 25% of the acreage) have low NDVI values. A soil test of the low areas and plant tissue testing of corn in the respective areas, that were identified using NDVI analysis, indicates a low availability of N in the soil and a low tissue N concentration in the plant. In order to reach the yield goal of an average of 200 bushels of corn per acre, the soil and tissue tests recommendations are to add an additional 30 pounds of N per acre in the low areas of the field where the soil and tissue samples were taken. For the 500 acre field, we will be topdressing 125 acres (25% * 500); for the 2,000 acre field, we will be top-dressing 500 acres (25% * 2,000). (See Tables 1 and 2).

The Budgets

The costs for non-irrigated high yield corn production used in the budgets in Tables 1 and 2 are based on data from the "Corn Cost-Return Budget in Northeast Kansas" (Ibendahl, O'Brien, Duncan, 2015). The costs of corn production are the same for both MAS and UAS. The costs for purchasing the equipment for the MAS and UAS were provided by the Applied Aviation Research Center at Kansas State University-Salina (Balthazor, 2015). The authors of this paper acknowledge that many of the costs associated with the production of high yield corn and the costs associated with the MAS and UAS are dependent on local and/or regional market conditions and could differ for an individual farmer. Therefore, the costs for the purchase of MAS and UAS equipment are paid in year 1. The authors did not know details necessary for performing an NPV or annual costs analysis. Individual readers (who know their own details, such as their own yield goals, appropriate discount [or interest] rate, years of useful life, and their other uses of MAS or UAS), may use our Tables 1 and 2 as a starting point and substitute appropriate data to prepare budgets that represent their own situation.

In addition, we have not included some important costs that an individual producer might need to consider. Some of these are government payments, crop insurance premiums and interest on capital investments. The crop insurance program is based on average county yield (ACY) and for Northeastern Kansas, the non-irrigated corn county yield averages can vary greatly, county to county, from 125 bushels an acre up to 180 bushels an acre. In some counties in Northeastern Kansas, farmers are already achieving 200 bushels an acre (Hallauer, 2014). However, because the hybrids being used have not been available long enough for farmers to have used them to calculate their own ten-year yield history, when calculating potential insurance premiums farmers will probably need to use the individual counties' ACY.

Results, Conclusions, and Implications

Our results indicate that precision agriculture is costly using UAS on a 500 acre and a 2,000 acre cornfield. For our analysis, we prepared the costs for both budgets (see Tables 1 and 2) using per acre costs. These were based on the data available as of August 13, 2015. Preparing our budgets this way did not consider economies of size associated with corn production or economies of scope associated with multiple uses of UAS or MAS. For example, per acre costs were identical for the 500 and 2,000 acre corn fields. Therefore, use of precision agriculture in larger fields and/or multiple uses of UAS or MAS could be less costly than our study suggests.

Our analysis suggests that UAS is less costly than MAS when only one pass of a field is considered (See Tables 1 and 2) for both the 500-acre and 2000-acre (cornfield size) producer. In our analysis, we attempted to calculate costs based on our expectation of real world situations and we budgeted only one pass over the field. In order to compare the two different aerial systems costs accurately, the producers are purchasing the equipment for both the UAS and MAS. Because we did not know loan terms or years of useful life, we did not use NPV or annual costs analyses. So, in our budgets we assumed that the costs of equipment would be paid in one year. Individual readers (who know their own details, such as their own yield goals, appropriate discount [or interest] rate, years of useful life, and their other uses of MAS or UAS), may use our Tables 1 and 2 as a starting point and substitute appropriate data to prepare budgets that represent their own situation.

In reality, producers will probably complete more than one pass over the field and/or rent some of the equipment (especially for the MAS), which could change per acre cost significantly. If larger fields were considered, then the cost of MAS and UAS would be spread over a larger number of acres. Also, producers who purchase UAS or MAS equipment will probably use the UAS or MAS equipment for other uses in addition to crop production, which is the focus of this paper. Thus, the impact of spreading fixed costs over a larger number of activities could dramatically decrease the fixed costs per acre for either system. However, if the producer owns a plane, but does not have a hanger to store the plane near or on the producer's farm, then this is also a factor which should be considered (adding more complexity to the use of MAS as a farmer than performing the UAS activity).

