HARVEST EQUIPMENT CAPACITY SELECTION CONSIDERING WEATHER UNCERTAINTY IN KANSAS

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Abstract

Proper sizing of harvest equipment has concerned farmers and lenders since advent of mechanized agriculture. Under-equipped farming operations may not be able to harvest crops without yield and/or quality penalties. Over-equipped farming operations expose themselves to unnecessary expenses. Uncertainty of weather conducive for field operations further complicates the decision- making process. The overall objective of this research was to estimate the machinery investment necessary to complete wheat harvest operations under a range of harvest-time weather risk, specifically for uncertainty of the number of good days suitable to conduct fieldwork (DSFW). We evaluate a range of weather probabilities for the nine USDA crop-reporting districts in Kansas to determine the winter wheat acreage that a single combine can harvest. Weather probabilities estimated from 33 years of observed weekly DSFW were analyzed to determine the expected number of days available to harvest wheat in Kansas. Results indicate that during bad weather years (20th percentile DSFW probability), 15% to 26% of acreage must be harvested outside the typical harvest dates leading to increased likelihood of reduced yield, harvest loss, and adverse quality impacts. Although a 30th percentile weather year was sufficient in at least one location, a 15th percentile weather year encouraged most farm decision makers to invest in additional harvesting capacity. Our conclusions are of interest to not only Kansas farmers but to farmers, agricultural lenders, equipment manufacturers, and salesforce across the wheat belt.

Keywords: days suitable for fieldwork, machinery sizing, wheat, harvest efficiency, machinery investment, acreage allocation, weather risk

1. Introduction

Harvesting wheat in a timely manner minimizes yield losses and quality penalties, but it requires sufficient equipment capacity under weather uncertainty. For the Bread Basket State, harvesting 3.6M acres in a 21 period is no trivial task. Kansas is the largest wheat (*Triticum* spp.) producing state in the United States, accounting for 15% of total US harvest in 2014. Figure 1 shows the variation and intensity of harvested acreage by county. Just as wheat production varies across Kansas, precipitation varies by crop reporting district. Fieldwork conditions are impacted by precipitation. Compared to other Midwestern states, Kansas is considered dry, receiving 29 inches of rainfall annually (USDA NASS 2012). These rainfall values vary by crop reporting district (CRD) causing regional variation in days suitable for fieldwork (DSFW).

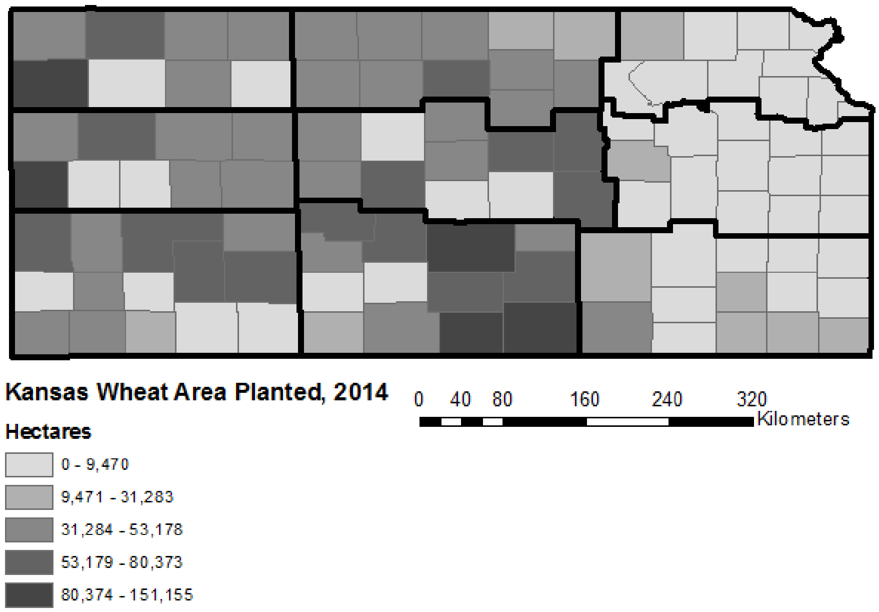

Figure 1. Map of Kansas counties by planted winter wheat acreage.

DSFW is reported by USDA NASS on a weekly basis (for details on Kansas DSFW data see Williams & Llewelyn 2013). The premise behind DSFW is to provide a prediction of the days with which work can be conducted in the field. Specifically, this study seeks to examine the impact of DSFW on optimal harvest equipment size. In a 21 day period from June 20th through July 10th the majority of wheat is harvested in the state of Kansas (USDA NASS

1997). Weather delays during this timeframe can result in significant profit loss for a wheat operation. This leaves decision makers to determine what size and how much equipment is needed to minimize this loss, given their weather expectations. Most decision makers would prefer to be over equipped to allow extra harvesting during times of need. However, being over equipped can put additional stress on the farm financials. This can be especially true during times of low commodity prices.

Harvesting before and/or after typical harvest dates is possible, but yield and/or quality penalties are incurred. McNeill, Overhults and Montross (2009) outline the costs and benefits of early harvesting. Their primary findings are early harvesting is only viable in areas where double crop soybeans are an option. Early harvesting, if the crop is not fully mature, can be an issue considering the high moisture content and the lack of yield maximization (shortening the grain filling period). As for yield and quality penalties for late harvesting, very little research has been reported. Delayed harvest results in both reduced yield and potentially higher head scab concentrations (Farrer et al. 2005). They found that when 3.8 to

5 cm of rainfall occurred after wheat maturation the loss can be minor; however, when the weather is hot yield loss could reach 20% or more. Quality penalties may have a higher impact on the producer relative to yield penalties. Farrer et al. (2005) found that late harvest could result in head scab or the fungal pathogen *Fusarium graminearum* to reach levels that make the grain unmarketable thereby causing revenue to go to zero.

Incorporating the weather uncertainty into the decision making process is accomplished by using DSFW. Kansas is one of the few states in the US that collects DSFW information by CRD. The preferred level of disaggregation would be the county level, but this information is not available. Figure 2 shows the historical frequency of DSFW for this 21-day period for

1981 to 2013 for the nine CRDs in Kansas. The South Central region of Kansas is the primary wheat producing region and over the 33 year period has only had two years where DSFW was less than 10 days. However, 23 of the 33 years are above 14 DSFW or 70 percent of the typical 21 day harvest period.