In an earlier version of this manuscript that involved renting the MAS equipment and purchasing the UAS equipment, the rental of the MAS equipment was more cost effective than purchasing the UAS equipment for one pass over the fields. Therefore, it may be more cost efficient for some corn producers to rent (or own) the MAS equipment than to purchase UAS equipment for use in precision agriculture.

An important variable cost in our budget is the per pound cost of fertilizer Nitrogen. Recent analyses suggest that the price of N may decrease in the future (e.g., Green Markets, 2015).

The authors expect the costs of UAS to decrease in the future because producers of UAS equipment and services are learning more cost effective ways to produce the equipment and services and there will be increasing competition as more UAS producers enter the market. In addition, the authors are hopeful that after the legal environment for UAS is clarified and costs stabilize, because of more extensive use of UAS, future authors might be able to use this manuscript as a starting point, to perform analyses for precision agriculture with MAS and UAS. Not everyone agrees on the usefulness of UAS (e.g., Measure, 2015; Morris, 2015).

End Notes

1 For recent news about K-State Polytechnic's FAA Approval of UAS Training see Teixeira (in reference list).

2 See FAA 2015a for a more recent prediction of Spring 2016; but previous forecasts had predicted the rules might not be out until 2016 or 2017 (Morgan and Reuters, 2015). (References are in the reference list.)

3 For more information about stages of corn growth and production practices see Abendroth, et al., 2011 and Ciampitti, et al., 2014. (References are in reference list.)

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Table 1. Budget for costs of non-irrigated high-yield corn in northeast Kansas using MAS (assume purchase MAS as of August 13, 2015).

		Budget for 500 Acres		Budget for 2000 Acres	
	Assumptions	500 Acres	Per Acre	2000 Acres	Per Acre
Costs of Corn Production Assuming 200 bu/ac Yield Goal:					
Seed (34,000 seeds/acre)[1]	$ 3.90 per 1,000	$ 66,300	$ 132.60	$ 265,200	$ 132.60
Nitrogen Fertilizer Anhydrous (82% N, 100 lbs N per acre)[2]	$ 0.71 per pound N	$ 43,293	$ 86.59	$ 173,171	$ 86.59
Anhydrous Application[3]	$ 15.83 per acre	$ 7,915	$ 15.83	$ 31,660	$ 15.83
Nitrogen Fertilizer (2nd Application)[4]	$ 0.56 per pound N	$ 4,200	$ 8.40	$ 16,800	$ 8.40
Nitrogen Fertilizer (3rd Application, Liquid Urea 28% N)[5]	$ 0.56 per pound N	$ 85,000	$ 170.00	$ 340,000	$ 170.00
Nitrogen Post Survey Application (Liquid Urea, 28% Nitrogen)[6]	$ 0.56 per pound N	$ 7,500	$ 15.00	$ 30,000	$ 15.00
Rental High Lift Equipment[7]	$ 5.25 per acre	$ 656	$ 1.31	$ 2,625	$ 1.31
Herbicide			$ -		
Burndowns (Winter weed herbicide treatment)[8]	$ 13.62 per acre	$ 6,810	$ 13.62	$ 27,240	$ 13.62
Preemergence[9]	$ 26.06 per acre	$ 13,030	$ 26.06	$ 52,120	$ 26.06
Post Emergence[10]	$ 4.16 per acre	$ 2,080	$ 4.16	$ 8,320	$ 4.16
3 applications[11]	$ 7.01 per acre	$ 10,515	$ 21.03	$ 42,060	$ 21.03
Fungicide[12]	$ 32.00 per acre	$ 16,000	$ 32.00	$ 64,000	$ 32.00
Fungicide Application[13]	$ 7.17 acre	$ 3,585	$ 7.17	$ 14,340	$ 7.17
No-Till Plant[14]	$ 20.83 per acre	$ 10,415	$ 20.83	$ 41,660	$ 20.83
Harvest:					
Base Charge[15]	$ 32.66 per acre	$ 16,330	$ 32.66	$ 65,320	$ 32.66
Extra Charge for Yields exceeding 93[16]	$ 0.19 per bushel over 93	$ 10,165	$ 20.33	$ 40,660	$ 20.33
Hauling[17]	$ 0.20 per bushel	$ 20,000	$ 40.00	$ 80,000	$ 40.00
Labor (2.5 man hours per acre at $15.00 per hour)[18]	$15.00 Hour	$ 18,750	$ 37.50	$ 75,000	$ 37.50
Total Costs Budgeted For Corn Productions		**$ 342,544**	**$ 685**	**$ 1,370,176**	**$ 685**
Cost Associated MAS[19]					
Cesna 172-S Aircraft[20]	$ 409,000 one-time cost	$ 409,000	$ 818.00	$ 409,000	$ 204.50
Pilots Certification[21]	$ 9,240 one-time cost	$ 9,240	$ 18.48	$ 9,240	$ 4.62
Camera (DSLR with Near-Infrared Conversion)[22]	$ 6,500 one time cost	$ 6,500	$ 13.00	$ 6,500	$ 3.25
Camera Mount[23]	$ 800 one time cost	$ 800	$ 1.60	$ 800	$ 0.40
Data Processing[24]	$ 0.20 acre	$ 100	$ 0.20	$ 400	$ 0.20
Total Costs for MAS		**$ 425,640**	**$ 851**	**$ 425,940**	**$ 213**