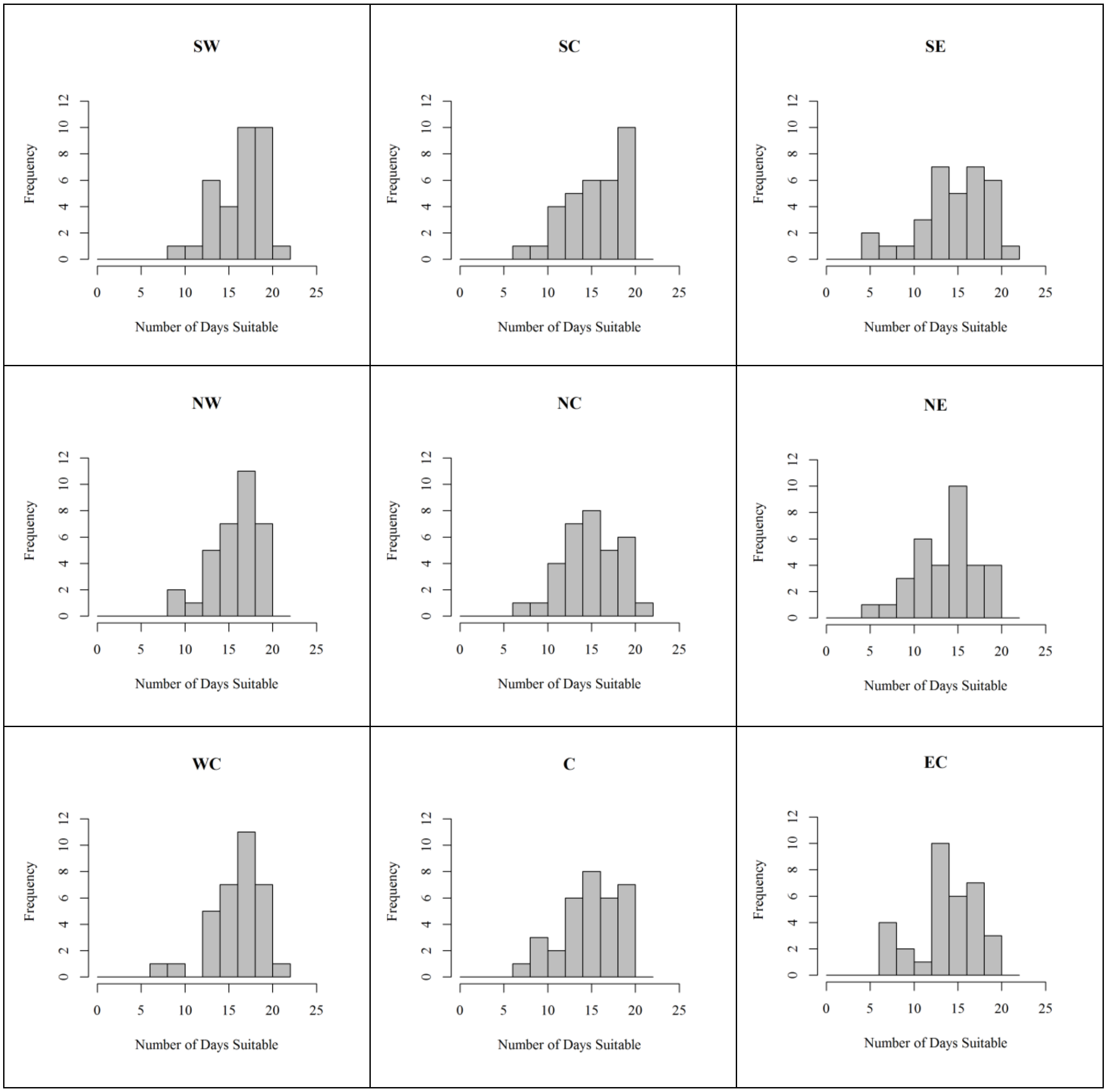

Figure 2. Histogram of wheat harvest days suitable for nine Kansas crop reporting districts during June 20 to July 10. Data source: USDA NASS Kanas Field Office 1981 to 2013.

2. Data and Methods

DSFW data is collected from USDA on a weekly basis (Griffin 2009). Table 1 shows the average number of DSFW, percentage of days that work can be carried out, and an approximation for the work hours available by region during this 21 day period. An annual summation of DSFW is used to determine the probability density for the 'most active' dates (displayed as a histogram in Figure 1). For Kansas wheat harvest, DSFW range from 14.5 to 17.1 across CRDs during the 'most active' harvest dates in a typical (50th percentile) year.

Table 1. Average days suitable for fieldwork, percent of days suitable, and number hours for median year by crop reporting district during most active winter wheat harvest dates (June 20 to July 10).

CRD	Average DSFW	Percent DSFW*	Number hours**
NW	16.4	78%	197
NC	15.0	71%	180
NE	14.5	69%	174
WC	16.9	80%	203
C	15.5	74%	186
EC	14.0	67%	168
SW	17.1	81%	205
SC	16.0	76%	192
SE	14.7	70%	176

*Relative to the 21 calendar days

**based on 12 hours per day

Data source: USDA NASS Kansas Field Office 1981 to 2013

Next the harvesting capacity for each combine needs to be determined. It is assumed that a combine can harvest wheat for 12 hours per day in Kansas. The working rate, i.e. the number of acres operated per hour, varies depending on equipment size, speed, and capacity. Although recent manufacturer claims indicate wheat harvest over 6 hectares per hour, typical working rates range from about 3.5 hectares per hour (for 6.7-meter platform) to 4.8 hectares per hour (for 9-meter platform) (Table 2). Utilizing this information we also used the Mississippi State Budget Generator (Laughlin and Spurlock) to estimate the costs to operate the three different combine combinations.

Table 2. Combine harvester working rates and costs in USD.

Width (m)	Working rate (ha hr^{-1})	Hourly cost	Annual costs ha^{-1}	Annual costs farm^{-1}	Annual use hrs	Hectares at capacity
6.7	3.5	\$209	\$60	\$62,819	300	1,045
7.6	4.0	\$242	\$61	\$72,440	300	1,187
9.1	4.8	\$244	\$51	\$73,073	300	1,427

Cost estimates obtained from Mississippi State Budget Generator (Laughlin and Spurlock 2014)

Although a combine harvester with a 9-meter header can harvest 1,427 hectares when fully utilized (Table 2), fewer hectares can be harvested due to weather constraints. A combine is considered to be fully utilized when operated at a specified number of hours, usually 300 hours per year (Laughlin and Spurlock 2014) for all crops on the farm. However, in an average year there are only 168 to 205 hours available for wheat harvest in Kansas. Therefore, in an average year a combine with a 9-meter header could harvest only 984 hectares. Acreage above this level would be harvested outside the 'most active' dates such that likelihood of yield and quality penalties increases.

Yield and quality penalties exist for delayed harvest although scarce information exists to estimate specific revenue losses for harvesting into late July (McNeill, Overhults & Montross 2009). In addition to yield loss, harvest losses are likely to increase as well as increased chance of fungal infestation (Farrer et al., 2005). Therefore, for the purposes of this study, yield penalties ranging from 0% to 100% were assumed to be representative of a range of conditions if harvest is delayed. It should be noted that in wheat-double cropped soybean systems, delayed wheat harvest is largely impacting soybean planting time and consequently, yields; although the rotation dynamic is beyond the scope of this paper. Using 2014 yields as a base and wheat price of \$195 per metric ton, gross revenue per acre averaged between \$301 per hectare and \$608 per hectare depending up region (Table 3).

Table 3. Kansas wheat yields and gross revenue per hectare by crop reporting district.

	Yield ($MT\ ha^{-1}$)	**Gross revenue ($\$\ ha^{-1}$)**
NW	2.2	419
WC	1.8	351
SW	1.7	326
NC	2.1	406
C	1.8	353
SC	1.5	301
NE	3.1	608
EC	3.1	602
SE	2.8	539

2014 yields for all wheat. Source: Kansas Farm Facts 2015

\$195 MT^{-1} price received by farmers

3. Results

The basis for the analysis is the 21 day 'most active' harvest period and the hours available for harvest in the 0 to the 50th percentile weather years (Table 4). The 50th percentile is considered the typical year, with base farm sized such that the combine can just harvest all the acreage. The 50th percentile is the median of all 33 years observed such that half of all years have more DSFW and the other half of all years have fewer DSFW. The 20th percentile DSFW year is considered a bad year, having 80 years out of 100 with more DSFW and only 20 years out of 100 with fewer DSFW. For SC Kansas, the 50th percentile DSFW year would have 16 DSFW to harvest wheat.

Using the above assumptions of 4.8 hectares per hour working rate for a 9-meter combine header, the number of hectares that could be harvested with a single combine was calculated from the hours available from Table 2. Table 4 shows the hours available for harvest during the 0 through 50th percentile weather years, the harvested acres, and the foregone harvested acreage, respectively. Only DSFW probabilities below the 50th percentile were evaluated because the hypothetical farm was sized to harvest all wheat acres in the median or 50th percentile year, therefore the farm would also harvest all wheat acreage during the 'most active' time period in any year with better conditions (50th to 100th percentile DSFW years).