Footnotes below cite data sources and explain how to calculate numbers for each line in Table 1 for 500 acres. In order to calculate numbers for 2,000 acres, multiply by 2,000 (instead of 500). References cited in the footnotes below may be found in the List of References.

Footnotes for Table 1

1. Price of $3.90 per 1,000 seeds is from Ibendahl, O'Brien, Duncan, 2015 (34 * $3.90 * 500 = $66,300).
2. Price of $0.71 per pound of nitrogen in 82% nitrogen is from Ibendahl, O'Brien, Duncan, 2015 ((100*500)*(100/82) * $0.71 = $43,293).
3. The cost of the anhydrous application is the custom rate reflecting labor and materials per acre. This custom rate comes from Ibendahl, O'Brien, Duncan, 2015 ($15.83 * 500 = $7,915).
4. The cost of $.56 per pound of nitrogen is from Ibendahl, O'Brien, Duncan, 2015 The 15 lbs. of nitrogen is applied during the planting operation and we assume that the farmer has the equipment needed to apply the nitrogen. (15 * 500 * $0.56 = 4,200).
5. The cost of $.56 per pound of nitrogen is from Ibendahl, O'Brien, Duncan, 2015. We assume the farmer has the equipment for this application. (85 * 500 * (100/28) * 0.56 = $85,000).
6. For the post survey nitrogen application, on the 500 acre corn field, 30 lbs. of nitrogen per acre is recommended on 125 acres (30*125*(100/28)*0.56=$7,500) (for 2,000 acre field, use 500 acres=25% of 2,000 acres). We assume that the farmer owns the equipment to apply the Urea
7. High lift equipment rental cost is from an agriculture business in Northeast Kansas. ($5.25 * 125 = $656).
8. The per acre cost of burn down herbicide is from Ibendahl, O'Brien, Duncan, 2015 ($13.62 * 500 = $6,810).
9. The per acre cost of preemergence herbicide is from Ibendahl, O'Brien, Duncan, 2015 ($26.06 * 500 = $13,030).
10. The per acre cost of postemergence herbicide is from Ibendahl, O'Brien, Duncan, 2015 ($4.16 * 500 = $2,080).
11. The per acre cost of the herbicide applications is the custom rate reflecting labor and materials per acre for all three applications. This custom rate comes from Ibendahl, O'Brien, Duncan, 2015 ($7.01 *3 * 500 = $10,515).
12. The per acre cost of a fungicide is from Ibendahl, O'Brien, Duncan, 2015 ($32.00 * 500 = $16,000).
13. The per acre cost of a fungicide application is the custom rate reflecting labor and materials per acre. This custom rate comes from Ibendahl, O'Brien, Duncan, 2015 ($7.17 * 500 = $3,585).
14. The per acre cost of no-till planting is the custom rate reflecting labor and materials per acre. This custom rate comes from Ibendahl, O'Brien, Duncan, 2015 ($20.83 * 500 = $10,415).
15. Base Charge for harvesting is the cost to pull the combine into the field. The per acre base charge for harvesting 93 bu. per acre of corn is from Ibendahl, O'Brien, Duncan, 2015 ($32.66 * 500 = $16,330).
16. The cost per bu. for harvesting yields greater than 93 bu. per acre is from Ibendahl, O'Brien, Duncan, 2015; the farmer expects an average corn yield of 200 bu. per acre. (107 * $0.19 * 500 = $10,165).
17. The cost per bu. for hauling is from Ibendahl, O'Brien, Duncan, 2015 (200 * $0.20 * 500 = $20,000).
18. Wage rate per hour for labor is from Ibendahl, O'Brien, Duncan, 2015. Burton (2015) estimated the amount of labor per acre above labor used in custom operations ($15 * 2.5 * 500 = $18,750).