The hectares presented in Table 5 and Table 6 indicate acreage harvested and failed to be harvested, respectively, in a bad weather year given the farm was sized to be harvested in a typical (50th percentile) year during the 'most active' time period. The first column of Table 5 provides the acreage that could be harvested with the standard combine harvester in the worst year observed from 1981 to 2013; it is this acreage that a farm decision maker would choose per combine harvester if they desired to harvest all acreage within the 21-day time period without ever having deficit acreage.

Table 4. Number of hours available for wheat harvest by Kansas CRD by percentile DSFW (50th percentile is median, 0th percentile is worst year observed).

Region	0th	10th	20th	30th	40th	50th
NW	114	150	164	185	188	197
NC	90	138	150	156	170	180
NE	62	115	129	139	155	174
WC	96	158	173	184	192	203
C	90	118	149	154	178	186
EC	74	93	139	159	166	168
SW	102	156	162	189	198	205
SC	88	138	150	157	183	192
SE	65	106	145	160	167	176

**based on 12 hours per day

Data source: USDA NASS Kansas Field Office 1981 to 2013

The information in Table 5 was rearranged in Table 6 to show the number of hectares not harvested in years worse than 50th percentile when wheat acreage was chosen based on the number of acres that the combine could harvest in a typical (50th percentile) year. Even by the 40th percentile worse year, more than 40 hectares were calculated to be in deficit in 6 of the 9 crop reporting districts. By the 10th percentile, all locations had more than 200 hectares in deficit. In the 0 percentile, or the worst year observed in the 1981 to 2013 data, all locations were at or above 400 hectares deficit.

Table 5. Wheat acreage harvested by Kansas CRD by percentile DSFW (50th percentile is median, 0th percentile is worst year observed).

	0th	10th	20th	30th	40th	50th
NW	547	720	787	888	902	946
NC	432	662	720	749	816	864
NE	298	552	619	667	744	835
WC	461	758	830	883	922	974
C	432	566	715	739	854	893
EC	355	446	667	763	797	806
SW	490	749	778	907	950	984
SC	422	662	720	754	878	922
SE	312	509	696	768	802	845

**based on 12 hours per day and 4.8 hectares per hour combine working rate.
Data source: USDA NASS Kansas Field Office 1981 to 2013

Table 6. Wheat acreage not harvested given wheat acres allocated to be harvested in typical year by Kansas CRD by percentile DSFW (50th percentile is median, 0th percentile is worst year observed).

	50th	40th	30th	20th	10th	0th
NW	-	43	58	158	226	398
NC	-	48	115	144	202	432
NE	-	91	168	216	283	538
WC	-	53	91	144	216	514
C	-	38	154	178	326	461
EC	-	10	43	139	360	451
SW	-	34	77	206	235	494
SC	-	43	168	202	259	499
SE	-	43	77	149	336	533

Utilizing Table 6, we estimated the revenue foregone by using a wheat price of $194.74 per metric ton and the expected yields by CRD presented in Table 3. Given the estimated revenue forgone in the event that harvest cannot continue after July 10 or yield penalties become severe, Table 7 presents the worst case scenario at each level of weather uncertainty from the median year (50th percentile) to worst year observed (0th percentile); and provides the outer bounds that the decision maker would consider paying for additional harvest capacity. Although it is feasible and common for wheat to be harvested outside these bounds, little empirical evidence were identified to suggest specific quantitative penalties for late harvest due to yield loss, harvest loss, or quality dockage. To evaluate expected revenue loss and opportunity for investment in additional harvesting capacity, a range of yield penalties were assumed ranging from no penalty to complete loss (Table 7). Using the annual per farm cost of a combine with a 9.1-meter header of $73,073 (Table 2), 2 of the 9 crop reporting districts could pay for an additional combine when faced with the 20th percentile weather year if harvest were constrained within the 'most active' date bounds.