19. Costs for MAS from Travis Balthazor, Kansas State University-Salina, Applied Aviation Research Center. Calculations for time to complete one pass using MAS: Calculated at 500 feet above ground level (AGL) with a 60% overlap: 500 acres * 2.34375 seconds an acre = 1,171.875 seconds to complete field. Divide Seconds/60 sec in a minute=time in minutes to complete one pass over field (500 * 2.34375 = 1,171.875/60 = 19.5 minutes to complete one pass). The costs for the purchase of MAS equipment are paid in year 1. The authors did not know details necessary for performing an NPV or annual costs analysis. (Individual readers who know their own details, such as their own yield goals, appropriate discount [or interest] rate, years of useful life, and their other uses of MAS, may use our Tables 1 and 2 as a starting point and substitute appropriate data to prepare budgets that represent their own situation.)
20. Costs for the Cesna 172-S Aircraft is from Travis Balthazor, Kansas State University-Salina, Applied Aviation Research Center. ($409,000*1).
21. Costs for Private Pilot Certification from Travis Balthazor, Kansas State University-Salina, Applied Aviation Research Center. ($9,250 * 1 = $9,250)
22. Digital single-lens reflective (DSLR) camera with the near-infrared conversion. Near-infrared conversion means the camera will be able to take photos of the infrared light reflected by the crop. (1 * $6,500 = $6,500).
23. The camera mount will need to be installed by an FAA certified Airframe and/or Powerplant (A&P) mechanic. An individual farmer is not allowed to install the camera mount unless the individual farmer is an A&P certified mechanic. The camera mount can be taken off the plane after the one-pass over the cornfield and kept by an individual farmer. The $800 one-time cost includes the installation and the camera mount. (1 * $800 = $800).
24. The farmer will probably use free online software. The data analysis is $0.20 an acre. If an individual farmer chooses to do the data analysis him or herself, the photo processing software costs about $3,499 and the data management software costs about $500. ($0.20 * 500 = $100).

Table 2. Budget for costs of non-irrigated high-yield corn in northeast Kansas using UAS (assume purchase UAS as of August 13, 2015).

	Assumptions		Budget for 500 Acres: 500 Acres	Budget for 500 Acres: Per Acre	Budget for 2000 Acres: 2000 Acres	Budget for 2000 Acres: Per Acre
Costs of Corn Production Assuming 200 bu/ac Yield Goal:						
Seed (34,000 seeds/acre)[1]	$ 3.90	per 1000	$ 66,300	$ 132.60	$ 265,200	$ 132.60
Nitrogen Fertilizer Anhydrous (82% N, 100 lbs N per acre)[2]	$ 0.71	per pound N	$ 43,293	$ 86.59	$ 173,171	$ 86.59
Anhydrous Application[3]	$ 15.83	per acre	$ 7,915	$ 15.83	$ 31,660	$ 15.83
Nitrogen Fertilizer (2nd Application)[4]	$ 0.56	per pound N	$ 4,200	$ 8.40	$ 16,800	$ 8.40
Nitrogen Fertilizer (3rd Application, Liquid Urea 28% N)[5]	$ 0.56	per pound N	$ 85,000	$ 170.00	$ 340,000	$ 170.00
Nitrogen Post Survey Application (Liquid Urea, 28% Nitrogen)[6]	$ 0.56	per pound N	$ 7,500	$ 15.00	$ 30,000	$ 15.00
Rental High Lift Equipment[7]	$ 5.25	per acre	$ 656	$ 1.31	$ 2,625	$ 1.31
Herbicide				$ -		$ -
Burndowns (Winter weed herbicide treatment)[8]	$ 13.62	per acre	$ 6,810	$ 13.62	$ 27,240	$ 13.62
Preemergence[9]	$ 26.06	per acre	$ 13,030	$ 26.06	$ 52,120	$ 26.06
Post Emergence[10]	$ 4.16	per acre	$ 2,080	$ 4.16	$ 8,320	$ 4.16
3 applications[11]	$ 7.01	per acre	$ 10,515	$ 21.03	$ 42,060	$ 21.03
Fungicide[12]	$ 32.00	per acre	$ 16,000	$ 32.00	$ 64,000	$ 32.00
Fungicide Application[13]	$ 7.17	acre	$ 3,585	$ 7.17	$ 14,340	$ 7.17
No-Till Plant[14]	$ 20.83	per acre	$ 10,415	$ 20.83	$ 41,660	$ 20.83
Harvest:						
Base Charge[15]	$ 32.66	per acre	$ 16,330	$ 32.66	$ 65,320	$ 32.66
Extra Charge for Yields Exceeding 93 Bushels[16]	$ 0.19	per bushel	$ 10,165	$ 20.33	$ 40,660	$ 20.33
Hauling[17]	$ 0.20	per bushel	$ 20,000	$ 40.00	$ 80,000	$ 40.00
Labor (2.5 man hours per acre at $15.00 per hour)[18]	$ 15.00	hour	$ 18,750	$ 37.50	$ 75,000	$ 37.50
Total Costs Budgeted Corn Production			**$ 342,544**	**$ 685**	**$ 1,370,176**	**$ 685**
Costs UAS[19]						
UAS (X-8) with Ground Control Station (GCS)[20]	$12,000.00	one-time cost	$ 12,000	$ 24.00	$ 12,000	$ 6.00
Camers (S100 with NDVI integration)[21]	700.00	one time cost	$ 700	$ 1.40	$ 700	$ 0.35
UAS Launcher[22]	200.00	one time cost	$ 200	$ 0.40	$ 200	$ 0.10
Data Processing [23]	0.20	acre	$ 100	$ 0.20	$ 400	$ 0.20
Total Costs UAS			**$ 13,000**	**$ 26**	**$ 13,300**	**$ 6.65**

Footnotes below cite data sources and explain how to calculate numbers for each line in Table 2 for 500 acres. In order to calculate numbers for 2,000 acres, multiply by 2,000 (instead of 500). References cited in the footnotes below may be found in the List of References.