Table 7. Revenue potentially foregone by not being able to harvest outside of 'most active' dates by Kansas CRD by percentile DSFW (50th percentile is median, 0th percentile is worst year observed). Assumes 100% loss from all acres not harvested.

	50th	40th	30th	20th	10th	0th
NW	$ -	$ 18,118	$ 24,157	$ 66,432	$ 94,616	$ 167,087
NC	$ -	$ 16,860	$ 40,463	$ 50,579	$ 70,811	$ 151,737
NE	$ -	$ 29,762	$ 54,825	$ 70,490	$ 92,420	$ 175,442
WC	$ -	$ 21,452	$ 37,054	$ 58,506	$ 87,759	$ 208,670
C	$ -	$ 13,538	$ 54,152	$ 62,614	$ 115,074	$ 162,457
EC	$ -	$ 2,894	$ 13,022	$ 41,961	$ 108,519	$ 136,010
SW	$ -	$ 20,433	$ 46,704	$ 125,517	$ 143,031	$ 300,656
SC	$ -	$ 25,988	$ 101,064	$ 121,277	$ 155,927	$ 300,304
SE	$ -	$ 23,270	$ 41,369	$ 80,153	$ 180,990	$ 286,999

In a more realistic case, where wheat acreage harvested outside the ‘most active’ date bounds is not a total loss, a small but measurable penalty may be expected. Table 8 presents the revenue foregone at differing levels of weather uncertainty assuming a 10% yield loss on any acreage not harvested from June 20 to July 10. Although these estimates are much less severe than the total loss example, losses at these and greater levels may entice the farm decision maker to secure additional equipment in bad years. More importantly, decision makers need to be aware of the trade-off between weather uncertainty and equipment sizing.

Table 8. Revenue potentially foregone by not being able to harvest outside of ‘most active’ dates by Kansas CRD by percentile DSFW (50th percentile is median, 0th percentile is worst year observed). Assumes 10% loss from all acres not harvested during ‘most active’ dates.

	50th	40th	30th	20th	10th	0th
NW	$ -	$ 1,812	$ 2,416	$ 6,643	$ 9,462	$ 16,709
NC	$ -	$ 1,686	$ 4,046	$ 5,058	$ 7,081	$ 15,174
NE	$ -	$ 2,976	$ 5,483	$ 7,049	$ 9,242	$ 17,544
WC	$ -	$ 2,145	$ 3,705	$ 5,851	$ 8,776	$ 20,867
C	$ -	$ 1,354	$ 5,415	$ 6,261	$ 11,507	$ 16,246
EC	$ -	$	$ 1,302	$ 4,196	$ 10,852	$ 13,601
SW	$ -	$ 2,043	$ 4,670	$ 12,552	$ 14,303	$ 30,066
SC	$ -	$ 2,599	$ 10,106	$ 12,128	$ 15,593	$ 30,030
SE	$ -	$ 2,327	$ 4,137	$ 8,015	$ 18,099	$ 28,700

One of our objectives was to determine what percentile bad year was necessary to consider the addition of a second or third combine harvester to the existing farm. If we assume that the farm is sized such that all acreage are harvested in the median (50^{th} percentile such that half of years have fewer and other half of years have more DSFW) weather year with a combine harvesting 4.8 hectares per hour, the number of hectares not harvested within the ‘most active’ dates were calculated. This acreage not harvested is considered deficit hectares. From the deficit acreage, the potentially foregone revenue can be calculated and compared to the costs of adding another combine harvester to the farm operation. Table 9 gives detail for the South Central CRD. The difference between crop revenue foregone and machinery costs were compared to the crop revenue foregone across a range of crop acreage deficit from 0 to 600 hectares. When the difference between revenue and machinery costs was negative, the farm decision maker would not invest in an additional combine; however when the difference was positive the decision maker would consider investing in the additional equipment. For the example in the South Central CRD, the rational farm decision maker would consider adding a second machine when 242 or more hectares were not being harvested (Table 10). The same farmer would consider a third and fourth combine harvester when 485 hectares were not being harvested (Table 10). For South Central Kansas wheat harvest, acreage deficits of 242 and 485 would occur during 20^{th} percentile and worse years (Table 6). Specifically, these acreage deficits would occur in the 15^{th} and 1^{st} percentiles, respectively, in the South Central CRD.