Footnotes for Table 2

1. Price of $3.90 per 1,000 seeds is from Ibendahl, O'Brien, Duncan, 2015 (34 * $3.90 * 500 = $66,300).
2. Price of $.71 per pound of nitrogen in 82% nitrogen is from Ibendahl, O'Brien, Duncan, 2015 (100 * 500 * (100/82) * $0.71 = $43,293).
3. The cost of the anhydrous application is the custom rate reflecting labor and materials per acre. his custom rate comes from Ibendahl, O'Brien, Duncan, 2015 ($15.83 * 500 = $7,915).
4. The cost of $.56 per pound of nitrogen is from Ibendahl, O'Brien, Duncan, 2015 The 15 lbs. of nitrogen is applied during the planting operation and we assume that the farmer has the equipment needed to apply the nitrogen. (15 * 500 * $0.56 = 4,200).
5. The cost of $.56 per pound of nitrogen is from Ibendahl, O'Brien, Duncan, 2015. We assume the farmer has the equipment for this application. (85 * 500 * (100/28) * 0.56 = $85,000)
6. For the post survey nitrogen application, on the 500 acre corn field, 30 lbs. of nitrogen per acre is recommended on 125 acres (30*125*(100/28)*0.56=$7,500) (for 2,000 acre field, use 500 acres=25% of 2,000 acres). We assume that the farmer owns the equipment to apply the Urea
7. High lift equipment rental cost is from an agriculture business in Northeast Kansas. ($5.25 * 125 = $656)
8. The per acre cost of burn down herbicide is from Ibendahl, O'Brien, Duncan, 2015 ($13.62 * 500 = $6,810).
9. The per acre cost of preemergence herbicide is from Ibendahl, O'Brien, Duncan, 2015 ($26.06 * 500 = $13,030).
10. The per acre cost of postemergence herbicide is from Ibendahl, O'Brien, Duncan, 2015 ($4.16 * 500 = $2,080).
11. The per acre cost of the herbicide applications is the custom rate reflecting labor and materials per acre for all three applications. This custom rate comes from Ibendahl, O'Brien, Duncan, 2015 (7.01 * 3* 500 = $10,515).
12. The per acre cost of a fungicide is from Ibendahl, O'Brien, Duncan, 2015 ($32.00 * 500 = $16,000).
13. The per acre cost of a fungicide application is the custom rate reflecting labor and materials per acre. This custom rate comes from Ibendahl, O'Brien, Duncan, 2015 ($7.17 * 500 = $3,585).
14. The per acre cost of no-till planting is the custom rate reflecting labor and materials per acre. This custom rate comes from Ibendahl, O'Brien, Duncan, 2015 ($20.83 * 500 = $10,415).
15. Base Charge for harvesting is the cost to pull the combine into the field. The per acre base charge for harvesting 97 bu. per acre of corn is from Ibendahl, O'Brien, Duncan, 2015 ($32.66 * 500 = $16,330).
16. The cost per bu. for harvesting yields greater than 93 bu. per acre is from Ibendahl, O'Brien, Duncan, 2015. The farmer expects an average corn yield of 200 bu. per acre. (107 * $0.19 * 500 = $10,165).
17. The cost per bu. for hauling is from Ibendahl, O'Brien, Duncan, 2015 (200 * $0.20 * 500 = $20,000).
18. Wage rate per hour for labor is from Ibendahl, O'Brien, Duncan, 2015. Burton estimated the amount of labor per acre above labor used in custom operations ($15 * 2.5 * 500 = $18,750).

19. Costs for UAS from Travis Balthazor, Kansas State University-Salina, Applied Aviation Research Center. Calculations for one pass using UAS: Calculated at 400 feet above ground level (AGL), 20 meters per second, with a 60% overlap: 500 acres * 5.1825 seconds per acre = 2,591.25 seconds/60 seconds = 43.19 minutes to complete one pass. The costs for the purchase of UAS equipment are paid in year 1. The authors did not know details necessary for performing an NPV or annual costs analysis. (Individual readers who know their own details, such as their own yield goals, appropriate discount [or interest] rate, years of useful life, and their other uses of UAS, may use our Tables 1 and 2 as a starting point and substitute appropriate data to prepare budgets that represent their own situation.)
20. The X-8 UAS is a radio controlled aircraft outfitted with a camera mount with an integrated autopilot and ground control station (GCS). (1 * $12,000 = $12,000)
21. A S100 compact digital camera that has been integrated with software to convert the pictures to a normalized difference vegetative index (NDVI) image. (1 * $700 = $700)
22. UAS launcher is not required to launch the UAS because the UAS can be launched by hand with practice. The farmer decides to purchase a launcher to make the process easier. (1 * $200 = $200)
23. The farmer will probably use free online software. The data analysis is $0.20 an acre. If an individual farmer chooses to do the data analysis his or herself, photo processing software costs about $3,499 and the data management software costs about $500. ($0.20 * 500 = $100).

Figure 1. X-8 Fixed Wing UAS photo provided by Travis Balthazor, Kansas State University Applied Aviation Research Center.

Figure 2. Wolverine helicopter UAS photo provided by Travis Balthazor, Kansas State University Applied Aviation Resarch Center.

Figure 3. Multirotor UAS photo provided by Travis Balthazor, Kansas State University Applied Aviation Research Center.

Figure 4. NDVI photo of the US, 1990. See USDA 2013 to access this picture.

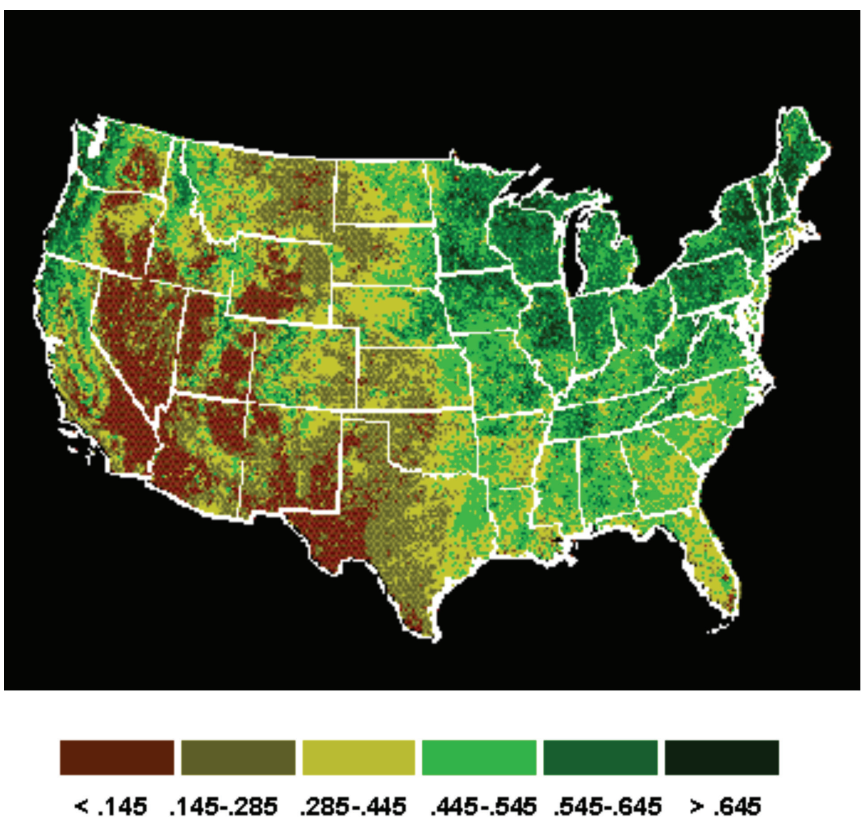

Figure 5. An example of an NDVI map. The labels explain what each part of the image shows a farmer about the health of the fields. Source is Balthazor, 2015.