Table 9. Crop revenue versus machinery cost for 1 and 2 harvesters under differing wheat acreage for South Central CRD in the state of Kansas. The higher the crop acreage deficit the worse the weather year.

Crop acreage deficit	Crop revenue foregone	Crop revenue minus machine cost for 1 harvester	Crop revenue minus machine cost for 2 harvesters
0	-	(73,073)	(135,892)
5	1,507	(71,566)	(134,385)
20	6,029	(67,044)	(129,863)
40	12,058	(61,015)	(123,834)
100	30,144	(42,929)	(105,748)
200	60,288	(12,785)	(75,604)
300	90,432	17,359	(45,460)
400	120,576	47,503	(15,316)
500	150,720	77,647	14,828
600	180,864	107,791	44,972

The breakeven acreage deficit for the remaining eight Kansas crop reporting districts are presented in Table 10. The Northwest CRD had the lowest acreage deficit for any CRD before an additional combine was feasible while the Southwest CRD had the highest deficit before adding machinery.

Table 10. Breakeven acreage deficit for additional combine harvester.

CRD	From 1 to 2 harvesters	From 2 to 3 harvesters
NW	174	348
WC	208	416
SW	224	448
NC	180	360
C	207	415
SC	242	485
NE	120	240
EC	121	243
SE	136	271

To address the objective of identifying how bad of a weather year to encourage a second combine harvester, the percentile worst year was estimated for the acreage deficit (Table 11). When wheat acreage and combine harvester is sized such that the harvester is just able to harvest all wheat acreage in the median year with respect to harvest time days suitable, a second harvester could be justified in 13th to 32nd percentile years depending upon crop reporting district. Using our example of South Central CRD, a crop acreage deficit would occur in the 15th percentile meaning that nearly 15 years out of 100 a second combine harvester would be a feasible alternative. About half of the CRDs would be nearly 20th percentile indicating only 20 years out of 100 would a second harvester be justified.

Table 11. Hectare deficit breakeven for 2nd combine harvester and percentile weather year

CRD	Hectare deficit (single harvester)	Percentile year
NW	174	0.15
WC	208	0.13
SW	224	0.19
NC	180	0.16
C	207	0.17
SC	242	0.15
NE	120	0.26
EC	121	0.32
SE	136	0.22

4. Discussion

The decision to size equipment to crop acreage under weather uncertainty has been complicated and continues to evade the best decision makers. It is intuitive that having sufficient equipment capacity to harvest all acreage in a timely manner during a bad year is needed, although the magnitude of the bad year to plan for is illusive. We have shown that farms sized to fully harvest all acreage in a typical year (50^{th} percentile DSFW) may invest in a second combine harvester at even the 36^{th} percentile year or more commonly around the 20^{th} percentile. An event that is expected to occur at the 20^{th} percentile would occur 20 years out of 100, or 2 out of 10, or 1 out of 5. An event in the 32^{nd} percentile would occur about once every 3 years. However these estimates ignore many financial considerations especially long-term dynamic relationships that will be addressed in future research.

There are big data implications that affect this research. Real time time-and-motion data may provide the basic data necessary for more precise analytics. Actual working rates can be detected from harvesters via telematics. Days suitable for fieldwork can be calculated from observing field operations. The number of hours per day that harvesters operate and downtime can also be observed.

5. References

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